# German Indian Partnership for IT Systems

Otthein Herzog (Ed.)

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SCIENCE AND ENGINEERING

**Imprint**

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**Project:** German Indian Partnership for IT Systems

**Recommended citation:** German Indian Partnership for IT Systems, acatech Materialien, München/Berlin 2014

**Published by:**
acatech – National Academy of Science and Engineering 2014

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Internet: www.acatech.de

ISSN: 2191-8481/ISBN: 978-3-942044-37-0

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Coordination: Prof. Dr. Otthein Herzog, Dr. Ulrich Glotzbach
Layout conception: acatech
Conversion and typesetting: work:*at*:BOOK / Martin Eberhardt, Berlin

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# INTRODUCTION

When I was asked by acatech to take on the lead of the new project GRIP-IT – German Indian Partnership for IT Systems I would have never imagined what was going to happen during the three years of this exciting project: not only that I could acquire a lot of knowledge in respect to India, its IT industry, and especially to a good part of its academic structures, I indeed found new friends and could build up lasting ties to many people, especially to the IISc - Indian Institute of Science in Bangalore and to the Indian National Academy of Engineering.

It was not without a certain reluctance that I agreed to take over such a project in a country I visited never before. But with the enormous help by Joseph Mathews I could get acquainted with the country and its people. In fact, I almost fell in love with this country with its immense opportunities – and challenges.

We choose the IT application area of Smart Cities as this subject appeared to be one of the immanent problems India is facing and has to solve. In view of this subject we organized several workshops with a very good participation, especially from the Indian industry. We then concentrated on three joint symposia together with the CiSTUP - Centre for infrastructure, Sustainable Transportation and Urban Planning at the IISc in Bangalore in order to present the findings by our cooperation partners and in addition also the voices of Indian science, governmental institutions, and NGOs:

- "Smart Mobility and Energy Concepts for Megacities" on May 19, 2011,
- "Socio-Economic Challenges for Smart Cities in India" on December 9, 2011, and
- "Smart City Technologies as Innovation Drivers" on April 25, 2012.

The papers presented in this volume cover the most important aspects raised during these symposia concentrating on mobility in Megacities:

- The joint Indian-German paper on a "Mobility Information and Communication Platform Bangalore" points out the requirements and the stakeholders for smart mobility solutions in Indian cities and gives some recommendations for an implementation.
- "SMART CITY - A Study on Technology Innovation for Smart City Initiatives – Opportunities from an Indo-German Perspective" lays out a joint Indian-German perspective on joint innovation processes.
- "Citizens' Preferences on Governance Structures in Bangalore with Regard to Urban Traffic Management" sheds light on the requests Bangalore citizens have towards the Indian organizational structures which influence planning and implementation of (the much needed) urban traffic improvements.
- "The Framework of Political Institutions in the Context of Smart Mobility Projects in Bangalore" explores the institutional framework of the state of Karnataka and its municipalities, the many different organizations concerned with mobility and recommendations which stakeholders to involve in mobility projects.
- In the initial study "PLaSMA - Multiagent Simulation - Last-Mile Connectivity – Bangalore the complete Bangalore road infrastructure from OpenStreetMap was incorporated into the PlaSMA tool (and public traffic was found to be meagerly represented there). Buses and people were modeled for the commute between airport and Bangalore in order to get a grip on the dynamic transportation needs of the Bangalore people by an extensive simulation of traffic and people.

I would like to thank all the researchers which took part in the studies and in the symposia, especially Prof. Akhilesh and Prof. Sitharam of IISc as they were instrumental to the success of this endeavor. Thanks go also to the Bundesministerium for Research and Education for funding this project and helping to establish completely new communication lines to India, and to Prof. Kagermann, President of acatech, who took part in the project from the very beginning until its successful completion. Last but certainly not least, my thanks go to Dr. Glotzbach and Joseph Mathew from acatech. Without their dedication it would not have been possible to build up the various relationships to our peers in India in such a profound way.

Otthein Herzog

# Mobility Information & Communication Platform Bangalore (MICPB) Preliminary Studies

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Project: German Indian Partnership for IT Systems

Recommeded citation: Mobility Information & Communication Platform Bangalore (MICPB) Preliminary Studies, acatech Materialien German Indian Partnership for IT Systems, München/Berlin 2014

Published by:
acatech – National Academy of Science and Engineering 2014

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Internet: www.acatech.de

ISSN: 2191-8481/ISBN: 978-3-942044-37-0

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# 0 EXECUTIVE SUMMARY

## A PRELIMINARY REMARK

The study is part of the project GRIP IT which is funded by the German Ministry for Education and Research (BMBF). Its general remit is to explore the possibilities for a German-Indian cooperation in the field of information sciences.

## B AIM OF THE STUDY

Comprehensive information and communication is the basis for smart mobility strategies to solve mobility problems in megacities. Taking this as the background for discussion, the aim of the present study is to answer the following questions: (a) who are the stakeholders for developing and operating smart mobility solutions in Indian megacities? (b) What would an ICT system for mobility look like? (c) Which data and components of such a system are already existent, available and reliable? (d) How can information about the current status in the transportation networks be delivered to users? (e) How should dynamic traffic information be obtained, and what methods should be used to deliver dynamic traffic information to the benefit of users? (f) What is necessary to connect fast public transport with available individual systems like the widely spread auto rickshaws ("autos") in Indian Megacities? (g) What are the last mile connectivity options, including non-motorised transport options and new ways for improvement of the logistic processes?

In this context, the study analyses the organisation and structure of stakeholders, different owners' databases, including their availability and reliability. The study also develops the framework for a mobility information and communication platform using Bangalore as an example. MICPB will be developed as an integrated platform for all who offer mobility services in a city and for anyone who needs information.

## C STATUS OF MOBILITY INFORMATION

This study examines static, dynamic and real time information about mobility (see Chapter 2). The research shows the following: public transport companies (bus companies BMTC and KSRTC, Namma Metro) provide information about their services (timetables, lines, stop sequences, used bus types, tariffs and booking options). This data is available and can be used for the construction of a cross-company information system. Demand data, however, is not yet available. It will be necessary to generate it via surveys, cross sectional counting and modelling. The commuter rail which serves the suburbs of Bangalore does not offer comparable data.

Schedules and line data are analysed via Google Maps and mapunity (Bangalore) in order to offer routing information for each company's network. A cross-company routing, including points of transfer from one company to another such as Metro plus bus is currently unavailable. Also, real-time information that would allow a passenger to adjust to actual departure times is yet to be developed.

There is currently also no informational link between public transport systems with individually used auto rickshaws ("three-wheeler taxis"), taxis or rental services. An ICT-based connection of fast public transport (in particular the Metro) with a means of transport for the last mile (cars, taxis, scooters, bicycles) play an important role in German discussions on the future of mobility in megacities. It could reduce the spatial gap between the network of stops with respect to stations of fast public transport, and could offer an interesting perspective for people who otherwise use their car or two-wheeler. Against this background, the study deals with an analysis of the structure of the auto system in order to determine the possibility for building ICT-based bridges between the public transport and auto systems (Chapter 6).

Autos play an important role as a transport system in Indian megacities. The number of vehicles is growing rapidly. With currently some 100,000 autos in Bangalore and a market share of 13% (2006), the attractiveness of autos as a low cost taxi is proven. Autos may also be seen as a solution for the "last mile" if organisation, communication, booking and payment procedures can meet customer needs. A survey about system structure showed that the most crucial problems for including autos in the last mile solution will arise from the fragmented supplier market, unreliability of individual drivers and outdated vehicle technology. In a practical trial it will be necessary to start with a limited number of selected auto owners and drivers.

In the discussions with the Namma Metro management the link to the auto system has been. The reason is that at the breakpoints there is not enough space for picking up the high number of exiting passengers in a short time. The management favoured a feeder bus system during peak hours, which would bring passengers directly to their destinations. At many stops and outside of peak times, however, volumes and distributions of destinations are quite suitable

for a last-mile service provided by individual means of transport. So a mix of offers could be the solution.

Bicycle usage for last mile services, however, seems so far to be limited to special groups of people (students, middle / upper class citizens who have opened their mind to sustainable mobility possibilities).

In the area of commercial and freight traffic, the research showed a substantial lack of data (Chapter 4). Basic statistical data about freight movements, vehicles, mileages etc. is missing. But for an information platform, German experience with logistical processes and the information needs of individual sectors can be employed.

## D FRAMEWORK AND STRUCTURE OF MICPB

The analysis of existing information systems showed that a mobility information and communication platform for Bangalore (MICPB) with the tasks of building an informational link between public and individual transport services must be redesigned from the ground up (Chapters 3 and 5). Questions of scientific and practical importance concern (1) the use of smart-phones to generate real-time data, (2) the combination of sensor data with models to map the current and predictive traffic on streets and in the public transport network, (3) the improvement of forecast reliability, (4) the improvement of data basis of freight and commercial traffic, (5) dynamic, individualised, unimodal and multimodal routing, (6) logistic chains and (7) user behaviour in terms of obtaining better information.

The mobility information and communication platform for Bangalore (MICPB) has been designed for these tasks as follows: MICPB requires a central server with a data warehouse and an application server as its main components. The data warehouse contains static data (map data, static data about services) and dynamic and real time data (real time updates of forecast traffic data and weather data). It should be taken into account that scenario modelling might require access to historic data, so some kind of archiving functionality should be planned.

Based upon the data warehouse information, the server computes intermodal routes meeting the user's requirements. Dynamic and simulation/forecast data is also taken into account to find the optimum route. Routing information will be updated automatically if conditions change. Independent of the routing functionality, a map showing the current and predicted traffic situation is made available through a web application or smart phone app. MICPB provides a communication platform which allows registered users to post structured mobility related information through various channels like web applications, smart phone apps and text messages or call centres.

For commercial traffic the information and functional requirements for MICPB – small freight transport have been categorised based on the various actors (customers, carriers and drivers). System components are the same as for passenger information. Some modules will be common across actors (e.g. routing, vehicle tracking). But the main task of MICPB will be to collect data in order to get a better understanding about freight and commercial traffic.

## E RECOMMENDATIONS

Against the background of increasing environmental and economic problems in megacities, it is necessary to think about new solutions to the mobility problem. The development of the framework for an ICT-based mobility system can be seen as the first step toward a practical application.

This research has shown the great interest of the stakeholders in the testing of such a solution. The rapid spread of smartphone technologies supports the development of a mobility information platform. Similar developments are in the pipeline on the German side, and experience in the construction and operation of initial modules can be used. This reveals the synergistic potential of German-Indian cooperation.

The testing of the platform as a pilot can concentrate on a sector of a megacity. The integration of the political hierarchy and NGOs in this area is important. Only a multidisciplinary, policy-supported approach will provide the opportunity to bring solutions in Indian megacities and German cities such that they will reduce actual and future mobility problems in a sustainable manner.

# 1 INTRODUCTION: AIMS AND WORK PROCESS

## 1.1 AIMS OF THE STUDY

Smart Mobility is defined as the movements of people and goods, which – when compared to an initial state – require less time, cause less environmental impact, are safer and cause lower costs for operators and users.

Smart Mobility needs a comprehensive information and communication system. Studies in major cities around the world have shown that better information about the current status of transportation networks provides significant benefits for users. The information can be used for changing individual mobility strategy. It is also of value for others who get a message about delayed arrivals ("informational advantage").[1]

When on a journey, it may be possible to identify alternative, faster routes. Reliable information before starting a trip may lead to a revision of mobility parameters like choice of transport, departure time or destination. Especially before starting a trip, reliable information thus opens up a variety of options for action. But also during a trip, significant benefits for individual road users can be identified.

Reliable dynamic information is also likely to create and use new transport combinations. However, this increases the complexity of the information network significantly, both in terms of static data (timetables, tariffs) and the composite of dynamic data. Conversely, it can be assumed that the transport network and especially the integration of public transport with individual transportation offers significant benefits that have not yet been harnessed. Such an integration of different transport methods could lead to a change in mobility behaviour in the sense of the above defined Smart Mobility.

These considerations also apply to commercial traffic. Here, route planning and navigation in the road networks undoubtedly benefit from reliable information as well.

The current situation of dynamic traffic information systems shows that there are still significant improvements necessary before reliability can be addressed. Many of the existing information systems have significant shortcomings in mapping the current traffic situation. Especially when it comes to road traffic, information systems are flawed. This is especially annoying regarding traffic jam information, when either the forecasted jam does not exist or existing congestion is not detected in time. This unsatisfactory situation is due to outdated reliance on detecting traffic flow at cross-sections or at nodes. In the future, cross section measurements will be supplemented by longitudinal measurements. The use of smart phone positions will play an important role in this context.

Other reasons for the unreliability of dynamic traffic information are the algorithms and models used for predicting traffic flow. Most road users are not only interested in the current situation, but also the situation in the future. The currently used models are not yet suitable for urban areas. New approaches have to be developed and tested, especially for urban settings.

This introduction has provided the background for the present study. The study is about a concept for a reliable dynamic database, models and algorithms that allow people to use dynamic information for their mobility needs. In passenger transport, the focus is placed on the combination of rapid public systems (metro, BRT) with low-cost individual systems (bicycle, auto rickshaw). In goods traffic, the focus is to open new methods for improving logistics processes.

The present considerations are based on two large previous studies.[2] While the drivers' needs for information of private and public transportation have already been explored and discussed in these two studies, the information required by the freight transport is still largely unclear. Another factor is the question of the information needs of auto rickshaws, which so far operate independently from other transport means. Auto rickshaws play a major role in taxi passenger traffic, but they also operate in the field of goods traffic. The structure of this means of transportation is widely unknown, but in the future, the system could play an important role in a networking strategy.

One aim of this study is therefore to analyse the structure and information requirements of auto rickshaw operators for passenger and goods traffic, to check possible databases of different owners, their availability and reliability as well as possibilities for using these databases for further developments.

## 1.2 WORK PROCESS OF PREPARING THE STUDY

For the realisation of the study, the following team was formed, with duties as described below:

1 Helling 2005.

2 Schönharting/Sitharam 2011, Akhilesh et al. 2011.

1) TRC, abstracture, CiSTUP, IIITB: Analysis of existing information systems for mobility of passengers from both user and operator's perspective. Data reliability analysis of different dynamic databases.
2) ITL, CiSTUP: Requirements analysis for online information for commercial traffic. Data analysis of freight auto rickshaws tracking and tracing. Possibilities for commercial traffic model structure, using static and dynamic data
3) CiSTUP: Analysis of Auto Rickshaw Mobility Structure.

The leadership of the study lay in the hands of TRC.

On April 23rd, there was a coordination meeting of all stakeholders in the CiSTUP office in Bangalore. Content and process of research and analysis obtained were presented and discussed during a workshop with representatives from industry, academia and policy in Bangalore on April 24th 2012.

In the days that followed, information sessions were held with the management of the KSRTC and BMTC bus companies and with the management of Namma Metro. Another interview was held with the social network Praja, Bangalore.

In Germany, the bike rental company nextbike has been included into the information retrieval by a meeting on site (Leipzig) on May 7th 2012. nextbike is an international company that rents out bicycles in many cities on different continents. nextbike is probably one of the most experienced companies in this sector and owns IT tools that are considered in the study.

In parallel, CiSTUP carried out a survey of auto rickshaw drivers. The method of analysing the data was discussed with ITL. On May 23rd 2012, Prof. Sitharam and Prof. Akhilesh (CiSTUP) visited the ITL in Dortmund (Prof. Clausen with staff). The meeting was also attended by TRC. The aim of the meeting was to discuss the initial results of the study and the further way forward.

The combination of the individual contributions into a coherent report was based on email correspondence. TRC brought the report into the actual version.

# 2 PASSENGER MOBILITY

## 2.1 GENERAL

An information and communication platform has to offer static and dynamic information about different content:

1) road infrastructure: actual traffic situation, journey time forecasts between origins and destinations, parking possibilities, etc.
2) metro: train tracking, arrival time forecasts at stations, ticket prices, etc.
3) buses: bus tracking, arrival time forecasts at stops, ticket prices, etc.
4) rickshaws: availability at stations and stops of public transport, phone numbers of operators, actual location, etc.
5) rental systems (bike, car): location of available vehicles, prices for renting, phone numbers, etc.

The availability of information will be identified from both a user and operator's perspective.

## 2.2 NETWORK OF STAKEHOLDERS

In the development of a new information system, different groups of people have to be involved:

- users for whom the information system will be developed and who will optionally act as data generators;
- private and public transportation operators and providers of transportation and services;
- the government, for sovereign functions, such as the use of public space as well as traffic management strategies serving urban development objectives.

The following target groups have been identified for the use of an integrated transportation system, consisting of public and individual transport, especially bicycles[3]:

1) Student community: The student community is a very attractive target group for many reasons: e.g. they are a large community, cycling is a feasible option for almost all students across age groups, they are often 'trend-setters', and of course, they are tomorrow's adults and therefore sensitising them today to the advantages of cycling is a good long term strategy.
2) Potential two-wheeler buyers: Such a service would provide a real choice which is lacking today, and it could be a significant factor in controlling the number of two-wheelers on the road.
3) Middle / upper classes: Middle and upper class citizens with short trips could adopt this mode if convenient. They are also likely to demand better facilities for cycling in the city.
4) Tourists: The Paris experience suggests that this service is preferred by tourists as an independent, cheap way of getting around town. Of course, the service would also have a positive feedback on tourism as it would eventually make the city greener and more pleasant.
5) Public Transport Users: This system can act as a feeder or for last-mile connectivity.

The network of bus operators include BMTC, KSRTC and the Namma Metro, the operator of the commuter rail and private operators of taxis and rent a car services, auto rickshaws and bicycle rental companies.

At the state level, the municipal government of Bangalore and the State Government of Karnataka with its various administrations are necessary partners during and after the development phase.

In addition, the dynamic information system is based on all smart phone users who are willing to deliver their dynamic position data to the information system.

## 2.3 DATA AVAILABILITY AND RELIABILITY

### 2.3.1 OVERVIEW

This section discusses the role of an information platform from the user's perspective. The existing information services have been researched and the information provided has been compared with the information required. Of particular interest are combinations of solutions, that is to say solutions where public transport facilities will be combined with solutions for the last mile ("combined solutions").

3 Praja.in 2012a.

The information, booking and payment system will be differentiated into pre-trip and on-trip solutions. Pre-trip offerings are used before starting a trip, a sequence of trips or a daily mobility programme. On-trip offerings allow access to information, booking and payment on the move.

The research should give answers to the following questions:

1) What information is offered for single mode trips from A to B (single trip) or for realisation of a trip chain (from A to B to C and others) or for realisation of a daily trip programme? As one uses the transport infrastructure networks, how much time is needed and what costs are associated with the offer? How complicated is the information and the use of an offer?
2) How can an offer be booked? How will these services be paid for?
3) What information is available for connected services within public transportation? What information is available for serving the last mile with individual traffic systems ("combined offers")?
4) Is the actual position of individual vehicles (auto rickshaw, taxi) and of buses visualised on a map and available for users?
5) Are dynamic traffic management measures available?
6) Is dynamic traffic information available for routing purposes?

### 2.3.2 PUBLIC TRANSPORTATION, BMTC BUSES

In addition to individual transport methods, the line-bound systems of public transport form the basic system for routes from A to B in Bangalore. When using the public transportation service, usually an additional walk is needed to reach the boarding point and another walk from the drop-off location is necessary to finish the trip.

In Bangalore, BMTC provides the bus services within the city. The network is very extensive; it currently includes some 6,000 schedules, 79,000 journeys and 13 million vehicle-miles driven by some 6,200 buses. The company owns 37 depots and 48 large bus stations. 32,000 people work directly in the company. 4.5 million passengers are transported daily. The revenues reach 3.78 million INR per day. BMTC bus services distinguish different tariffs and different bus qualities.

Figure 1: BMTC bus network in Bangalore.[4]

The network of bus routes in Bangalore is designed as a half diameter network in combination with ring routes. Trips through the centre usually require a change. Transfers between two or more lines are also required for tangential journeys, if ring lines cannot be used directly.

Selected routes can be visualised on maps. Users of the BMTC information service can use functionalities of line routing (presentation of the entire line or presentation of a part of the line, which begins with the user selected initial stop and ends at the exit station) provided by three different information providers (BMTC itself, BTIS.IN and Google Maps).

The coordinates and names of bus stops, timetables, fares and bus types used are widely available for BTMC's operating area in the form of tables. Also available are services that calculate journey times and rates at predetermined stop combinations. These data can be made available to the consortium for research and development purposes.

In unfavourable situations, a destination can be reached only with multiple transfers and in combination with long walks.

The BMTC information as well as that of BTIS.IN is limited to direct trips. Unlike Google Maps, transfer connections are not available.

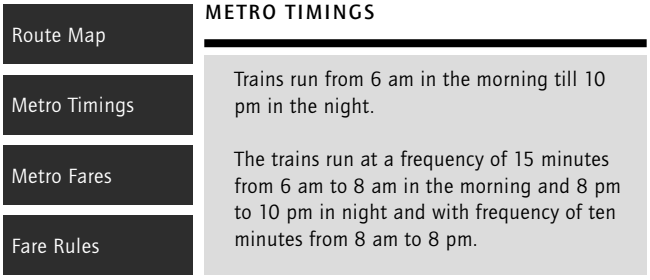
4 BMTC 2012.

However, the quality of the determined transfer connections with their key data should be tested in the future. Google Maps not only offers the combination of several bus lines, but also a comparison of routing for road traffic.

Current routing is based on static information, which is why dynamic information about roadworks and delays are yet to be included.

There is no link between public transport providers KSRTC (Bangalore Metropolitan Region) and Indian Railways. Between bus and metro, however, BMTC prepares an informational link.

Figure 2: Information about Namma Metro timings in Bangalore.




A link to individual systems such as car rental, taxi, auto rickshaw or bike rental is not currently being considered. Dynamic bus tracking was abandoned after a trial run. Dynamic information about current departure times at bus stops or the map-based tracking of buses by users of public transport has not yet been implemented.

The current schedule, booking and payment information system of BMTC buses is restricted to the BMTC bus network; transfer connections within BMTC bus lines are offered as a service only by Google Maps. Booking issues play no role so far; they will become necessary only after integrating BMTC buses with individual systems that allow reservations. Payment is possible in different ways. Card solutions which connect BMTC buses with other transport methods are not yet available. Mobile payment via mobile or smart phone is also not yet implemented.

More dynamic information (delays, disabilities, arrival time prediction) is yet to be included. Also not included is the linking of buses with individual modes of transport. Finally, bus positions are currently not detected and cannot be communicated externally (with users).

We can assume that the information provided will be expanded in the future, both in terms of linking bus routes within the BMTC system and linking BMTC information with that of other public transport providers. We may also expect that a common smart card solution will be developed by BMTC and Namma Metro. However, a big challenge will be the extension of the current static information system to a reliable dynamic information system. This and the link between public transportation and individual offers have not been considered thus far.

### 2.3.3 KSRTC

The company responsible for overland traffic in the Bangalore metropolitan region is KSRTC. Their network includes some 7,000 schedules, which are driven by 7,600 buses. Around 25 million bus-kilometres are travelled every day. The daily passenger volume exceeds 23 million.

Table : Key Statistics of KSRTC.[5]

| | | |
|---|---|---|
| 1 | Depots | 72 |
| 2 | Divisions | 15 |
| 3 | Bus stations | 128 |
| 4 | Vehicles | 7599 |
| 5 | Effective Kms per day | 24.91 lakhs |
| 6 | Schedules | 6881 |
| 7 | Average traffic revenue per day | 589.78 lakhs |
| 8 | Average passengers travelled per day | 23.60 lakhs |
| 9 | Staff | 34019 |
| 10 | Staff ratio per schedule | 4.94 |

Currently, the company's schedule and fare information are available in the form of tables. A description of routes on a map is not yet implemented. Therefore, it is unclear whether the coordinates of the stations are already available. Potential passengers are obliged to find out the connection which is suitable for the desired trip from a list of links. Further information offerings have not yet been realised. Thus, the integration of their schedules with BMTC, Namma Metro and the suburban services is absent.

5 KSRTC.in.

Table 2: Example of a table for O-D-connection Kozhikode-Bangalore (bus network of KSRTC in Bangalore Metropolitan Area).[6]

| Bus Name | Bus Type | Departure | Arrival | Seat Availability |
|---|---|---|---|---|
| 22.00 Kozhikode-Bangalore (SE726)<br>Via- S Bathery | Super Express | 00:35:00 | 05:50:00 | Today (0)<br>Fare - 274.00 |
| 7.00 Kozhikode-Bangalore (SF721)<br>Via- Sulthan Bathery, Mysore | Super Fast | 09:50:00 | 03:20:00 | Today (Time Passed)<br>Fare - 241.00 |
| 7.30 Kozhikode-Bangalore (SDA721)<br>Via- Sulthan Bathery, Mysore | Super Delux Air Bus | 09:55:00 | 15:50:00 | Today (Time Passed)<br>Fare - 340.00 |
| 8.00 Kozhikode-Bangalore (SF722)<br>Via- Sulthan Bathery, Mysore | Super Fast | 10:50:00 | 16:20:00 | Today (Time Passed)<br>Fare - 241.00 |
| 10.00 Kozhikode-Bangalore (SF7210)<br>Via- SBY | Super Fast | 12:50:00 | 18:20:00 | Today (Time Passed)<br>Fare - 241.00 |
| 12.00 Kozhikode-Bangalore Air (SDA725) | Super Delux Air Bus | 14:10:00 | 20:00:00 | Today (Time Passed)<br>Fare - 340.00 |

Similar to BMTC, real-time tracking of buses has not yet been provided, and neither have other aspects of dynamic timetable forecasting of timetable or the inclusion of individual supply systems covering the last mile. It is assumed that the information currently offered by KSRTC will reach a similar status to that provided by BMTC in the near future.

### 2.3.4 NAMMA METRO

Since opening in the fourth quarter of 2011, Namma Metro has represented a new key transportation system in Bangalore. The first section of Line 1 with seven stations is now operational and available for passengers. Other sections of lines 1 and 2 are under construction. Bangalore is planning to consolidate the metro network in the future with further lines. The network plan can be accessed at: http://bmrc.co.in/RouteMap.htm.

Currently, clicking "Travel Info" on the homepage provides the user with network information, and the schedule as a list. The different fare tables are accessible online: http://bmrc.co.in/Fares.htm

At present, no combined information between the metro network and the BMTC bus network is available. However, an informational link between the bus lines, their timings and the Metro line is being prepared by BMTC.

6 KSRTC 2012, kran consulting 2012.

Looking at the page "Metro feeder and Services"[7], one will find the following text:

> *"Ordinary services, including Parisaravahini vehicles, are operated at ordinary passenger fare. At present there are 5.402 of those services operating in city and sub-urban areas. City Black Destination Board buses are operated within the erstwhile BMP limit.*
>
> *Sub-urban: Red Destination Board buses are operated within the jurisdictional limit of BMTC (which extends up to 25 km beyond the BBMP outer limits). Mofussil services are introduced on public demand to few destinations beyond BMTC jurisdiction and operated on KSRTC fare. These are limited services."*

It is assumed that with increasing extension of Namma Metro the supply of feeder bus lines will be adjusted and that new feeder bus routes will be added to the BMTC schedules.

### 2.3.5 COMMUTER RAIL

No official website exists for the existing commuter railway, Namma Railu. We have been informed that actually 14 train services run per day to nearby places in the Bangalore suburbs. This information, however, is not properly provided to citizens.[8]

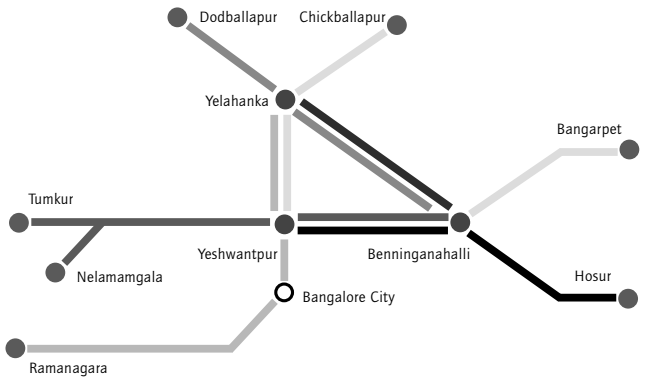
Praja, involved as a volunteer social network for the development of mobility in Bangalore, has also developed and presented proposals to decision makers with regards commuter traffic.[9]

7 BMTC 2012.

8 Information by S. V. Dyamannavar, Bangalore. Furthermore: "the Directorate of Land & Urban Transport (DULT) of the Government of Karnataka has assigned the detailed project report to Indian Railway Organization RITES (www.rites.com) during Nov 2011. RITES presented the draft report on Commuter Train to DULT / Govt. of Karntaka during April 2012. The final project report will be submitted by 1st week of July. After this, the Government of Karnataka will send the proposal to the Government of India for approval and execution."

9 Praja (2012b) about themselves: "We are neither trying to be alternate media, nor yet another NGO. There is some wide and serious space between journalism and activism that we are trying to fill and bridge. Our dream is to create a platform where citizens highlight their local issues, then network with like-minded people to evolve possible solutions, and find ways of engaging with local government bodies to get things fixed."

Figure 3: Proposed commuter rail network.[10]




After this, the existing network for commuting should be developed further. The Praja proposal envisages eleven major stations at different neighbouring towns/cities around Bangalore.

The current lack of information on rail transport facilities in Bangalore is described in the following excerpt, which has been taken from the aforementioned Praja page:

> *"We had done such rush hour train watch exercises two years ago at Whitefield station. Last week, got a chance to do it at KR Puram station. Had to be at KR Puram station early in the morning for a pick up. Was there on Friday, 6th April, from 7.05 am to 8.25 am. From commuter rail perspective, that would be rush hour, right? During these 90 minutes: Total number of trains that passed through KR Puram station was 6! 4 inbound (towards city), 2 outbound (towards Whitefield).*
>
> *Only 1 freight train, rest passenger trains. 6 in 80 minutes, 1 every 13 minutes. Let's assume 2 trains missed their slots due to delay etc, even then the passage would be 1 every 10 minutes. What on earth prevents upping this to 1 every 5 minutes, and squeezing in 5 commuter train from Malur to at least Byappanahalli of Cantt? One problem would be time and space required for terminating trains at Byp or say Cantt (For a Commuter Train would have to reverse directions, switching from left side track to right side track would block the entire direction for 2-3 minutes)."*

The use of existing stations for an information network between the commuter rail, bus and metro systems would certainly be of great benefit to commuters. Currently, this combination has not been implemented. If additional commuter trains with stations in the city of Bangalore were provided, the information network would increase in density accordingly. This is currently only one option, and nobody knows when or if it will be implemented.

### 2.3.6 AUTO RICKSHAW, TAXI

With a taxi or auto rickshaw one can realise all inner-city routes between two addresses. Of interest here are (among other things) the locations, the prospective travel time and the costs in relation to possible alternatives. The mobile phone serves as a communication medium, so the telephone numbers must be known.

At present, taxi trips play a subordinate role in Bangalore because of the relatively high price. Several taxi companies are registered and numerous locations available (for example www.starcitytaxi.com/; www.carhireinbangalore; www.citicabsinc.com; etc.). The taxi offer is distributed across several offers, so that no uniform number exists like "taxi call" in Germany. The telephone numbers for requesting a taxi must be found from their respective web pages.

Further information such as the actual location of the individual taxis, or whether a call to the taxi centre leads to the allocation of the taxi with the current most favourable location cannot yet be determined. Thus, it is unclear whether taxis have a location finding and communication system installed. The use of the taxi system for last mile solutions requires large organisational changes in the way that the telephone numbers of the taxi companies are provided to prospective customers. Since no Smart Card solutions which include the taxi system exist, the passenger has to pay separately.

The status of the auto rickshaw system is somewhat different, since as well as being picked up from fixed locations, auto rickshaws are more frequently stopped and used from the road. For the pre-trip selection of a suitable vehicle in the context of a "combined trip offer", the telephone number of the driver is sufficient. For the on-trip variant the current position is necessary. This leads to an optimisation problem, whereby the MICBP information platform takes over the role of a taxi centre.

10 Praja.in 2012c.

### 2.3.7 RENTAL SYSTEMS: CAR, SCOOTER

Apart from taxis, there is also the possibility of renting cars or scooters in Bangalore. If the inquiring person has rented a vehicle or if the inquiring person possesses their own vehicle (scooter, passenger car, truck), then the information platform should be able to answer to questions about the prospective travel time and free car parks, if necessary.

### 2.3.8 RENT A BICYCLE

The main questions about bicycle use – which must be rediscovered in Bangalore as a means of transport for the everyday life – involve confidence in handling the bicycle, the traffic capacity of the road system, the travel time which can be expected and, as a boundary condition, the distance of the trip or of the trip chain. With the deployment of E-bikes (pedelecs), an extension to the radius of action for bicycles can be expected.

The infrastructure problem in Bangalore is articulated under the listed source Praja.in 2012a as follows:

> *"Bangalore, like other Indian cities, has increasingly shown a trend towards motorised transport and an accompanying neglect of non-motorised transport such as bicycles and pedestrians. As in other cities, more road space is being taken up by the large number of motorised vehicles, and non-motorised transport is getting correspondingly lesser space and facilities. Also, there is no provision for non-motorised transport in both the Master Plan for Bangalore or in the budgets allotted for the city's infrastructure. This is in spite of the fact that in a city like Bangalore, a high percentage of trips less than 4km long are done by cycling or walking. In fact even motorised trips have non-motorised components such as walking and cycling which act as feeder elements for commuters in helping them reach their destinations.*
>
> *It is against this background that the Directorate of Urban Land Transport (DULT) of Government of Karnataka, in association with PRAJA, a Bangalore-based non-profit citizen initiative, has drawn up a plan to set up a Non-Motorised Transport (NMT) Network in the city. Praja, which takes up issues across a wide spectrum, assists local citizens in coming up with collective solutions to problems and presenting them to the government.*
>
> *Giving the background of the NMT project Sathya Sankaran, a founding member of Praja says, "Since 2007, Bangalore citizens and the experts of Praja have been dissecting the transportation mess in our cities, especially Bangalore. Thus, Praja RAAG (Research, Analysis & Advocacy Group of Praja) came up with the justification, alignment and benefits of doing a pilot study of an NMT project. This report was also vetted by the Centre for Infrastructure, Sustainable Transport & Urban Planning (CiSTUP). DULT expressed keen interest in the proposal and constituted a task force on NMT of which Praja was a part. DULT and the Transport Department, Bruhat Bengaluru Mahanagara Palike (BBMP) then jointly conducted field trips to finalise the feasibility of the alignment. Transport Training Institute and Consultancy (TTIC) were appointed as consultants for the project and they prepared a detailed project report."*
>
> *The area of the city identified for the NMT Network is the Central Business District (CBD) of Bangalore. The CBD area is a very dense and severely congested area with the congestion likely to worsen because of the new facilities such as Museum and Open Air Theatre being planned along the Bangalore Metro Corridor which passes through this area. The NMT Network will be 8 km long and will cover important roads such as MG Road, Residency Road, St. Mark's Road, Richmond Road, Brigade Road, and Kamaraja Road. The bicycle routes and the pedestrian walkway together will provide safe and convenient connectivity to the metro stations, shopping complexes, schools and other important places in the area."*

From the perspective of an information platform, the most interesting case is bicycle rental systems. If the cyclist uses his own bike, the need for information is reduced to the routing in the road system.

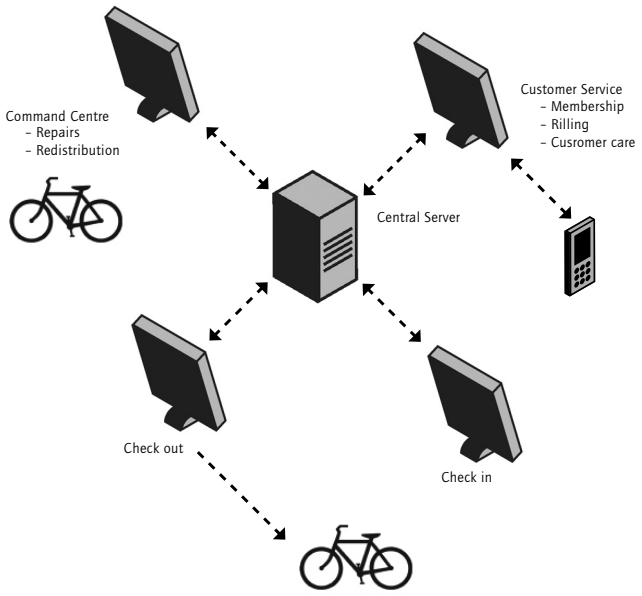
When using a lending system, the costs of the usage play a major role. Information about tariffs and locations of bike rental companies must be readily available.

> *"CycleMan – All about Cycling*
>
> *Inspired by my visit to Copenhagen, where 37% of the population ride bicycles each day, I wish to transform Jambalore to city of gardens, Bangalore. USA bought Trek 3700 21", 19.5" all-around mountain bikes with 21 gears – World's lightest Aluminium Frame, Front suspension, Quick release/ adjustable Saddle with Bottle Holder. Helmet and basic tools on*

*rent, too. Contact Writika on OR Vivek on or email at cycleman.bangalore[at]gmail.com."*[11]

Bicycle rental systems do not yet exist in Bangalore. This gives a good opportunity for the Indian-German Consortium to unlock the market and bring in German experience and know-how. In the meantime, an independent project has been initiated by IISc and a start-up by Namma Cycle.

Figure 4: Rent a bicycle system planned by Namma Cycle for the IISc campus.




The intent is to install 10 cycle racks with 20 bicycles each on the IISc campus during 2012.

### 2.3.9 METRO – BUS CONNECTION

Currently, only the social network PRAJA (http://praja.in) is working on solutions for the improvement of the link between the metro and bus systems. For the linking of these two systems, the site http://praja.in/en/projects contains a reference to a study in progress with the following text:

*"This is the project to look at newly opened Metro stations and analyze as-is situation on Metro-BMTC connectivity. A report would be the outcome of this project. The report is intended to help in advocacy efforts towards the expectations of public transport commuters such as:*

- *BMTC along with BMRC should get committed to provide reliable last mile connectivity*
- *Both agencies need to study the catchment area. For ex. work places like Bagmane Tech Park/ RMZ infinity have a concentration of prospective Metro users.*
- *Promoting usage of shuttles as well as Metro, well defined stops for Metro pick-ups, with display of schedules.*
- *Staggered schedules of shuttles. Higher during peak hours and leaner in non-peak.*

*[Project created on behalf of Srinidhi, idontspam, silkboard.]"*

In this context, the BMTC homepage shows (and this has also been confirmed in discussions) that the topic "linking the bus system with the metro stations" is on the company's agenda for the future.

For the other side, Namma Metro has also stated in discussions its interest in a link, favouring the employment of small town centre buses, which bring and/or take the passengers in round trips between the metro and their destinations. So far, however, a common solution has not been realised.

### 2.3.10 METRO – AUTO RICKSHAW CONNECTION

Auto rickshaws are usually ordered directly at the point of departure or hailed from the road. There are currently no links between the metro and auto rickshaws in Bangalore. From the Namma Metro organisation's point of view, a link between metro and auto rickshaws is of only subordinate interest. A link at the crowded stations will stress the space too much, and the auto rickshaw system is not efficient enough to serve large passenger volumes with sufficient quality.

### 2.3.11 METRO – BICYCLE CONNECTION

So far, the metro and bicycle rental systems are not linked, because no practical bicycle lending services currently exist in Bangalore. From Namma Metro's perspective, a bicycle rental system is of little interest, because the infrastructure for using bicycles is only regarded as good enough within a few areas. At present, bicycle use

[11] Cycling Man 2012.

on major roads is risky. A widening or change of roads in favour of bicycle lanes or the development of an independent bicycle network is not yet in sight.

The social network PRAJA is concerned with a link between the metro and bicycles as a feeder system. The following is written under the topic "bicycling infrastructure for last mile & intermodal connectivity"[12]:

> *"In Indian cities the share of NMT (Non-Motorised Trips) at peak hours ranges from 30 up to 70%; trips undertaken by bicycle account for about 10% to 35% of the total trips. Bicycles are not only important for the entire trip (from origin to destination), but, particularly in developed countries, also as a feeder mode to public transport. In a rich country like The Netherlands, 27% of all trips are by bicycle, whereas only 5% is by public transport. Although bicycle trips to and from public transport stops are only a small proportion of the total number of bicycle trips, it is true that the bicycle has a role to play when it comes to the promotion of public transport. Its potential as feeder system is very high.*
>
> *These are some of the reasons why a public bicycle system should be considered.*
>
> 1) *Accessibility: Make cycles and cycling more accessible to citizens. Today, if one wants to use a cycle to run an errand or one is 'in a mood' to cycle on a given day, it is not possible unless one owns a cycle. Making cycles readily and widely accessible would eliminate this tight coupling between owning a cycle and using it.*
> 2) *Extend public transport reach: A system such as this can also help to tremendously boost the reach of a public transport system, including the BRT, as it would be possible to use bicycles to access the public transport network even if the public transport station itself is at some distance.*
> 3) *Safety in numbers: It is well-known that the more cyclists there are, the safer it is to cycle. The proposed system, if successful, should contribute to a significant increase in the number of cyclists on the road, and therefore make Bangalore a safer city for cyclists.*
> 4) *Image: Cycling suffers from an image of either being a poor man's mode, or a school child's mode, or the enthusiast's mode. In short, anything but a desirable transport mode. Such an image has a strong negative impact on cycling and cyclists in the city. A city-wide cycling system with good, 'cool' cycles supported by cutting edge technology and branding, and backed by administrative and political support could help transform the image of cycling – and in the process, the entire transport scenario – radically.*
> 5) *Co-benefits of cycling: It is now accepted that cities benefit from promoting active lifestyles, which has enormous repercussions for public health. Cycling also helps reduce pollution, congestion and plays an important role in reducing carbon emissions.*
>
> *The target groups for such a system would broadly be follows.*
>
> 1) *Student community: The student community forms as a very attractive target group for many reasons e.g. they are a large community, cycling is a feasible option to almost all students across age groups, they are often 'trend-setters', and of course, they are tomorrow's adults and therefore sensitizing them today to the advantages of cycling is a good long term strategy.*
> 2) *Potential two-wheeler buyers: Such a service would provide them a real choice which is lacking today, and could be a significant factor in controlling the number of two-wheelers on the road.*
> 3) *Middle / upper class: Middle and upper class citizens with short trips could adopt this mode if convenient. They are also likely to demand better facilities for cycling in the city.*
> 4) *Tourists: The Paris experience suggests that this service is preferred by tourists as an independent, cheap way of getting around town. And of course, the service would also have a positive feedback on tourism as it would eventually make the city greener and more pleasant.*
> 5) *Public Transport Users: This system can act as a feeder or for last-mile connectivity."*

The last statement is of great interest. PRAJA can also imagine the bicycle as a feeder system to public transportation. Currently, however, such systems are not available and therefore no information has been found on the internet.

12 Praja.in 2012a.

### 2.3.12 DYNAMIC INFORMATION ABOUT TRAFFIC CONDITIONS

The current traffic conditions are a basic service, which is used, among other things, as the basis for navigation. One can differentiate traffic conditions with respect to the road system and traffic conditions with respect to the net of public transport enterprises. The traffic conditions are of special interest for the road system. Disturbances affect all who use the road system (individual traffic, buses, auto rickshaws, rental systems etc.). In Bangalore, dynamic information about actual traffic conditions is published by the information system BTIS.IN.

It is indicated on the road map of Bangalore how many active mobile phone devices are in the catchment area of an intersection. So far, the intervals of actualisation have not been investigated. The problem with the information is that it is not suitable for routing. For a routing application the situation on the links of the road system and, at intersections, in the lanes and turns is of great interest. This information cannot be derived from the number of active mobile phone devices in the catchment area of an intersection.

One theoretically small problem which is actually a severe detriment to navigation applications is that the information is obviously not correctly positioned on the map, since zooming in on map moves the points of information.

For the public transportation network (BMTC, Namma Metro, KSRTC and commuter rail), dynamic information is presently not realised. Departure times of buses are not currently available, even though this is important information for passengers, especially on lines that operate infrequently.

# 3 REQUIREMENT ANALYSIS FOR MICPB PASSENGER TRAFFIC

Functional requirements for the Mobility Information and Communication Platform Bangalore (MICPB) depend on the type of data available and the clients accessing the data. The first part of this chapter will therefore deal with how a suitable set of data can be collected and maintained. The second part will list clients and their requirements regarding data and interfaces.

## 3.1 DATA WAREHOUSE BUILDING AND MAINTENANCE

There are two main data categories: (Semi-) static and dynamic data.
The static data pool will be built via an initial load and infrequent updates (> monthly). The static data pool contains:

- map data (GIS data, e.g. OpenStreetMap):
  - traffic model,
  - special routes/lanes (e.g. bicycle, bus),
  - points of interest (POI),
- public transport data (bus, metro, trains)
  - stops (General Transit Feed Specification: GTFS),
  - schedules (GTFS),
  - pricing data,
- rental company data (e.g. location of cycle stands),
- Taxi data (e.g. location of stands, phone numbers).

Dynamic data will have to be updated with a high frequency (up to once per minute) and consist of:
- traffic data (e.g. floating car data),
- public transport real-time updates (GTFS-real time),
- rental companies real-time updates (availability, current location),
- e-rickshaw data (availability, current location),
- simulation/forecast data from a traffic simulation system,
- weather data (METAR).

It should be considered that scenario modelling might require access to historic data, so some kind of archiving functionality should be planned.

## 3.2 CLIENT REQUIREMENTS

As mentioned before, one of the main goals of the MICPB is to provide support for intermodal mobility. The data warehouse described in the previous section contains the required information to deliver the following functionalities through specialised client modules:

**Intermodal Routing**
The user enters the start and end point and the starting time of a route by means of a suitable graphical user interface (e.g. website, smart phone app). Optionally, other criteria like maximum travel time, maximum number of transfers or a list of transportation systems could be defined. The complete list of potentially available transportation systems includes the following:

- BMTC bus,
- KSRTC bus,
- Commuter Rail Trains (Namma Railu),
- metro trains (Namma Metro),
- taxis,
- e-rickshaws,
- auto rickshaws,
- rental bicycles,
- private bicycle,
- private two-wheeler,
- private car.

Based upon the data warehouse information, the server computes routes meeting the user's requirements. Dynamic and simulation/forecast data is also taken into account to find the optimum route. Routing information will be updated automatically if conditions change and if the user stays online (e.g. with a smart phone app).

**Point of Interest (POI) Search**
The user can search for POIs by providing search criteria like type of POI or name, optionally in combination with a search radius around a geographical point. POIs can be registered in the system by customers (e.g. restaurant owners, entertainment companies etc.), who will be required to pay a registration fee. This allows MICPB to generate some revenue, which can be used to lower the cost of operations.

Once a POI has been chosen by the user, the system will offer routing to that POI. Additional services like making a reservation at a restaurant or buying a ticket for a cinema could be considered.

**Modelling / Scenario / Forecast**
The MICPB data warehouse provides access to supplementary or external systems for modelling, scenario and forecast purposes. A traffic simulation/forecast system is considered part of the MICPB and will store its results in the data warehouse as input for the routing functionality. Other registered clients are provided access to MICPB data and functionality through interfaces based on standard protocols.

**Traffic Information**
Independent of the routing functionality, a map showing the current and predicted traffic situation is made available through a web application or smart phone app.

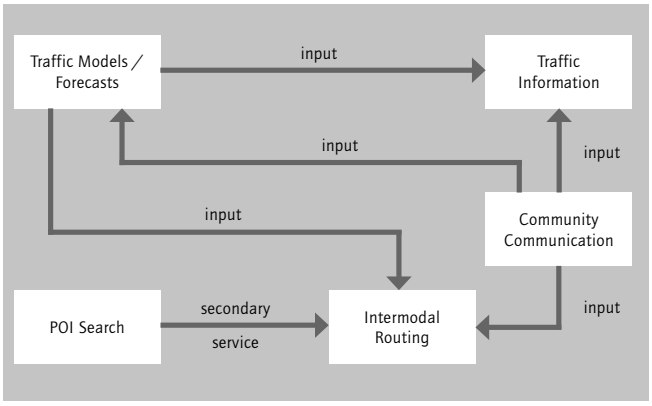
**Community Communication Platform**
MICPB provides a communication platform, which allows registered users to post structured mobility related information through various channels like web applications, smart phone apps and text messages or call centres. Structured mobility information means that the messages have to adhere to a simple syntax defining at least a message category and location. Supplemental information might be requested depending on the message context. An example of such a message would be "traffic: heavy: M.G. Road at Kamaraj Road". The message syntax will be extendable to eventually cover all common mobility related events.

The messages will be made available on web map views with predefined or custom filters. Messages can also be pushed to smart phone apps or sent to SMS subscription lists.

**Additional Requirements**
Some of the aforementioned functionalities require user management with the typical use cases.

**Dependencies between Client Modules**
The client modules implementing the functionalities described above are linked with each other in such a way that a module might complement another module by providing a secondary service. Some client modules provide input by collecting or computing data for other modules as well.

Figure 5: Dependencies between client modules.




## 3.3 CONCEPT FOR MICBP

The Mobility Information and Communication Platform for Bangalore (MICPB) requires a central server with a data warehouse and an application server as its main components. Both external and client applications running on the application server will deliver and receive data in various formats, amounts and at different frequencies. Non-functional requirements for the operation of such a server will not be discussed in detail. It is clear, however, that since there will be a multitude of very different clients, the server has to be designed with a flexible and extensible architecture. Both incoming and outgoing data interfaces to clients should be restricted to standard formats whenever possible in order to keep the server maintainable.

One of the key components of the MICPB server is a data warehouse for GIS data with an ancillary conventional relational database. In general, data warehouses prepare data for further processing steps employing methods and tools to store, read and transform information as well as managing metadata.

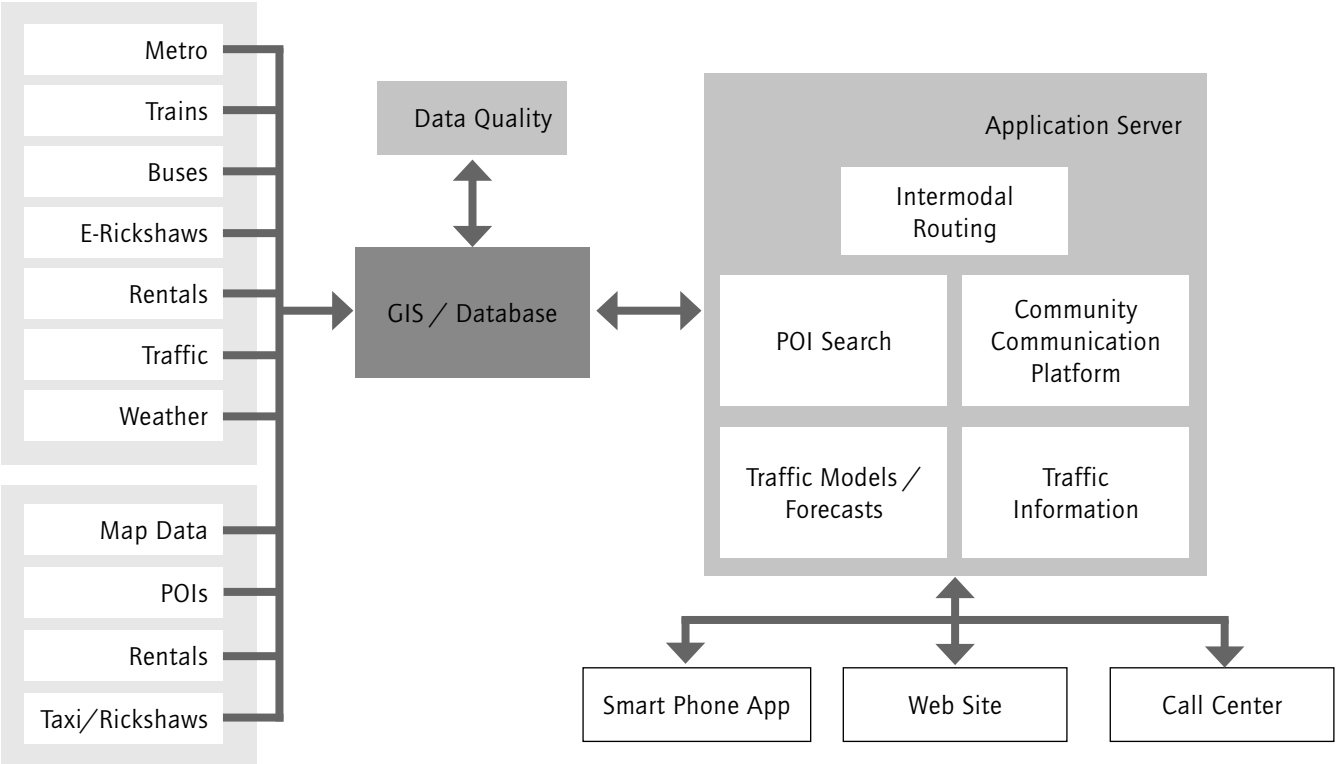
The other key component is an application server, which hosts the client applications.

**Web server**
All external applications are connected with MICBP through a web server and standard web-based protocols.

**Database**
The database needs to provide the functionality to store both GIS and regular relational data. Data stored in relational tables are any non-geographical data, e.g. telephone numbers of taxi companies or complex attributes for geographical objects.

**Map server**
The map server provides geographical functionality and standard OGC services to query and send data to the GIS data store. If necessary, OGC services (e.g. WFS services) are routed through the web server to allow external clients to connect with the GIS data store. Geo Server is a mature map server and reference implementation of many OGC standards and would therefore be a good choice as the map server for MICPB.

Figure 6: MICBP: components and dataflow.




**Application Server**
The application server hosts client applications. It allows links between clients and sharing of common functionality. In addition, it provides interfaces for external applications.

**Administration**
Last but not least, there needs to be a component to allow the administration and management of the MICBP.

## 3.4 DATA MODEL

OpenStreetMap data is used as the main GIS data source, because OpenStreetMap already contains a fairly extensive map of Bangalore. For performance reasons, a copy of the Bangalore metropolitan area is obtained at regular intervals and stored in the local GIS data store. Map data is improved directly in OpenStreetMap through their standard tool set.

Many databases provide a model for geographical objects. A suitable model is part of the open source PostgreSQL database.

For the relationally stored data, a model needs to be developed which allows execution of typical client queries with good performance.

## 3.5 PROCESSES

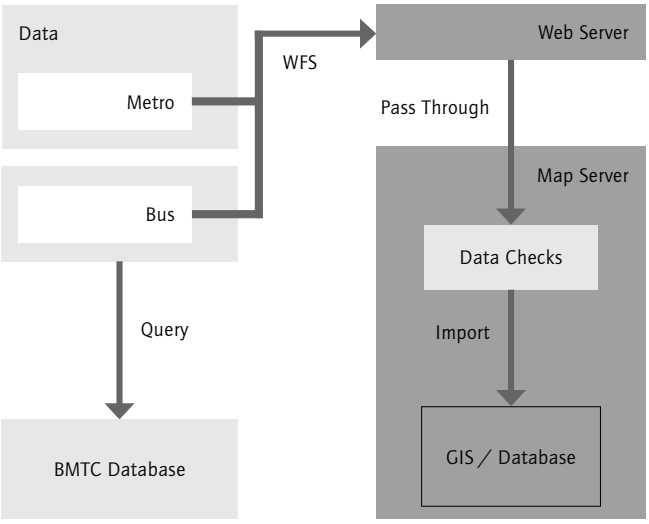
**Data upload from clients**
GIS data from clients is uploaded using standard WFS requests. If necessary, transport agencies will be offered custom upload tools to simplify data upload. The additional benefit of this approach is a single, clearly defined interface for uploading data to MICBP. Part of the upload process will be data quality checks.

For non-GIS data, web services will be used as upload interfaces.

**Data quality checks**
Large data stores have the potential problem of bad data quality. Mechanisms are implemented to allow regular, more complex data checking routine to be run on the complete dataset. Beyond the basic data checks are performed during upload. They will check

consistency and plausibility of the data and perform cross checks with redundant data.

Figure 7: Example for client data upload mechanisms either directly from a transport agency (Metro) or through a separate upload application querying a transport agency's database (BMTC).




**Data queries**
Registered external clients, i.e. clients not running on the application server, will be allowed access to MICPB data and functionality through web services and OGC standard protocols.

**Client Data Access**
Internal clients have direct access to the data warehouse to execute spatial and standard queries and to persist data they produce.

## 3.6 APPLICATION SERVER

Client functionality may be accessed through several different applications implemented by web applications, smart phone apps or smart client desktop applications. Therefore, a clean separation between business and presentation functionality will be enforced. On the application server, the business layer of a client module is the central component. For each internal client (web applications) there is a shared presentation layer. Separate views for each application type deal with the respective special requirements. For communication via external applications (e.g. smart phone apps), web service interfaces are provided.

**Intermodal Routing**
As a starting point for implementing intermodal routing, the open source software OpenTripPlanner will be used. It already delivers a useful set of features, which can be extended to meet the goals of MICPB. The following list provides an overview of the current features of OpenTripPlanner:

- planning of multi-modal walking, biking and transit trips,
- taking travel time, road type/safety, and elevation data into account when planning bike trips, and providing an interface for customising the weighting of these three factors,
- showing graphical elevation profiles for bike trips,
- planning trips within about 100ms in a moderate sized city,
- exposing a Restful API (XML and JSON), which other apps or front-ends can build on,
- GTFS-real-time support for service changes and alerts,
- bike rental support.

The following new features will be added for MICPB:

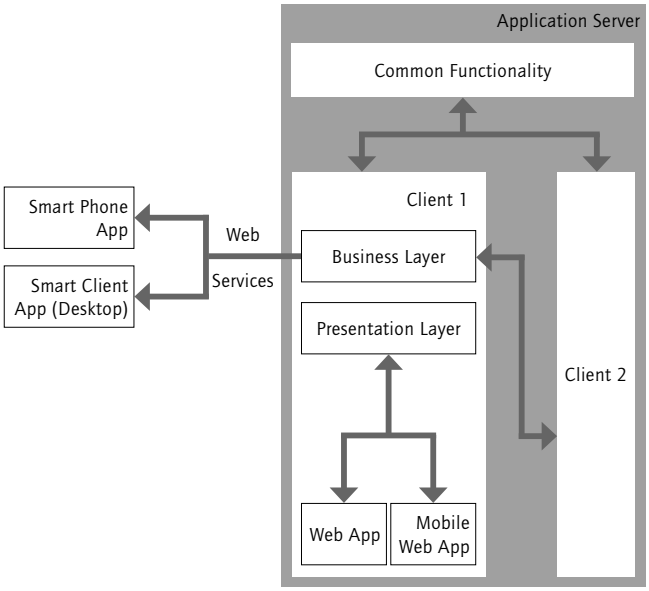
- extending multi-modal trips to include individual transportation: cars, two wheelers, rickshaws, taxis,
- providing real time traffic data and forecasts,
- providing real time routing updates for users already in transit.

Adding these features will make routing significantly more complex. However, there is a high potential benefit for the individual traveller and the overall traffic in the city. Therefore, it is considered worthwhile to develop new innovative solutions to implement these features.

**Point of Interest search**
Starting with the POIs on OpenStreetMap, users will be able to add new POIs to the MICPB map. When a commercial POI is registered, a fee will be charged. POIs can be searched via a range of spatial and other criteria (e.g. "show me all restaurants within 2 kilometres of the junction of Race Course Road and Ananda Rao Flyover").

One very important requirement for intermodal routing in MICPB is getting a detailed picture of the traffic situation at any given time with a limited network of sensors or other real-time data. That means that there needs to be a reliable traffic simulation, which also can deliver forecasts up to one to two hours in the future. Software based on the multi-agent simulation platform PlaSMA and developed at the University of Bremen, offers an innovative approach to dealing with exactly these kinds of problems.

Figure 8: Architectural view of internal and external client applications.




The MICPB data can also be used for planning purposes, such as improving the traffic infrastructure or connecting newly developed areas of the city.

**Traffic information**
Traffic information from real-time and simulated data is presented by the map server and made available through a standard WMS service. The goal is to provide the user quick access to the relevant information for his specific trips.

**Community Communication Platform**
The Community Communication Platform of MICPB allows users to share mobility related information. There will be a variety of interfaces for sending messages to MICPB: website, smart phone app, email and SMS. The system needs to be able to parse these messages, so they have to follow a simple syntax. Each message will be given a category by the sender. The syntax of the messages needs to be extendable to eventually cover all common mobility related events.

Incoming messages are parsed, and a location service computes geographical coordinates from the message text when appropriate. Messages that fail to be parsed will be rejected, telling the sender that the message cannot be processed. Messages will be redistributed to the user community via map interfaces, RSS feeds, email or SMS subscription lists. Users can define filters to select only those messages that are of special interest to them.

**User and Access Rights Management**
There will be a common user management for all client applications of MICPB. It provides implementation of the typical use cases like registering, assigning access rights via groups and managing user properties.

## 3.7 SYSTEM ADMINISTRATION

Since MICPB is a fairly complex system, it needs to be managed via an administration interface, which allows access to standard and custom administration tools.

**Data Management**
To manage the data warehouse, data functions for archiving, backing up and eventual deletion of data need to be provided. These functions will usually be executed automatically. An administrator will have access to the logs and also the ability to execute data management functions manually.

**Monitoring**
Depending on the number of users, it is crucial to monitor the performance of the system. Access statistics, system load, and database sizes can usually be monitored using standard tools.

**System Controls**
There should be a mechanism to control the operation of the system. Updating client applications requires taking one or more applications temporarily offline. Also the whole system will have to be restarted from time to time. During these times users should be notified that the service is temporarily unavailable.

# 4 MOBILITY OF GOODS

## 4.1 GENERAL

Freight transportation plays a crucial role within the worldwide economy. The flow of goods enables regional, domestic and international trade and thus economic growth. Furthermore, it ensures people's daily provision with everything they need and want, as well as providing a large number of jobs for people in the transportation industry as a whole. For example, in Germany, about 1.5 million people work in the field of traffic and logistics. Furthermore, 1.6 million people work within the field of machinery-building which is (part of) the basis for actual freight transport. This is about 11% of all statistically captured full-time employment in Germany.[13]

To provide people with jobs is a necessity. In addition, it is important for a country to ensure and increase economic growth. This is a challenge not only within the European Union, but worldwide. Economic growth is important for *every* country, but it is not sufficient to focus on statistics and the percentage by which GDP rises or is expected to rise. It is also essential to manage the increasing demand for freight transport and the limited infrastructure available.[14]

The methods of transportation mentioned previously and the respective infrastructural elements are of vital importance in freight transport because they enable actual movements. Furthermore, they also contribute to the previously mentioned satisfaction of people's needs and the fields of work freight transport makes possible. These are factors that affect the social environment. But to consider the whole depth of this topic, one cannot ignore a further, very important factor: the ecological aspect.

Freight transport has a big impact on the environmental balance (or rather imbalance) of our planet. Basically, fossil fuels are necessary to operate trucks, trains, ships and aircraft, which creates ecological pressures. Fossil fuels cannot be dispensed with, as there is currently no sustainable alternative yet invented that is as efficient in its overall concept. The main fossil fuels used as an energy source are crude oil and coal. These are burned and thus release the required energy. As a side effect, harmful particles are ejected: heat and carbon dioxide ($CO_2$) gas is released. The results on our planet are recognisable: worldwide, lakes and oceans are unnaturally polluted and contaminated, and the air is polluted with fine dust. Greenhouse gases heat up the planet. A well-known effect often mentioned is climate change.[15]
The industry is aware of these threats. Given the importance of freight management in its economic sense, but faced with the inevitable ecological impact, the industry is seeking for sustainable solutions. Negative ecological effects were first given recognition in the 1970s, and by the 1980s, the field for a more sustainable freight transportation started to evolve. This desire to create environmentally friendlier, "greener" freight transportation is nowadays called *Green Logistics*.[16]

Green Logistics considers the environmental effects of all processes in a supply chain from the extraction of raw materials to the final disposal of goods. The demand upon Green Logistics is to create transport processes that meet both ecological and economical goals within a company's system of objectives in a sustainable way.[17] The growth of environmental awareness, the proliferation of environmental regulations, and the development of national and international standards for environmental reporting and management are fundamental for the implementation of Green Logistics concepts.[18] Key goals of Green Logistics are to minimise carbon dioxide and other emissions, save resources and other raw materials, optimise the workflow, increase efficiency and utilise available synergies.[19]

Within Green Logistics, each player motivates other players to "go green" and provide the necessary information, support and guidance. Environmental objectives and performance measurement are then integrated with financial and operational objectives.[20] Various measures are well known and established in Western companies, related to different topics like traffic bundling, telematics and modernisation of the vehicle fleet, to name a few.

India is classified as a less-developed country (LDC). At the moment it ranks 134th out of 187 countries according to HDI (Human Development Index).[21] Due to the country's size and population, it "represents one of the great intellectual and practical develop-

13 Federal Statistical Office of Germany 2011.
14 Helmreich 2011, p. 3.

15 Holgate et al. 1999, p. 2; Hill, M. K. 2010, pp. 5-11.
16 McKinnon et al. 2010, pp. 6-7.
17 Gallus 2011, p. II.
18 McKinnon et al. 2010, pp. 6-8.
19 Federal Ministry of Economics and Technology, Germany 2011.
20 Emmett 2010, p. 9.
21 Hindustan Times 2011.

ment challenges of the century".[22] India has undergone major socioeconomic changes within the past 60 years, which were initiated when India gained independence in 1947.[23] Back then its industrial base was very small, but in 2005 India became the fourth largest economy in the world.[24] In general, the political leadership of India is committed to economic development and to implementing social change to raise the standard of living of the population. These facts underline the country's great potential for growth and development.

India is currently undergoing a period of notable rapid urbanisation. During the last 50 years, the population in India has increased 2.5-fold.[25] Simultaneously, the urban population has increased fivefold, as more and more people have moved from rural to urban areas. Moreover, India is expected to have an even larger number of urban centres and higher urban growth in the near future. This shows the growing demand for supplying urban areas in India.[26] This massive and rapid urbanisation leads to the problem of insufficient infrastructure, which can only be built up gradually. But the urban population growth is immense and new infrastructure cannot be built up quickly enough to serve people well. The consequences are congested streets and major pollution.[27]

Every large industry, as it has developed and will furthermore develop in India, requires new business to be established and execute a logistics function, such as e.g. transporting goods back and forth. As the market in India is relatively new and has enormous potential for growth, there is great incentive for India to implement aspects of Green Logistics into the evolving business sector.

Implementing Green Logistics into the Indian business habit has several advantages. Due to the massively growing population, the rate of freight transport within the country is continuously rising. Pollution in India is causing various problems, which retard India's economic and social development and also influence the HDI. If India wants to become a medium-developed country, it must go greener as soon as possible, because more developed countries cannot ignore ecological factors. In addition, the impact of pollution, especially within urban areas, will increase unless such measures are taken. But implementing Green Logistics habits at this stage of development should decrease levels of congestion and pollution. Because of this revelation, we will emphasise the idea of including Green Logistics into further technological development in India within this project.

### 4.1.1 MOTIVATION AND GOALS

The project needs to get an overview of available data on commercial traffic and goods flow in India. Relevant and necessary characteristics of freight transport, e.g. number and type of transport vehicles, transport volume, transport service, transport distances, routes and modal split should be identified in available datasets of official and unofficial statistics in India. In Germany, there are several databases of official and unofficial statistics available (e.g. KiD, MiD, KBA). The research question is which data exist in India and which data are necessary for analysing commercial traffic and deriving efficient solutions for improving goods and freight transport flows in India. The data should be sufficient for forecasts in this field. The forecasts would be the basis for efficient concepts to improve the infrastructure.

Possible references and sources should be identified. Here is a summary of potential statistics:

- Statistics on commercial traffic
- Statistics on vehicle registration
- Data collection at border controls
- Data collection from transport billing

Our main goal within this project is to analyse and describe mobility of goods in India, especially in Bangalore. The study will make a decisive contribution to gaining a comprehensive overview of existing data to commercial traffic and goods.

In order to reach this objective, it is necessary to find available data on commercial traffic and goods flow. Thus, we have looked for official statistics for India, Karnataka and Bangalore as well as freight traffic data of companies, containing data such as:

- Number and type of transport vehicles
- Transport volume
- Transport distances
- Routes
- Modal split

22 Hardgrave 2008, p. 3.
23 Hardgrave, p. vii.
24 Hardgrave, p. 10.
25 World Resources SIMCenter 2010.
26 Nath 2007, pp. xv-xx.
27 Dutt 2003, p. 92.

From there, structural characteristic values of the freight transport sector and logistics aspects should be identified in existing data sets, for example:

- Logistics master data (total and transshipment area)
- Carriers (unimodal, multimodal)
- Traffic infrastructure (railway sidings)
- Integration of the nodes in network structures and transport chains
- Transport and transshipment objects (cargo units, range of products)
- Transshipment capacity

Furthermore, the characteristics and characteristic values for the standardised description of material and transport flows (modal choice, type of vehicle, transport range, cargo types, loading units, cargo volume, number of vehicles, handling volumes, directions of freight flows) are of particular interest in this context. These primary data will be used for the analysis of network structures with regard to material flows, locations and transport and travel volume. Solutions for a sustainable transport in commercial traffic could be derived from this database.

GDP and other aggregated data are an insufficient basis for deriving freight transport values. For commercial transport modelling, we need to consider logistics structures. Transport flows can vary depending on logistics strategies. In many cases network structures are not taken into account. For transport flows, modelling of logistics factors and structures need to be considered.

In the field of commercial transport, one sub-goal is to promote an environmentally sound development of Indian urban goods transport. In this study, the main focus is on the central distribution centres, which distribute the majority of the freight to shop-owners using light trucks and auto rickshaws. The auto rickshaws and light trucks could be equipped with electrical motors and ICT-based systems. The main concern should be to explore the freight transport flows and goods. Against this background, this project aims to promote an environmentally sound development of Indian urban goods transport.

The study foresees measures which concentrate on increased investment in transport telematics infrastructure in urban areas. On this basis, an attractive offer of traffic information and communication services for improving the efficiency of transport and logistics processes should be provided to the logistics service providers. Furthermore, implementing an information and communication network can improve information, material and transport flows. One measure of green logistics determines which role a smarter use of Information and Communication Technologies (ICTs) can play. Process improvements lead to more efficient use of available transport methods. Thus, these ICT solutions reduce GHG emissions and achieve greener transport. Transport costs, journey times and reliability are improved as well.

### 4.1.2 FUNDAMENTALS OF LOGISTICS AND COMMERCIAL TRAFFIC

Commercial traffic summarises all transport which takes place in conjunction with economic or business activities, including freight transport, business personal transport and a combination of freight and personal transport in the context of service trips. This implies no limitation to any particular vehicle category or mode of transport. Furthermore, the validity of the commercial traffic imposes no geographical limit, but also applies to all transport at a regional and global level.[28]

Commercial traffic, especially freight traffic, belongs to the fastest growing transport sectors. According to data from the Federal Statistical Office, the transport services in freight transport in Germany amounted to over 630 thousand million ton-kilometres in 2011.[29] Forecasts predict an increase in the transport services of freight traffic to over 1,200 billion ton-kilometres by the year 2050.[30] Road freight traffic is mainly predicted to see an enormous growth in transport services. Yet in the political and economic decision processes, commercial traffic is accorded a high degree of significance.

The aim is to simulate commercial traffic as realistically as possible for decision finding in planning processes. Commercial traffic is distinguished by its high diversity and complexity. It takes place in networks and uses logistics nodes. Thus, the aggregate characteristic structures of source and target cells do not cover the complete behavioural scope of these transport modes. In addition, the structures of the companies and the networking activities of the logistics service providers have to be considered. Characteristic values of the source and target transport volume of the logistics

28 Steinmeyer 2004.
29 destatis online 2012.
30 ProgTrans AG 2007.

nodes are required in order to simulate the networks via models. Differentiated values must be taken into account when modelling freight transport demand. These values cannot be obtained exclusively from secondary data sources. Data requirements, which cannot be derived from official and unofficial statistics, have to be determined through primary data acquisition.

Logistics, as a relatively young discipline, requires the research of innovative approaches and solving methods for future challenges and the fulfilment of sustainable objectives. Germany is one of the leading nations in the field of logistics. In 2010, Germany was identified as being the most efficient at logistics activities in the world, whereas India was ranked 47th (see Table 3).

As an economically booming nation, India has a comparably insufficient infrastructure and a great need for investment and professionalisation in the logistics sector. A further problem is the lack of qualified specialists; despite a good capacity for training, there are too few educational establishments to meet the demand.

India's logistics sector is one of the fastest growing service industries and still has huge potential. In 2010, logistics companies recorded an increase in sales of 9% to USD 82 Bn. According to forecasts, in 2020, sales are expected to more than double to USD 200 Bn. However, fulfilment of these expectations strongly depends on the success of the expansion of the logistics infrastructure. Nonetheless, the logistics sector still has problems with existing inefficiencies. In India, the costs for logistics currently account for 12% of GDP while in Western industrial countries it remains at under 10%.

Table 3: Logistics Performance Index.[31]

| Rank | Country | LPI | Customs | Infrastructure | International shipments | Logistics competence | Trackung & tracing | Timeliness |
|---|---|---|---|---|---|---|---|---|
| 1 | Germany | 4.11 | 4 | 4.34 | 3.66 | 4.14 | 4.18 | 4.48 |
| 2 | Singapure | 4.09 | 4.02 | 4.22 | 3.86 | 4.12 | 4.15 | 4.23 |
| 3 | Sweden | 4.08 | 3.88 | 4.03 | 3.83 | 4.22 | 4.22 | 4.32 |
| 4 | Netherlands | 4.07 | 3.98 | 4.25 | 3.61 | 4.15 | 4.12 | 4.41 |
| 5 | Luxembourg | 3.98 | 4.04 | 4.06 | 3.67 | 3.67 | 3.92 | 4.58 |
| 6 | Switzerland | 3.97 | 3.73 | 4.17 | 3.32 | 4.32 | 4.27 | 4.2 |
| 7 | Japan | 3.97 | 3.79 | 4.19 | 3.55 | 4 | 4.23 | 4.26 |
| 8 | United Kingdom | 3.95 | 3.74 | 3.95 | 3.66 | 3.92 | 4.13 | 4.37 |
| 9 | Belgium | 3.94 | 3.83 | 4.01 | 3.31 | 4.13 | 4.22 | 4.19 |
| 10 | Norway | 3.93 | 3.86 | 4.22 | 3.35 | 3.85 | 4.1 | 4.35 |
| 47 | India | 3.12 | 2.7 | 2.91 | 3.13 | 3.16 | 3.14 | 3.1 |

However, one must also bear in mind that India is a country with strong economic growth rates, increasing industrialisation and is being integrated ever more into the world economy. Therefore, logistics will become more important for India. The main challenges in logistics concern the efficient use of infrastructural resources. So far, the further extension and development of the infrastructure has not been able to keep up with the rising demand for freight transport and its corresponding requirements. The same applies to the professionalisation of the management of material flows according to the preservation and improvement of individual mobility.

The market segment for third party logistics (3PL) is also expected to increase. In India, external logistics service providers traditionally provide freight transport. On the other hand, warehousing and value added services are mainly managed in-house. Due to the increasing complexity of customer markets growing far beyond the borders of metropolitan areas, combined with the poor experience in logistics services of industry and retail, a reorientation has been induced. Currently, the 3PL sector accounts for approximately 25% of all logistics activities in India. However, the logistics market is very fragmented.

31 World Bank 2010.

This is especially true for road transport, which accounts for 75% of total freight transport, dominated by small forwarding agencies. Most service providers only own between one and three trucks. As a result, industry and retail companies need to engage different service providers for each logistic activity. The individual logistics service providers are not capable of offering multiple services simultaneously.[32]

In this context, India has a large 'backlog' demand. For example, both transport infrastructure and warehousing capacities are operating at their upper limits. Furthermore, most multimodal freight centres are still in their development phase. Yet, the interest of private investors in establishing Free Trade Warehousing Zones (FTWZ) has been growing. Also, there are plans to connect seaports more efficiently to road and rail networks over the next few years and the first global hub and intermodal node for road, rail and air transport, is currently being built in Nagpur. Finally, foreign logistics service providers are extending their activities with cooperation on the subcontinent.[33]

The emission levels in the transport sector and especially in commercial traffic have rapidly increased. "The transport sector in India consumes about 16.9% (36.5 mtoe: million tons of oil equivalent) of total energy."[34] For these reasons, today more than ever, the logistics sector must make significant efforts to reduce their greenhouse gas emissions. They have to implement integrated business and sustainability strategies. With regard to transport emissions, the use of alternative power trains and fuels is being debated. More attention is being paid to synthetic fuels and electric propulsion mechanisms for automobiles, trucks and auto rickshaws. In addition, they produce significantly less noise than a standard diesel vehicle. The disadvantage of limited ranging, however, prevents use outside short-distance travel.

### 4.1.3 CURRENT STATE OF THE ART IN FREIGHT TRANSPORT DATA ANALYSIS

In Germany, an extensive data collection for the field of freight transport exists in official and unofficial statistics as well as from different scientific perspectives (e.g. journey samples, production statistics, goods flows at logistics nodes etc.). It is difficult to derive a consistent map of the transport network structures from these data.

Although the relevance of commercial traffic has been recognised in many fields, the state of data currently available has been inadequate. The main reason is that the official statistics only collect a specific sub-segment of commercial traffic.[35] For example, heavy goods traffic, which is collected in the statistics of freight traffic (paragraph 3 VerkStatG), is clearly identifiable.

Heavy goods traffic data applies to trucks and tractor-trailers which have a maximum permissible gross laden weight of more than six tons or payloads over 3.5 tons. Since 1994, the transport services and the transport volumes of German trucks have been collected continuously and collated and updated periodically. The survey for commercial traffic is carried out by the Federal Office of Goods Transport (Bundesamt für Güterverkehr, BAG); the survey for hires and reward is carried out by the Federal Motor Transport Authority (Kraftfahrtbundesamt, KBA). In general, the totality of the transport of goods within foreign vehicles is not taken into account.

For example, the Road Statistics Directive from the Federal Bureau of Motor Vehicles and Drivers (Kraftfahrtbundesamt, KBA) does not include any details about the economic sectors where the trips begin (source) and end (destination). Within the data available and with the aggregation method currently practiced, the integration of transport chains is also difficult. However, both kinds of information are important for using these data for traffic distribution in combination with a generation and attraction model. Furthermore, all of the official and unofficial statistics, which are based on the Central Vehicle Register (Zentrales Fahrzeugregister, ZFZR) from the KBA, only collect vehicles registered in Germany or their journeys (nationals concept). But all of the journeys which are carried out by foreign vehicles are not collected, since these vehicles are not registered in the ZFZR. This is a significant gap which cannot be closed with the data available.

Thereby, both transit transport and transport which has its source and destination within Germany are excluded from the scope of the survey.[36] This gap is closed to some extent by the annual traffic statistic "Traffic in Numbers" (Verkehr in Zahlen), which is initiated by the Ministry of Transport, Building and Urban Affairs and is carried

32 Fink 2008, pp. 185-191.
33 Alex 2011.
34 Ramachandra, Shwetmala 2009.
35 Wermuth 2003a, p. 49.
36 Statistisches Bundesamt 2008, p. 423.

out by the Institute for Economic Research. The study presents data on transport services and transport volumes of foreign trucks. However, light trucks and cars, which make up a large share of commercial traffic, are excluded from all of the official statistics. Their share amounts to 19%, measured in terms of vehicle driving performance per vehicle and working day.[37] For these categories of motor vehicles, only the official data from the Federal Motor Transport Authority (KBA) exists in the form of statistics on the stock of transport vehicles derived from all vehicles registered in Germany.

In addition, irregularly conducted traffic surveys provide further information (e.g. the mileage survey by the Federal Highway Research Institute (BASt) or the study KiD initiated by the BMVBS). The last survey mentioned offers an enormous advance in knowledge related to private passenger and commercial traffic.

The Federal Ministry of Transport, Building and Urban Affairs (BMVBS) provides current and extensive fundamental data with regard to the structures and the development of road-related transport for use in transport policy and planning. These data are not sufficiently covered by official and unofficial statistics. This is particularly applicable to commercial traffic. Within the survey "Motor Vehicle Traffic in Germany 2002" (KiD 2002) valuable information was gathered which allows road-related commercial traffic to be considered in planning processes by federal, state or local administrations in the future. This survey has been repeated in 2010.

A database update is essential because of changing transport conditions, e.g. structural change in economic fields, fuel price changes and the expansion of the EU. Therefore, the Federal Ministry of Transport, Building and Urban Affairs carried out another nationwide survey on motorised vehicle traffic between November 2009 and October 2010. Once the questionnaires were completed in October 2010, the collected data were subjected to extensive plausibility checks regarding utilisation of motor vehicles. The evaluation of the data basis is now complete.[38]

One relevant part of the basis evaluation is the basis tables, which contain elementary transport characteristics like:

- Share of mobile vehicles per day
- Trip volumes
- Driving performance per vehicle type
- Volume of people transported
- Volume of goods transported
- Duration of transport investment

These attributes are described and analysed by vehicle group, area type, economic sector and days of the week. Nevertheless, important variables (e.g. numbers of transported consignments) are missing from the survey.[39] The lack of continuity in conducting the surveys is a serious problem. The KiD study has only been conducted twice so far, in 2002 and 2010.

A fundamental problem is that there is not sufficient existing knowledge about logistics processes and structures in networks to simulate them in models. In statistics, mostly only aggregated data are available to present and model freight transportation.[40] In contrast, in passenger transport detailed findings are available regarding actor behaviour, with studies including "Mobility in Germany" (MiD 2008).[41] The nationwide survey "Mobile Vehicle Traffic in Germany" (KiD 2002) has remedied important data gaps on the federal level (business passenger traffic, transport with trucks with a payload of not more than 3.5 tons and the use of private vehicles for business purposes).[42]

Nevertheless, these data also allow only limited conclusions concerning goods flow as the cause of traffic. Within this vehicle-related survey, a classification of vehicle owners by economic sector is carried out. However, the description of the trips by trip destination and trip purpose allows no conclusions to be drawn regarding the link between logistics strategies and goods flows. In the continuation of the KiD 2002 supported by the BMVBS, entitled "Motor vehicle traffic in Germany (KiD) 2010", questions concerning instrumentalised logistics strategies and concepts are also not planned. Although progress from a logistical perspective has been achieved for the characteristics "Load Units" and "Goods Types", any conclusion about the logistics strategies adopted by enterprise is almost impossible from the characteristics provided (e.g. address and type of sources, time of trip beginning and ending, journey purpose, load unit, load weight – gross weight of the load, goods type, number of persons in the vehicle, address, type of destination and trip distance).

37 Wermuth 2003b, p. 241.
38 Federal Ministry of Transport, Building and Urban Affairs 2012.
39 Steinmeyer 2004, p. 39.
40 de Jong 2004, National Institute for Transport and Logistics 2005.
41 Infas, DIW Berlin 2004.
42 Wermuth 2003c.

It is apparent that commercial traffic in Germany constitutes an area of major importance. Its existence is not restricted to a defined area, but exhibits a high transport volume on a national level (e.g. within the scope of long-distance traffic) as well as in regional areas within short distance traffic. Furthermore, it can be recognised that the current state of data is insufficient, and thus, any explanation and estimation of commercial traffic on the basis of the existing data collections would not provide satisfying results.

Acquiring data is a basic condition for development and application of transport-related models to visualise freight transport.

## 4.2 BEST PRACTICES IN GERMAN LOGISTICS

**Location advantages and efficiency – distribution system of a hinterland hub in Germany**

An important factor for an efficient logistics system is geographical location. The Metropole Ruhr is the best connected region in Europe in terms of transport links. North Rhine-Westphalia is Europe's central hub. Three of the four logistics core regions in NRW are located in the Metropole Ruhr. There are a huge number of efficient logistics companies. The local focus of the metropolitan region is in the Duisburg-Niederrhein area (Western Ruhr district), which has been established especially as a logistics hub of ports for the North Sea due to, among other factors, Europe's largest inland port in Duisburg. The major focus of the logistics region of Gelsenkirchen, Herne, and Herten in the centre of the Metropole Ruhr (Eastern Ruhr district) is last-mile logistics. In the Dortmund area, competencies are located in the intersection between trade, logistics and IT.

The strength of the region is based on its efficient infrastructure and strong industry. There is a well-educated labour force. A major contribution is the dense network of universities and research institutions, which is the basis for the success in logistics. For example, the TU Dortmund University offers specific programmes in logistics. Within this region, there is also the Fraunhofer Institute for Material Flow and Logistics (IML), which is the world's largest logistics research institution.

The Metropole Ruhr is a European logistics hub with a dense trimodal infrastructure. About two-thirds of German exports and imports are served by the seaports of Antwerp, Rotterdam, Amsterdam and Zeebrügge. In this case, the Metropole Ruhr serves as a hinterland hub. 33 of the top 100 of logistics service providers have their headquarters in this region (e.g. IKEA, SSI Schäfer, Schenker AG, SimPlan AG, Rhenus AG).

The Metropole Ruhr maintains the densest road, water and rail network in Germany. Therefore, it is one of the most dynamic logistics locations in Germany. The individual transport modes are networked effectively. Important intermodal transhipment nodes include the inland ports, especially Duisburg and the central freight terminal. Many industrial parks are connected to the railway.

No other region in Europe is as well and as systematically connected to the transport network as the Metropole Ruhr. The region is home to two airports (Dortmund, Essen/Mülheim) and five additional international airports (including Düsseldorf and Cologne/Bonn), all of which can easily be reached by road and rail. All of the EU's most important urban agglomerations can be reached from the Metropole Ruhr by road within a maximum of 48 hours.

The rail network in the Metropole Ruhr consists of:

- 1,600 km of rails
- More than 70 stations run by Deutsche Bahn AG
- 12 ICE / IC lines
- 15 regional express lines
- 22 regional connection and 11 S-Bahn lines

With a waterway network 572 km in length, the Metropole Ruhr has the densest canal and port system in Europe. Europe's densest waterway network includes:

- 272 km inland shipping ways
- Approx. 80 ports
- Rhine, Ruhr, Rhine-Herne Canal, Wesel-Datteln Canal, Datteln-Hamm Canal and Dortmund-Ems Canal connect the region and convene in Datteln (District of Recklinghausen) to the largest canal hub of Europe

Duisburg Harbour (Duisport):

- World's biggest inland port
- 21 docks
- More than 180 ha water surface, 1,350 ha area
- 9 container terminals with 14 container bridges
- 16 km of handling watersides with rail links
- More than 110 million tons handled in 2012
- Location of Germany's first driving simulator for inland shipping; also used for research purposes

Figure 9: Ports in the Ruhr region, © Regionalverband Ruhr 2010.[43]

1 Städt. Rheinhafen Weser
2 Wesel Rhein-Lippe-Hafen
3 Voerde Hafen Emmelsum
4 Stadthafen Dorsten
5 Hafen Marl-Brassert
6 Hafen Chemiepark Marl
7 Marl Hafen Auguste-Victoria
8 Rheinberg Rheinhafen Orsoy
9 Duisburg Hafen Walsum-Nord
10 Duisburg Hafen Walsum-Süd
11 Duisburg Hafen Schwelgern
12 Duisburg Hafen
13 Duisburg Rhein-Ruhr-Terminal
14 Duisburg Hafen Rheinhausen
15 Duisburg
16 Duisburg Hafen Krupp Mannesmann
17 Mülheim Rhein-Ruhr-Hafen
18 Bottrop Hafen
19 Stadthafen Essen
20 Essen Hafen Coelln-Neuessen
21 Stadthafen Gelsenkirchen
22 Gelsenkirchen Hafen Grimberg
23 Herne Osthafen Wanne
24 Stadthafen Recklinghausen
25 Castrop-Rauxel Hafen Victor
26 Castrop-Rauxel Hafen Rütgers
27 Castrop-Rauxel Hafen Luck
28 Lünen Stadthafen
29 Stadthafen Hamm
30 Dortmund Hardenberghafen
31 Dortmund Hafen
32 Herne Westhafen Wanne

Well-established logistics concepts are required to transport goods inland. Without the use of multi-modal systems, in particular for container inland transport, the motorways of the Metropole Ruhr would be even busier. Increased congestion on the highways can be prevented through target-oriented use and expansion of the inter-modal transport network. Only by optimising the performance of all forms of transport in future can the growth and regional importance of this sector be secured.

The Duisburg inner port of Duisport is an example of intelligent multi-modal connections with more than five inter-modal terminals. Waterways, railways and roads link Duisport with other areas of Central and Eastern Europe. Duisport is a strategically significant inland hub for the North Sea harbours, in particular Amsterdam, Rotterdam and Antwerp. In addition to distribution and contract logistics for high quality cargo, usually in containers, Duisport also plays an important role in handling conventional piece goods and mass-produced products. For the first time in the harbour's close to 300-year history, more piece goods are handled than mass-produced goods.

The fact that the Metropole Ruhr is so well positioned in terms of its inter-modal transportation of large quantities of goods is rooted in tradition: in this area large quantities of bulk cargo were loaded and transported onwards long before the days of container shipping, IT-controlled terminals and sophisticated logistics concepts.

**Last mile logistics**

Distribution logistics refers to the setting-up and controlling of all processes required to transport finished products and commodities from the company to the customer as quickly as possible. This final section of the distribution process, also known as 'last mile logistics', links production to the downstream stage of the process – the customer. Distribution logistics are therefore aimed at supplying the external market. The term 'the last mile' is derived from the field of telecommunications: the last mile describes the pathway from the local distribution box of the telecommunications company to the connection in the user's house. In logistics, 'last mile logistics' refers to collection and delivery in towns and cities.

The logistics sector is undergoing turbulent times in many respects. Online trading has completely changed the face of distribution, and distribution logistics is severely subject to time pressure. The Fraunhofer Institute for Material Flow and Logistics (IML) in Dortmund estimates that some 600 million consignments were generated electronically in German-speaking countries in 2006. Ever more and ever smaller consignments are being dispatched, all of which must be received on time. Sales and delivery systems are essential for the further expansion and success of online businesses, and both must share crucial features: they must be efficient and cost-effective.

**European Goods Distribution Center**

Sweden's largest furniture chain, IKEA, has now set up its largest European distribution centre in the region, a success story for Dortmund as a centre of logistics. In September 2007, the company opened two new distribution centres at its European centre of distribution in Dortmund-Ellinghausen on the Dortmund-Ems canal. The two new buildings at the cargo transport centre are equipped with three fully-automated high bay warehouses and have a storage capacity of approx. 430,000 pallet spaces over a floor space of around 200,000 sq. meters. The distribution centre, opened in 2003, is very close by and supplies customers in Germany, Belgium and the Netherlands directly. In summer 2007, planning work began for a fourth stage of construction with a storage capacity of approx. 290,000 pallet spaces over a floor space of around 125,000 sq. meters to the south of the site.[44]

43 Wirtschaftsförderung metropoleruhr 2012.

44 Wirtschaftsförderung metropoleruhr GmbH 2011.

**ELVIS Crossover traffic**

The main goal of the ELVIS crossover traffic project (EBV) is to improve the productivity of road freight traffic. This goal can only be achieved for the highest turnover transport segment if it succeeds in decoupling driver working time from vehicle usage time. As individual companies, due to their structure and size, have not succeeded in creating new synergies and synchronising individual transport in terms of a sequential multi shift operation, an intercompany network within the cooperation must be established. In this network, the full load transport should be industrialised.

This approach should remedy the previous deficiencies in development and implementation of adaptive mechanisms to market requirements. Another issue is to sustainably improve the efficiency freight transport providers' services. Using multiple shifts (driver change "at home"), should achieve the necessary increase in productivity. The innovation competencies of ELVIS AG within a network of leading representatives from research and other partners enable an expansion of independent skills and competencies in applied research and development within the comprehensive process optimisation for the logistics sector (ELVIS AG 2012).

**Efficient management in the trucking sector**

Today, the companies in the trucking industries face huge challenges: tightening of professional drivers' working and driving hours, increasing diesel costs, a lack of drivers, etc. Within the CARGO eXchange research project, researchers from the Fraunhofer ATL investigate how companies can use their capacities more efficiently.

The German trucking market used to be less coordinated. Although nowadays medium-sized companies are often integrated in forwarding networks, many of them still dispose independently from each other. As a result, vehicles are not optimally loaded and exploited. This implies a reduction in vehicles' rateability and an unnecessary increase in the number of journeys.

Since the 1990s, so-called Advanced Truckload Firms (ATLF) have implemented centralised disposing systems and coordinated a huge number of trucks and trailers in the US. The CARGO eXchange research project wants to transfer this concept to the German or European market. Under the auspices of a Fraunhofer working team for technology of logistics service sector ATL, the companies CargoLine, Schmidt-Gevelsberg and Wanko Information Logistics are participating in this project. The project is supported by the "Smart logistics in freight and commercial traffic" funding initiative from the Federal Ministry of Economy and Technology. The practical analysis and implementation of the concepts is based on the company network CargoLine.

**Optimal route planning and capacity utilisation**

Company-wide disposing systems to support the complex order, vehicle allocation and personnel planning, which are particularly used by American companies, are currently only rarely applied in Europe. Planning processes are mainly carried out on a decentralised basis. Since 2008, within CARGO eXchange the project consortium has investigated which conditions and internal organisational changes are useful and realisable. In this context, select approaches of advanced truckload companies should be established, especially the development of a centralised disposition of the 2,800 interurban trucking units including fleets belonging to CargoLine's cooperation partners.

**Share of resources and capacities**

The companies should use a method from the field of operations research to be able to centralise control and coordinate the complex network. They could calculate the optimal route planning and utilisation with this approach and thus avoid empty trips, long trip distances with partial utilisation and unproductive vehicle downtimes. Shared vehicles could serve the distribution terminals of the customers of different forwarders to reduce individual trips. In cases where previously vehicles would separately drive for customers, in future several forwarders could use the free capacities together. Better vehicle utilisation and external business synergies create opportunities for partner companies to compete successfully with financial powerful forwarding concerns in the long term.[45]

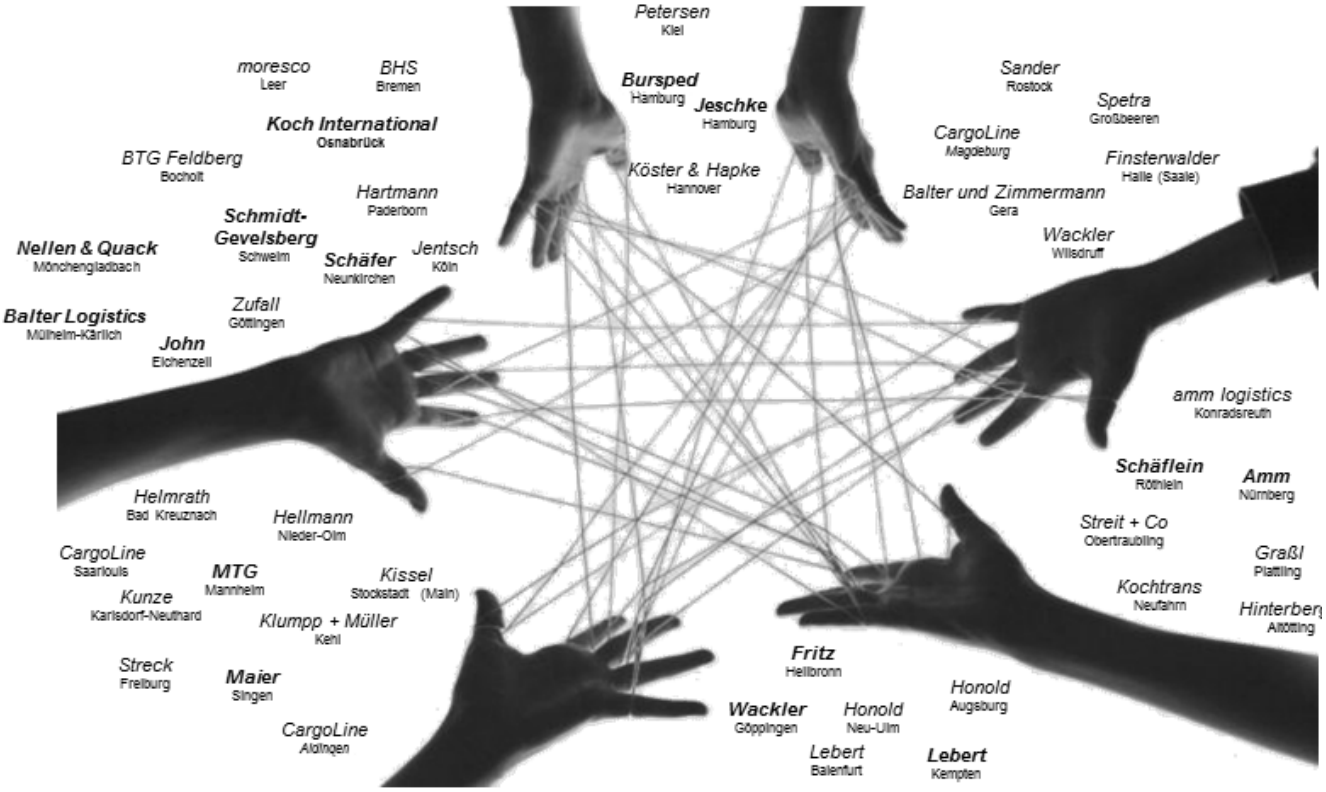
**CargoLine – an efficient and well-managed forwarding network**

CargoLine is a cooperation for standardised and systemised general cargo transports in Germany and Europe. They specialise in system-controlled transport services, distribution, procurement and warehouse logistics. They are made up of about 70 medium-sized partners, 45 of which are based in Germany. They operate in 42 countries across Western Europe, Eastern Europe, the CIS, the Middle East and Northern Africa.

CargoLine commands a dense network of partners.

45 Walther 2009.

Figure 10: Forwarders network of CargoLine.[46]




**CargoLine innovation: Track & Trace – Cepra II**

"Whatever stage of its journey your consignment is on, you can trust our Cepra 3.0 Track & Trace system (Figure 11) to provide full transparency. Track down your packages in real-time and call up the digital delivery receipts. Either check at your convenience round-the-clock via the Internet or request automatically generated emails, for example, to inform you whether and when your packages have been delivered. So you can keep a watchful eye on all your consignments and act flexibly. Advantages for the customer:

- More transparency through close monitoring of all intersections
- Compatibility with any inhouse IT infrastructure
- Real-time automated feedback function
- Reduced process flows"[47]

Figure 11: Track and Trace – Cepra 3.0.[46]

46 CargoLine 2013a.

47 CargoLine 2013b.

## 4.3 EXAMINING EXISTING DATA RELATED TO COMMERCIAL TRAFFIC AND GOODS

In the following chapter, we provide detailed information about existing data for India and especially for Bangalore. Furthermore, we derive issues and data gaps with regard to freight transport data based on these findings and discuss possible suggestions for freight transport data collection and forecasting.

### 4.3.1 STATISTICS FOR INDIA

Fink[48] examines the transport volumes in India. According to his report, there is currently a remarkable growth of transport volume in India. In the year 2005/2006, the total volume of goods transported grew to 12.5% and reached an annual volume of more than 5.2 billion tons. The most important transport method is road transportation, with a freight volume of nearly four billion tons. This has a 72% share of total transport volume. Road-related transport exhibited an above-average rate of growth of 12.8%. The railway is also relevant for transport, with a share of 12.8% and a growth of 11.0%. Freight volumes of 668 billion tons were transported by rail. The transport volumes of sea freight traffic, which is very important for exports, increased by 12.0% and accounted for 580 billion tons. Air freight traffic reached a freight volume of 1.4 billion tons and exhibited an increase of 7.9%, a relatively low growth in comparison to the other modes of transport (cf. Table 4).

Table 4: Transport volumes in India (own diagram[50]).

| Transport mode | Goods transported (1000 tons) | Share (%) | Change to 2004/2005 (%) |
|---|---|---|---|
| Road | 3,960,000 | 76.0 | 12.8 |
| Railway | 668,000 | 12.8 | 11.0 |
| Sea freight | 580,000 | 11.1 | 12.0 |
| Air freight | 1,380 | < 0.1 | 7.9 |
| Total | 5,209,380 | 100.0 | 12.5 |

48 Fink 2008, p. 186.
49 CargoLine 2013a.
50 based on Alex 2006.

The **Centre for Infrastructure, sustainable transportation and urban planning (CiSTUP)** carried out a research project entitled "Transportation Networks in India – Vision 2020". Their research focus is on the current state of the transportation infrastructure, the commercial traffic and the traffic distribution with regard to the different modes of transport. According to their information regarding the current status of the road infrastructure, the majority of roads have two lanes. However, there are more and more highways with four or more lanes. Rs 3.2 trillion were invested in infrastructure in the 11th five-year-plan. The total Indian road network currently includes 3,335,748 km of roads. The total length of the highways is 72,382 km. Current activities in road network development are:

- The work on the "Golden Quadrilateral road network" with a length of 5,846 km. The network should connect the four metros in the four corners of India. This project is in the last leg of completion.
- Furthermore, the North-South and the East-West corridors are planned, with lengths of 7,300 km and 1,157 km respectively. This initiative is 42% complete and the remainder is under progress.
- Highway widening and upgrading from four to six lanes is also under progress and at various stages of completion.

The modal split shows that road-related transport is the most important with a share of 50%, followed by the Indian railways inter-regional freight transport with a share of 36%. Coastal shipping (6%) and air (8%) are currently not so important for freight transport. Rail and road together share 91% of the total transported freight volume. The average lead distances moved per ton of cargo by rail transport is 661 km. The railway network is popular for middle and long range transport distances. In contrast, road infrastructure is used in freight transport for shorter distances of up to 453 km. The range for coastal shipping is 1,450 km and for air 1,027 km.[51]

The **Government of Indian Planning Commission** founded a working group on road transport who developed the eleventh five-year-plan. Its focus was the share of different transport modes in GDP. According to their data, between 1999 and 2005 the share of railways (17.19%), water transport (3.13%) and air transport (3.13%) stagnated. Only road transport showed a significant growth of 0.7% of the GDP. Overall, road transport accounts in total for 70.31% of total transport in India in 2005 (see Table 5).

51 Centre for Infrastructure 2010, pp. 11-23.

Table 5: Share of Different Modes of Transport in GDP.[52]

| Sector | 1999–2000 | 2000–2001 | 2001–2002 | 2002–2003 | 2003–2004 | 2004–2005 | 2004–2005 |
|---|---|---|---|---|---|---|---|
| | As percentage of GDP (at factor cost and constant prices | | | | | | % |
| Transport of which | 5.7 | 5.8 | 5.8 | 6.1 | 6.1 | 6.1 | 100.00% |
| Railways | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 17.19% |
| Road Transport | 3.8 | 3.9 | 3.9 | 4.1 | 4.3 | 4.5 | 70.31% |
| Water Transport | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 3.13% |
| Air Transport | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 3.13% |
| Services* | 0.4 | 0.4 | 0.5 | 0.5 | 0.5 | 0.4 | 6.25% |

** Service identical to transport*

The transport sector accounts for a share of 6.4% of India's GDP. The total increase in the transport sector's share of India's GDP only came from road transport (cf. increase from 3.8% in 1999 to 4.5% in 2005).[53]

Table 6: Average annual growth (%) in freight and GDP *constant prices.[54]

| Period | Freight in Billion Tonne Kilometres | | | GDP* |
|---|---|---|---|---|
| | Road | Railway | Combined | |
| 2004–05/1992–93 | 6.5 | 3.6 | 5.2 | 6.2 |
| 1998–99/1992–93 | 7.6 | 1.7 | 5 | 6.4 |
| 2004–05/1999–2000 | 5.3 | 5.8 | 5.5 | 5.9 |

**Based on estimates of GDP of factor cost at 1993-94 prices.*[55]

Table 6 shows that road transport has grown significantly. There is a higher share of mobile population.

In 2012, the **Ministry of Road Transport and Highway Government of India** published a report by the sub-group "Passenger and Freight Traffic Assessment". They generated a data collection with information on the number and types of transport vehicles (see Table 7) and the use of IT in the transport sector in the Twelfth Five-Year-Plan (2012-1017).

Regarding number and types of transport vehicles, goods vehicles constituted 5.3% of the total registered vehicle population during 2008-09. During 2008-09, the latest year for which data on registered motor vehicles is available, goods vehicles grew at 7.9%. On 31st March, 2011, there were over 6 million registered goods vehicles. From 2009-10 to 2010-11, the production of total commercial freight vehicles increased by 35.6% (cf. Table 7). Domestic sales of commercial freight vehicles increased by 30% from 2009-10 to 2010-11.[56]

The World Bank offers specific data regarding the transport sector. They focus on the current state of infrastructure according to different modes of transport.

Total road length in India is 3,516,452 km. The density is 1,115 km of road/1,000 sq. km. Total track length for rail is 63,327 km. There are a total of 125 airports in India.

The Ministry of Statistics and Programme Implementation offers a detailed statistic on Indian railways. It presents an overview of specific data for the last ten years (2001-2009). The Railway Statistic not only has data on the number of passengers carried but also data on freight transported by railways (e.g. total goods carried, net tonne kilometres). Between 2008 and 2009, 836,607,000 tons of goods were carried by rail, compared with 2001, when 522,233,000 tons were carried by rail. In 2009, freight transport carried 552 billion km by railways. They offer specific data for different types of trains In addition, they provide data of load and earnings from goods .

52 Own diagram based on Government of Indian Planning Commission 2005, p. 1.
53 Government of Indian Planning Commission 2005, p. 1.
54 Own diagram based on Government of Indian Planning Commission 2005, p. 2.
55 Transport Research Wing, Ministry of Shipping, Road Transport & Highways, Government of India; Data on rail Freight traffic from Ministry of Railways.
56 Ministry of Road Transport & Highway Government of India 2012, pp. 9-14.
57 Society of Indian Automobile Manufacturers (SIAM).

Table 7: Production and domestic sales of commercial vehicles.[58]

| Production and Domestic Sales of Commercial Vehicles[57] | | | | | |
|---|---|---|---|---|---|
| Commercial Freight Vehicle | | Production | | Domestic Sales | |
| | | 2009–2010 | 2009–2010 | 2009–2010 | 2009–2010 |
| 1 | Max. mas up to 3.5 to | 238,563 | 319,266 | 212,943 | 271,937 |
| 2 | Max. mass exceeding 3.5 to up to 5 to | 8,778 | 11,949 | 7,288 | 10,772 |
| 3 | Max. mass exceeding 5 to up to 7.5 to | 35,336 | 38,970 | 33,133 | 33,431 |
| 4 | Max. mass exceeding 7.5 to up to 12 to | 44,201 | 49,616 | 43,679 | 55,330 |
| 5 | Max. mass exceeding 12 to up to 16.2 to | 56,148 | 77,344 | 48,605 | 61,478 |
| 6 | Max. mass exceeding 16.2 to up to 25 to | 79,785 | 88,503 | 76,556 | 85,389 |
| 7 | Max. mass exceeding 25 to | 18,294 | 63,895 | 14,348 | 44,046 |
| 8 | Max. mass exceeding 16,2 to up to 26.4 to | 0 | 0 | 0 | 0 |
| 9 | Max. mass exceeding 26.4 to up to 35.2 to | 2,651 | 4,458 | 8,923 | 12,818 |
| 10 | Max. mass exceeding 35.2 to | 3,043 | 6,174 | 9,750 | 16,174 |
| **Total** | **Commercial Freight Vehicles (1–10)** | **486,799** | **660,175** | **455,225** | **591,375** |

carried for the year 2009. The distribution of goods to the different Indian regions is also shown. The Transport Research Wing of the Ministry of Road Transport and Highways provides the current road length statistics for highways, urban roads and project roads across different Indian states between 2001 and 2009.

Table 8: Transport sector key statistics for India.[59]

| India: Transport Sector Key Statistics | | |
|---|---|---|
| | Units | As of 2009 |
| **Length of Road** | km. | 3,516,452 |
| Main Roads | km. | 666,452 |
| Paved Roads | % | 47.3 |
| Access to All-Season Roads | % | 61 |
| Road Density | km/1,000 sq. km. | 1,115 |
| **Rail Track Length** | | 63,327 |
| **No. of Ports** | days | 199 |
| Turnaround time | | 3 |
| **Airports** | | 125 |
| International | | 11 |

### 4.3.2 STATISTICS FOR BANGALORE

The **Bangalore Metropolitan Region Development Authority** focused its Comprehensive Traffic and Transportation Study on the road, rail and bus network in Bangalore as well as goods transport. In terms of road network, the Bangalore Metropolitan Region (BMR) has approx. 6,000 km of roads in an area of 8,005 sq. km. There are two national expressways, three highways and 12 state highways.[60] Regarding rail networks, five broad-gauge radial rail corridors currently exist. In terms of bus transport, the Bangalore Metropolitan Transport Corporation (BMTC) and Karnataka State Road Transport Corporation (KSRTC) connect the two cities with a common bus system. BMTC operates approximately 5,370 routes with 5,593 buses and 3.8 million passengers per day.

For goods transport, BMR is served by the Container Corporation of India (CONCOR) through its Inland Container Depot (ICD) at Whitefield. There is one container freight station with ten warehousing facilities.[61]

Urban transport in Bangalore is essentially road-based, since the national rail lines were neither designed nor operated with regard to urban and regional traffic (infrequent stations, no pass-through

58 Ministry of Road Transport & Highway Government of India 2012, p. 14.
59 Ministry of Road Transport & Highway Government of India 2012, p. 14.
60 Bangalore Metropolitan Region Development Authority 2010, p. E-4.
61 Bangalore Metropolitan Region Development Authority 2010, p. E-5.

lines, low service frequency). The traffic is dominated by motorised two-wheelers and three-wheelers as well as auto rickshaws. The conventional public transport services provided by Bangalore Metropolitan Transport Corporation buses operate in mixed traffic, without any privileges like exclusive lanes or priority of passage at signalised intersections. In addition, many companies arrange for transport of their employees, using their own or contracted minibus fleets or.[62]

The following table shows the transport trend for Bangalore.

The Ministry of Road and Transport and Highways provides the total numbers of different vehicles for Bangalore 2004. Table 10 shows the vehicle population in Bangalore in 2004. The total number of passenger car units (PCU) is 62,911. In addition, there are 6,132 trucks which distribute the goods in Bangalore.

The Bangalore City Traffic Police provides data on the vehicle population in Bangalore City. There are almost 2.7 million two-wheelers.

Based on this data, the increase in the vehicular population to about 1.5 million, with an annual growth rate of 7-10% is considerable. Two-wheelers and cars almost comprise 90% of the total registered vehicular population in the city. Two-wheelers constitute more than 70% of the total volume, while cars comprise 15%, auto rickshaws 4% and the remaining 8% includes other vehicles such as buses and vans.

Table 9: Transport Trend BMR.[63]

| No. | Transport Parameter | Classification | Units | 2009 |
|---|---|---|---|---|
| 1 | Average Journey Speed | BMR | Kmph | 18 (BBMP) & 29 (Rest of BMR) |
| 2 | Population | BMR | Millions | 10.3 |
| 3 | Population Density | BMR | People/Sq km | 1292 |
| 4 | Average Household Size | BMR | | 4.2 |
| 5 | Total Travel Demand | BMR | Lakh Trips | 128.38 |
| 6 | Average Trip Length | BMR | Km | 10.1 |
| 7 | Total Vehicle Population | BMR | Lakhs | 33 |
| 8 | Bus Fleet for Lakh Population (BBMP) | BMR | | 73 |
| 9 | Per Capita Trip Rate (PCTR) – Total | BMR | Trips | 1.28 |
| 10 | PCTR – Motorised | BMR | Trips | 0.81 |
| 11 | Auto Rickshaw / Lakh Population (BBMP) | BMR | - | 1576 |
| 12 | Fatal Accident Index | BMR | Acc/LakhPop | 17 (BBMP) & 20 (Rest of BMR) |
| 13 | Vehicle Pollution Load | BMR | Tonnes/Day | |
| 14 | Modal Trip Shares | PT | Percentage | 30 |
| | | IPT | Percentage | 8.5 |
| | | Personalised | Percentage | 23 |
| | | NMT | Percentage | 38.5 |
| | | Rail-Bus-Split | Percentage | 1.99 |

Due to the increase in total vehicle population, the whole transport system is suffering. Two-wheelers dominate the vehicle composition. Cars and jeeps account for 17% of all vehicles. Urban traffic is dominated by road traffic as rail services are not yet designed for urban transport. About 5,500 buses operate without being given priority (cf. Figure 12).

62 Bangalore Metropolitan Region Development Authority 2010, p. E-6.
63 Bangalore Metropolitan Region Development Authority 2010, p. E-9.

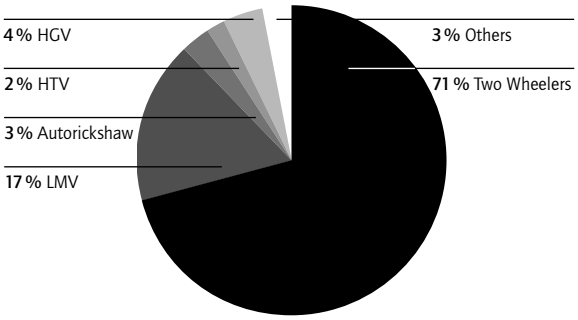
Table 10: Vehicle population in Bangalore in 2004.[64]

| Sl. No. | Location (km) | Nearest Towns | Total in PCUs | Cars | Buses | LCV | Trucks | MAV | M/Cycles | Cycles |
|---|---|---|---|---|---|---|---|---|---|---|
| 7 | 321 | Bangalore | 62,911 | 20,578 | 4,063 | | 6,132 | | 23,392 | 105 |

Table 11: Vehicle population in Bangalore City.[65]

| Two Wheelers | L.M.V | A/R | H.T.V | H.G.V | Others | Total |
|---|---|---|---|---|---|---|
| 2,690,409 | 818,029 | 100,199 | 94,918 | 85,571 | 97,315 | 3,886,441 |

Figure 12: Vehicle Composition.[66]




### 4.3.3 ISSUES IN FORECASTING ROAD FREIGHT AND PASSENGER FLOWS

Forecasting the demand for freight traffic, especially road freight traffic, is a daunting task. As the demand for freight movement is a derived demand, forecasting is dependent on the forecasts of the economy's production. Other factors which affect transport demand include the pattern of industrial location and consumption centres.

It is the quantity of goods produced, international trade and the method of distribution which create the demand for freight movement. Unlike in developed countries, historical data on freight flows in terms of origin-destination and the commodities carried are not regularly available through official statistics.

As a result, one has to rely on aggregate estimates of ton kilometres (TKM) moved or tons lifted with real output of goods and services as captured by GDP to estimate elasticity i.e. TKM moved or tons lifted as a function of GDP. Moreover, freight comes in various sizes, shapes and physical states, which require different handling methods and suit the various modes (and sub-modes) of transport differently. The mode choice decisions made by the industry concerning the transport of large volumes of bulk materials are of particular interest. Increasingly, bulk materials are switching to road transport. These behavioural changes are generally poorly documented.

Freight transportation encompasses the movement of a wide variety of products, from raw materials to finished goods, from comparatively low value to weight products (coal, gravel, grain, etc.) to high

64 Ministry of Road and Transport and Highways 2011.
65 Bangalore City Traffic Police 2011.
66 Bangalore Metropolitan Region Development Authority 2010, p. E-8.

value to weight items (electronic goods, pharmaceuticals, etc.). It includes easily perishable items such as fresh fruits and vegetables, a wide range of refrigerated items, and a growing number of time-sensitive items for which on-time delivery is crucial to business success. Today, freight needs to be moved safely and at a reasonable cost. It must also be moved in an environmentally sound and socially acceptable manner. Effective freight movement requires effective freight planning, which in turn requires realistic forecasts of freight traffic.

The level and structure of economic activity determine the demand for transport and the relationship between the two can be depicted with varying degrees of sophistication. The easiest and simplest approach is to link transport activity to an economic aggregate like GDP. For instance, domestic road freight traffic expressed in TKM can be linked to GDP.

In a more refined version, these values can be broken down. For example, freight traffic can be broken down by goods carried and traffic in each of the goods explained in terms of characteristic values of the sector concerned. Passenger freight distance can also be broken down by distance.

The simple relationship between transport activity per mode of transport and economic aggregates tends to overlook a number of factors such as structural effects which, for example, steadily reduce TKM for a given amount of GDP. However, that is not necessarily a problem if the time horizon of the study is relatively short.

In more general terms, such simple relationships ignore transport supply, assuming it to have no effect on demand. This may be true to some extent when transport makes up a small share of the price of the goods being transported. However, this may not hold true if one composition of the basket of goods being produced shifts in favour of goods for which transport cost is a sizeable portion of the final price. Other problems faced in demand forecasting in the transport sector include the geographic distribution of the origins and destinations of freight/passenger flows and the prediction of their change over time.

Forecasting presents other problems in as much as it is directly or indirectly based on econometric relationships that cause explanatory variables to intervene. The first is forecasting the future value of explanatory variables. The second lies in the stability of the relationships and the parameters that enter into them. This stability may well hold over the medium term – a five year time horizon for example – but not over a longer period in which more complex and less easily quantifiable factors tend to arise.[67]

### 4.3.4 DATA GAPS IN THE ROAD TRANSPORT SECTOR

There are significant data gaps in the transport sector that need to be addressed. In the case of India, the data for vehicles is available in terms of number of registered vehicles. However, internationally it is the data on 'vehicles in use' that is used for the purpose of analysis, comparisons and policy formulation.

*Vehicles in use* is a more accurate indicator of the number of vehicles on the roads than total registered vehicles, which provides data on the cumulative number of vehicles registered without accounting for decommissioned/scrapped vehicles. The absence of data on "vehicles in use" could be addressed through a specially created Motor Insurance Database wherein all insurance companies should provide details of the initial insurance policy and all renewals for each vehicle they cover.

As of now, there is no mechanism in place for generating regular data on freight movement (in terms of ton kilometres) by motorised means in the road transport sector. This is a major gap, as the freight operations by road in the country are primarily carried out by private operators or personal operations (cars, three-wheelers, two-wheelers). The data for private operators, who account for an overwhelming share of road transportation, is not collected on a regular basis.

With regard to freight traffic, it is observed that the majority of freight traffic services are operated by individual owners with one to three trucks. The data on important variables such as ownership patterns, fleet utilisation, age profile, vehicle productivity, fuel efficiency, cost of operation, passenger and freight tariff rates, etc., for such private operators, who account for an overwhelming share in the road transport industry, is not available.

Regarding the details of description of goods, number of articles, freight charges, etc., there is scope for generating regular data on freight movement, provided by the Motor Vehicle (MV) Act of 1988. For non-transport goods vehicles, it is necessary to submit Form no. 50 (Bill of Lading containing the details of goods, number of articles, freight charges, etc.) as per Central Motor Vehicle Rules

67 Ministry of Road Transport & Highway Government of India 2012, p. 7.

(CMVR) Rule 90 (3) under additional conditions for National Permit Vehicles. For other goods vehicles, returns are to be furnished by the operator concerning the description of goods, weight of goods, kilometres travelled, freight charges, etc. as per MV Act 1988, Section 96 (XXXII) and Maharashtra Motor Vehicle Rules, Sub Section III, 1(a). However, there is a lack of enforcement at the state level, resulting in serious data gaps in the transport sector.

### 4.3.5 DATA GAPS – PROBLEMS ENCOUNTERED IN FORECASTING

For the purpose of projecting the vehicle fleet, the number of registered motor vehicles has been used. However, this is not synonymous with the actual number of vehicles "in use". In the absence of information on the number of vehicles which have been scrapped, the number of vehicles actually using the roads is not easy to estimate.

There is a considerable time lag in the data made available to the centre by the respective Transport Departments. Presently, this lag is over two years. The problem is further aggravated as there is no single agency in the state which can provide all the data. Besides, the bulk of freight traffic is in the private sector.

**Time lag in receiving information** – Though the time lag in receipt of data and subsequent publication of reports has reduced in the last two years, it still continues to be an issue of concern. The main factors contributing to such time lags are:

a) Multiplicity of agencies – there is no single source from which data is collected.
b) Non-response or delayed response from the agencies.
c) Incomplete data
d) Inconsistencies in the data – as the data is received from a number of different sources, validation and compilation takes time.

**Paucity of specific data** on areas handled by the private sector like goods and passenger traffic carried by road transport, traffic carried on different types of roads and operational aspects of private operators.

The Constitution of India has put road transport under List-II of the Seventh Schedule, thereby placing road transport primarily in the domain of state administration. The relative availability or absence of relevant data is essentially attributable to the efforts of the states.

### 4.3.6 SUGGESTIONS FOR THE IMPROVEMENT OF ROAD TRANSPORT SECTOR DATA

**Road Freight**

The lack of data on freight by private bus operators makes it difficult to arrive at realistic estimates on freight movement by road. A system of data collection and an institutional mechanism to ensure fuller coverage, regular inflow and better monitoring of relevant data of the transport sector are needed. With a view to overcoming the data gaps, following suggestions were made:

Currently, no comprehensive data on freight movement is available to indicate origin, destination, type and size of freight carried on roads by motorised transport. Therefore, regular surveys at five yearly intervals on freight movement by road covering lead, load and other relevant characteristics would be necessary.

The load factor needs to be further disaggregated in terms of broad categories, viz., fodder and food grains, vegetables, building materials, raw materials, liquid materials, finished goods, origin and destination of cargo and age and type of vehicles by which they are carried. The organisation best suited for detailed surveys based on large sample size is the National Sample Survey Organization (NSSO) of the Ministry of Statistics and Programme Implementation. Also, the Directorate of Economics and Statistics at the state level could be involved in this task. This could be supplemented by surveys by professional organisations during the intervening period if so required.

**Trucking Industry**

At present, there is no regular arrangement for the collection of data relating to trucking operations. The structure of the trucking industry can be studied as a system consisting of truck operators, intermediaries and users. There is also a complete lack of regular information on many other parameters related to the trucking industry, such as vehicle acquisition cost, operational cost, cost of financing, vehicle technology, vehicle age, time and resources spent on detention of vehicles, turnaround time, distance travelled, etc. Information on these parameters is fragmentary, based on anecdotal experience or dated studies. This makes the task of evaluating trucking operations and related policy formulation difficult.

The Carriage by Road Act, 2007 provides for registration of a "common carrier" (person engaged in the business of collecting, storing, forwarding or distributing goods to be carried by Goods Carriages) with the commencement of the Act. Large transport companies are registered under the Partnership Act or the Companies Act. The MV

Act, 1988 only mandates registration of vehicles by owners and obtaining a permit for operation. There are no provisions for qualitative aspects, such as professional competence, financial standing, good reputation, etc., which are essential requirements in countries like the UK and USA.

There is a need for a detailed study to assess the status of the trucking industry in India by the NSSO or some other professional organisation on a five-yearly interval basis.[68]

### 4.3.7 CONCLUSIONS

**Major Gaps in Transport Statistics in India**

- Indian system of transport statistics is marked by:
  - Decentralised generation of data
  - Multiplicity of agencies and time lag
- No data on movement of people, goods and vehicles.
  - Hence lack of data on volume and geographic flow of traffic
- Passenger and freight flows measured in a variety of ways
  - Vehicle km of travel (passenger and freight)
  - Passenger km: (Distance travelled x No. of passengers carried)
  - Freight flows: Tonne km (movement of tons of cargo over kms)
- No Price Index to measure changes over time in actual prices paid by the users.
- Data on vehicle population gathered in terms of registration rather than "vehicles in use".
- No information on vehicle weights, which impact the condition and longevity of infrastructure.
- Lack of data on other dimensions makes it difficult to assess current capacities and plan expansion.[69]

Several sources of data concerning freight traffic are available in India. There are ministries which provide data for modal split, goods transported, freight volumes, number and types of transport and the current state of existing infrastructure. Current data is available between 2001 and 2011. There is no historical data. It is difficult for transport planning to forecast freight traffic without historical data. Furthermore, for freight volume there are different units from different sources. The problem is how to combine these different units into a single database. A unified system for statistics should be established for the different freight transport modes in uniform units. The database should be maintained every year by a single institution. This systematic approach enables the gathering of uniform data, which could help understand the changes in terms of freight transport. These data could be used for forecasts and could be implemented in freight transport models.

In road transport, only the number of the registered vehicles is available, but there is a huge informal sector which is not registered. In this case, it is impossible to evaluate the current state of the existing vehicles in freight transport. An origin-destination matrix of the transported goods in the different freight transport modes is also required. This would allow a visualisation of the distribution of goods and the material and freight traffic flows in India. Based on this information, it would be possible to efficiently plan the infrastructure and see where the largest demand for new railways and roads is. These specific data could be integrated into a geographical information system.

The research shows that both Germany and India have problems regarding generating sufficient and usable data collections in their respective freight transport sectors. Against this background, it seems useful to create an extensive base of information and to capture the current state of the art of Indian freight transport statistics. The experiences of researchers and actors in policy and transport planning should be combined. Both sides could learn much about the other side, about the problems and issues for surveys regarding freight transport. It would be help to find a way to exchange this knowledge and could develop research designs for future surveys more efficiently and practicably.

## 4.4. RESEARCH INTO REQUIREMENTS FOR ICT-BASED SYSTEMS

Beyond the exclusive observation and control of freight, the project's objective is to implement green factors in the ICT-based system to enable sustainable development. To define the requirements of green ICTs, existing ones must first be identified. Then ICTs relevant to the project should be selected, which means that the function of these ICTs should be implemented into the ICT-based systems. We examine two German best-practices to illustrate the state-of-the-art in a developed country. Then, as a comparison, actual activities in Green Logistics and in ICT-application in India are

68 Ministry of Road Transport & Highway Government of India 2012, pp. 18.
69 Ministry of Road Transport & Highway Government of India 2012, p. 21.

discussed. Finally, conclusions that can be drawn from the analyses are specified.

### 4.4.1 EXISTING ICTS WITH GREEN COMPONENTS

Since road is the main mode of transport examined in this project, the research has been focused on ICTs with green components and objectives used for road traffic.

In the following, ICTs that seem particularly interesting in terms of traffic reduction, and thus $CO_2$ emissions reduction, in Bangalore are examined in more detail.

**AMV Audio Mobil traffic management**
The AMV system collects real-time data of vehicles involved in traffic. This data can be collected via an "intelligent control unit" (ICU), for example a mobile phone SIM card or wireless LAN, which is integrated into the car, or a GSM device that is attached to the vehicle. The determination of the vehicle's position is done via GPS or GSM. The data is sent out in a minute cycle via mobile radio communication. The AMV system then sets up a data pool with the anonymised data. This data pool is analysed to gain precise data and to provide a dynamic overview of the current traffic situation. This information is useful for adapting infrastructural signals (for example traffic lights) accordingly. Furthermore, traffic participants can be led on detour routes to avoid traffic congestion.

The use of real-time data has the advantage that the data is up to date. Average data does not provide accurate information for a fast-changing traffic situation. The system always gives the latest and most suitable account to achieve good capacity utilisation. Another advantage is that the car itself only needs to be equipped with a small device and functions as a sensor itself. Thus, investment costs are quite low. The consumer saves time, fuel and money, because he is led efficiently to his destination.[70]

**Different technologies to provide traffic information**
A driver can choose how he wants to gain information about the latest traffic situation. These information sources influence his speed, route and time frame.

*Variable traffic* signs are mainly used to provide information about the traffic situation for traffic participants to avoid further traffic congestion or accidents. *Dynamic road control systems* involve a smart coordination of traffic signals, especially in peak hours, with the same aim as for variable traffic signs.[71]

There are several technologies available to reflect the traffic situation and react to it accordingly.

There are various *analogue and digital broadcasting systems*. These make use of transmitting information via radio channels. The information is gathered beforehand and then sent out individually or collectively to the user. One negative aspect of this is that some places have no reception for transmitted radio waves, which means that coverage is not assured everywhere. Without a signal, no information can be received, which leaves the traffic participant without possibly relevant updates.[72]

*Mobile radio systems*, as for example in mobile phones, on the other hand, have large network coverage. Due to continuously decreasing charging rates, those possibilities are becoming more and more attractive.[73]

*Location based services* are services that include the use of a mobile phone as well as positioning technology. Locating the phone and, thus, the user can be done via different possibilities. One advantage is the mobility of the end-user and that he or she can get the information according to demand.[74]

**Car-to-X-Communication**
Within the system, traffic participants in separate vehicles are linked with each other and/or the street infrastructure. The system is able to inform the driver in case of potential dangerous road situations, which includes nearby accidents or traffic congestion. Information is transmitted via technology such as wireless LAN or radio. To be able to operate this system over a large area, for example the whole of Europe, the technology needs to be uniform.

The system can be used for various different interests. It can be useful for entertainment, as well as informative and safety-orientated. For example, it provides solutions for better ways of navigation, driving aids and/or self-organising traffic.

70 Pommer 2008.

71 Schnieder 2007.
72 Schiller 2003, Haspel 2008, Schierbaum 2009.
73 Haspel 2008, Schnabel 2005.
74 Shen 2011.

This system is very effective for avoiding accidents and navigating through risky parts of the road network. However, it is difficult to introduce a standardised radio frequency over such a large area as Europe. But to make the system useful it needs to be introduced over a large area.[75]

**Online Freight exchange systems**

Online Freight exchange systems are electronic marketplaces between hauliers, freight forwarders and customers. On this platform, which runs on the internet, they can acquire or sell cargo or meet to start cooperation with each other. It is an open system and any company from the sector can take part.

The system makes a company's work very spontaneous and flexible. This is good, as the company can then avoid sending out dead heads or LTL's. Partial shipments are now bundled and, thus, street congestion can be reduced. On the other hand, the use of this system provides a certain threat to a company, because the company needs to rely strictly on the functioning of this system and it also needs to be flexible enough to even out uneconomical transport at certain times.[76]

**Platooning**

Platooning is an innovative system to decrease the distance between cars by using electronic or mechanical coupling. This innovation was invented for cars but can also be conferred to trucks. The aim of platooning is that vehicles can drive close and safely together. This maximises the throughput and capacity on the streets.

An on-board computer system permanently controls all relevant parameters like distance and speed. Thus, it is possible to fix the separation between two vehicles at 21 feet. Magnetic sensors and markers attached to the street control the position of the vehicle. All these platooning technologies make the movement of these vehicles safer than a human driver could.

The system saves fuel and reduces drag. But it is very expensive to realise because of the markers needed on the streets. Furthermore, the drivers have no control over their fate because it is in the hands of software.[77]

**Congestion Charging**

The aim of this system is to reduce traffic and avoid traffic jams. In this way, it also aims to reduce $CO_2$ emissions. Therefore, all users of the transportation network should pay a surcharge when using certain roads or driving at peak times. Because of the extra cost, road users might switch to other means of transport, resulting in fewer road users.

Such a system is very effective and is an important element of a successful urban transport policy, but it is also very expensive to install. For the success of this system, it is very important to have a supervisory system that controls the payments. Otherwise no one will stick to the rules. Furthermore, it is important to consider whether such a surcharge will apply only to commercial traffic or also to private consumers. It has been shown in the past that such a system, despite its advantages, can be realised only if it is accepted by the public. The system is working correctly if all peaks are reduced and the traffic is distributed equally throughout the day.[78]

### 4.4.2 GERMAN BEST PRACTICE

**CargoLine's environmental activities**

CargoLine sets network-wide standards to ensure the same transport quality to all customers. For example, all partners use a tracking and tracing system which is compatible with every customer's in-house IT infrastructure. In this way, a shipment's status can be called up at any time. Furthermore, the alliance has been awarded with the DIN EN ISO 14001 environmental certification, entitled "Environmental management systems – Requirements with guidance for use".[79]

Further environmental activities can be listed from a company presentation in January 2011[80]:

*"Fleet management*

- *Continuous exchange of trucks used in long- and short-distance transports in accordance with the latest exhaust emission standards*
- *Trainings to reduce petrol consumption*
- *Computer-based monitoring of all vehicle data and truck repair shop stops in order to detect any anomalies immediately and to prevent needless wear*

75 Lübke 2004, Winter 2009, Schnieder 2007, Chapman 2009, Car2Car 2010.
76 Kreowski 2011.
77 Ioannou 1996.
78 OECD 2010.
79 CargoLine 2012b.
80 CargoLine 2011, pp. 34-36.

- *Use of low-rolling-resistance tyres*
- *Partly use of bio diesel. The area-wide use might not be appropriate as it might further the spread of monocultures and the release of nitrous oxide („laughing gas"), which is detrimental to the ozone layer*
- *Planning of transports*
- *use of modern planning and scheduling tools and telematics as well as operation of four hubs in order to avoid deadheads*
- *Combined road/rail transports wherever applicable*
- *Participation in so-called city logistics concepts to reduce inner-city traffic*
- *Avoiding waste and saving resources*

*Waste reduction and separation*

- *Significant reduction of paper thanks to up-to-date computer technology [...]*
- *Electric power reduction thanks to rows of windows in roofs, energy-saving light bulbs and interval timers*
- *Installation of solar power plants to produce electric power [...]*
- *Installation of truck car washes using water that has been biologically treated [...]*
- *Modern evacuation systems for the cleaning of tank trucks [...]"*

As a large green initiative, in September of 2011, CargoLine implemented a cooperation-wide investigation of GHG emissions, the so-called Network Carbon Footprint (NCF), according to ISO 14064. Using the results as a basis, CargoLine is planning to develop a table of shipments which includes $CO_2$ e-values.[81] This table will then be usable by the entire alliance. The partners can make use of the table by abstracting customer-specific values to illustrate the emissions that have actually been produced (Product Carbon Footprint). The value calculated like this is much more specific than any value that could be derived from an analysis of average emissions. Furthermore, CargoLine's GHG emission calculation is rather innovative in terms of the decision to collect real data instead of reference data. This ensures a full, realistic and transparent analysis. Partners' emissions are also taken into account. The data collection has been separated into three sections[82]:

- Transport (divided into short-distance traffic and different alternatives for the main run)
- Administration, referring to the alliance's headquarters and partners' offices
- Stationary processes, like handling in hubs or partners' depots

**Truck Toll System**

The German toll system is the world's first satellite-based toll-collecting system. It is called Electronic Toll Collection (ETC) and was introduced in Germany in 2005. It charges a toll for the use of the German federal highway (the so-called "Autobahn") on heavy good vehicles (HGVs), starting at a permissible total weight of 12 tons. Toll collection starts on entering the highway's slip road. It is a "user-funded" or "user-pays" system and is supposed to relieve the tax burden on infrastructure. A user in this case is any driver of a HGV who utilises the German motorway; this means both domestic and international trucks are asked to pay. The system is easily accessible and thus does not provide large bureaucracy barricades to foreign users.[83]

As it is satellite-based, certain gadgets need to be installed. These are absolutely necessary for the data collection and ultimately toll collection. An "on board unit" needs to be integrated into the truck. It is connected with a GPS satellite that registers the movement of the truck and with it the actual distance driven in kilometres. In areas with uncertain GPS access, control bridges are installed and a gadget called DSRC (Dedicated Short Range Communication) is able to provide the necessary information flow. All data is saved within the customer's profile. Furthermore, an antenna can also be installed on the truck's roof that combines both gadgets. To detect vehicles using the highway and register toll evaders, control bridges are used. They contain smart software, for example video-based software analysis, to detect the number plate of a vehicle and compare it with the database to see if the truck is actually registered.[84]

The toll is based on various factors. As trucks create major $CO_2$ emissions, which impact the environment, the respective toll is orientated among the pollution impact a truck has on the environment. For that, each truck is categorised into different emissions

81 $CO_2$e stands for $CO_2$equivalent. This includes the emissions of GHG ($CO_2$ and non-$CO_2$) convertefd to $CO_2$ by using the global warming potentials. Ravindranath 2002.

82 CargoTime 2012, pp. 16-17.

83 Toll Collect 2009, pp.2-5, Ruidisch 2004, pp. 2-5, Wieland 2005, pp. 119-120.

84 Toll Collect 2009, pp. 8-17, Ruidisch 2004, p. 11, Wieland 2005, p. 120.

classes.[85] Trucks with the least $CO_2$ emissions are favoured in this system and pay significantly less. The most favourable category is gained via the latest generation of exhaust systems or the installation of extra particle reduction filters. The number of axles on an HGV is also considered. The more axles an HGV has and/or uses the more weight it can possibly carry. The weight of a truck is responsible for road attrition, and that is why it is an important factor to consider. The respective rate that applies is a function of these two factors. For each individual truck it is then multiplied by the number of kilometres travelled. Bills are sent out monthly. The exact number of kilometres reflects actual road use. Thus, the truck driver or company is responsible for the bill they receive. It is a so-called "user-funded" or "causer" system. [86]

Since there are no toll portals such as toll stops or toll lanes, the system does not affect traffic flow. Access for foreign users is just as easy as for German users. The whole system is supported by over 3,500 terminals distributed all over Germany, an online platform and a call centre for customer service. For foreign drivers and companies who rarely use the German federal highway, the possibility of manual charging at the toll station terminals or online is optimal.[87]

There are various reasons for implementing the toll system. First of all, it is an additional income source for the funding of infrastructural development and it relieves public budgets. An HGV's weight has a large impact on the degradation of infrastructure, such as road and bridges. With transport numbers increasing yearly, a solution for the progressive movement of road attrition was desperately needed. The weight of the vehicles damages the surface and roads have to be renewed, which requires large amounts of money. Revenues from the toll collection are meant to be used for the improvement of the infrastructure, for repair work and extension. A further reason is to utilise the capacities of infrastructure more efficiently. The toll makes it even more uneconomical for a company to drive less than truckload (LTL) or even deadheads.[88]

The implementation of the Electronic Toll Collection system is also meant to impose fairer competition between road and railway. With a toll on HGV transport, forwarding companies are more inclined to take the environmentally friendlier option of railway transport into account, as road transport has become less attractive because of the additional fees. The advantage of using rail for freight transport is thus emphasised.[89]

The system is not only aimed at financing the infrastructure. It is also supposed to have a positive impact on the environment. Large positive environmental effects of the system were considered before its implementation. Since they were reasonable, the ecological reasons were a further impact on the final decision to implement the German toll system.

One of the effects considered was the increase of the modal shift from road to rail. According to the Federal Agency for Road Transport this aim has not been achieved. Nevertheless, a slightly increased turn-over in intermodal transport can be seen.[90]

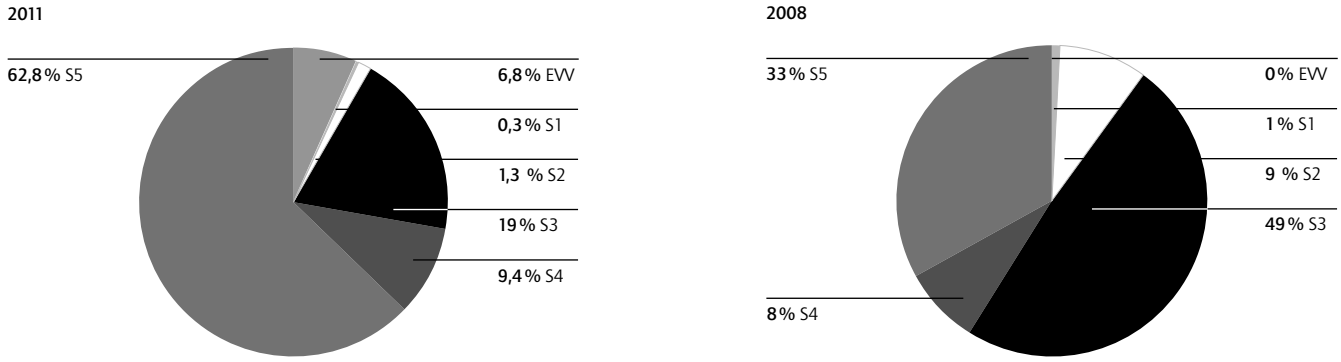
Another effect that has been considered is the reduction of $CO_2$ emissions due to an increase in the use of trucks with better emissions classes. Considering truck traffic as a whole, more low-emission trucks were used in 2011 to fulfil transhipment than in 2008 (see Figure 13). The number of more sustainable trucks has constantly increased since implementation of the toll. A reason is the significantly lower rates that companies are charged for low-emission trucks. Thus, it is worth investing in new vehicles. This is a benefit to the environment, because low emissions trucks mean less pollution.

To organise freight transport more efficiently initially requires more organisation, but it pays off when the result is full truckloads (FTL) and fewer trucks on the roads. Reduced fuel consumption is supposed to be the outcome as freight transport is organised more efficiently, thus less $CO_2$ is emitted. This is a huge benefit for the environment as well.[91]

Furthermore, the company Toll Collect GmbH itself is keen on always using green technologies within the implementation of the system. Their key goals are to use renewable energy, minimise waste and think ecologically wherever possible. For example, Toll Collect changed to recycled paper for written correspondence with a service

85 Currently defined emissions classes are S1 – S5 and EEV. EEV is the best class with lowest emission rates. This is followed by S5 and drops to S1 with the highest emission rates.
86 Toll Collect 2009, pp. 20-29, Ruidisch 2004, p. 5.
87 Ruidisch 2004, pp. 9-12.
88 Ruidisch 2004, pp. 3-7, Wieland 2005, pp. 119-121.
89 Jahncke 2006, p. 15, Ruidisch 2004, p. 2.
90 Jahnke 2006, p. 15, Wieland 2005, p. 124.
91 Christidis 2010, pp. 51-53.

Figure 13: Share of driving performance by emissions class.[92]




provider, made use of Deutsche Post AG's "Go-Green" product for carbon neutral mailing of letters and installed drinking water vending machines instead of using bottled water.[93]

A negative effect is that avoiding traffic has increased. Avoiding traffic is when HGVs make use of federal roads ("Bundesstraßen") instead of the highway to avoid toll collection. This affects and damages the less-robust streets in the countryside and villages. To prevent this, so far eight federal roads have become toll-obligatory. Extending the HGV toll to even more federal roads is already planned for the near future.[94]

There are also truck drivers who try to bilk the ETC system. This generally not easy to do because, as mentioned above, there are various control bridges installed on the German motorways which are equipped with smart IT. These control bridges can recognise number plates and compare them to the related customer in the database. They are also able to check the number of axles a truck has to see if the information provided by the truck driver is correct. If a truck cannot be identified, for example, due to foreign letters or because the truck is not registered, then the collected data and pictures taken by the control bridge devices are sent to a manual control authority and processed there. Identified drivers or companies are then asked to pay appropriate fines.[95]

### 4.4.3 ACTIVITIES IN GREEN LOGISTICS IN INDIA

For the Indian industry sustainability and with it environmental responsibility is increasingly becoming an issue. Reasons include political decisions, as some states are integrating environmental objectives in the State Industrial Policy, stakeholder requests, cost saving measures and improvement of company image. Observing this development, Indian researchers and consulting companies have begun publishing literature on Green Logistics. Among them was Shete96 from the Global Research Center of Consulting, Wipro Consulting Services. In his paper he discusses the reasons for companies' green activities and identifies the activities which are usually performed. He critically points out areas he thinks should receive increased focus for green optimisation. These are warehousing, the optimisation of manufacturing by-products, product life-extension, recovery at the end of a product's life and remanufacturing.

Palanivelu and Dhawan from Tata Consultancy Services (TSC) Limited also published a white paper on Green Logistics. After illustrating the meaning of the term "Green Logistics" they describe Green Logistics' drivers of mounting energy costs, alarms about GHG emissions, climate change, policies and improved community awareness.97 They then localise those stages of the supply chain where companies impact the environment. After that, "four areas wherein a successful green logistics implementation can have a positive im-

92 BAG 2009, p. 16, BAG 2012, p. 24.
93 Toll Collect 2011, pp. 14-15.
94 Toll Collect 2012, Wieland 2005, p. 125.
95 Ruidisch 2004, pp. 13-14.

96 Shete 2009.
97 Palanivelu 2010, p. 5.

pact on the overall Supply Chain"98 are examined. These areas are network optimisation, packaging reduction, sustainable procurement and warehouse layout optimisation. The authors furthermore draw up recommendations for implementing IT solutions to enable Green Logistics. They suggest that IT solutions can play a key role for the success in green initiatives, e.g. optimising transportation routes, paperless processes, dynamic scheduling of transportation tasks and measuring and reporting the carbon footprint accurately.[99] As well as theoretical consideration, green initiatives are actually implemented by Indian companies. Some specific examples are outlined in the following section.

**Damco International A/S**

Damco International A/S is a part of the A. P. Moller – Maersk Group's logistics activities with its corporate head office in Copenhagen, Denmark. Damco ships 2.5 million TEU of ocean freight and 110,000 tons of airfreight every year. The Logistics Service Provider (LSP) operates all over the world with 300 offices in more than 90 countries. The company also has several local offices in India, including in Bangalore.[100]

Damco has recognised their environmental responsibilities, and they are very active in the field of Green Logistics. They developed a so-called "Eco-efficiency Strategy" that is supposed to enable Damco, their customers and their service providers to reduce their environmental impact. The strategy focuses on the following five main areas[101]:

1) Environmental performance
2) Responsible procurement
3) Supply chain carbon footprint
4) Collaboration
5) Green product portfolio

Damco underlines their green initiative by offering three green logistics products to their customers. According to their White Paper on Sustainability Highlights 2010, these products enable the customer to reduce their waste and $CO_2$ emissions by 10% on average. The products are called "SupplyChain CarbonCheck™", "SupplyChain CarbonDashboard" and "Packaging Optimization Service".[102]

The first objective of the SupplyChain CarbonCheck™ is to identify carbon and cost reduction potentials in the user's supply chain. The second objective is to then realise these reduction potentials. The product was launched in late 2007. Referring to several projects, Damco claims that $CO_2$ reductions "can be achieved through increased supply chain efficiency, which translates into reduced supply chain costs."[103] SupplyChain CarbonCheck™ consists of five steps that can be accessed in detail online:

http://www.damco.com/Service/SustainableLogistics/SupplyChainCarboncheck.aspx

Visibility of a company's $CO_2$ emissions is usually the first step for further activities in reducing carbon emissions. Therefore, Damco provides a product called SupplyChain CarbonDashboard that was released in 2009. It aims to regularly report supply chain carbon emissions and compare issued periods. This way weak points and principal $CO_2$ generators can be identified and countermeasures can be taken. The Damco approach includes a team of experts that analyses the customer's supply chains and maps freight traffic to identify the exposure of carbon emissions.[104] The results of this analysis are regularly reported to the customer, across four different levels. For more information see:

http://www.damco.com/Service/SustainableLogistics/SupplyChainCarbonDashboard.aspx

The Packaging Optimization service was launched in 2010 by Damco in partnership with a packaging design company. It particularly aims to eliminate the customer's waste and thus minimise environmental impact. Nevertheless, Damco also suggests that their measures save 10-20% in logistics costs. A remarkable point regarding this green product is that Damco only gets paid an agreed percentage of the first year's savings. This means that they only get paid according to the success they were able to implement, which reduces the customer's risk of unprofitable investments.[105] The procedure followed when a customer makes use of this service is illustrated online:

http://www.damco.com/Service/SustainableLogistics/PackagingOptimisation.aspx.

98 Ibid., p. 6.
99 Ibid., pp. 14-16.
100 Damco 2012a.
101 Damco 2012b.
102 Damco 2010, pp.3-4.
103 Damco 2014a.
104 Damco 2014b.
105 Damco 2014c.

**Safexpress Pvt Ltd**

Founded in 1997, Safexpress is India's largest express cargo service provider with more than 3,600 vehicles, 7 million square feet of warehouse space and 48 Hubs and Mega-Hubs. The LSP delivers over 80 million packages annually. Apart from express distribution, Safexpress also operates as a supply chain and logistics company, offering Third Party Logistics, warehousing, Air Cargo management, consulting etc. While the corporate headquarter is situated in New Delhi, Safexpress also runs one of its logistics parks in Bangalore.[106]

Safexpress take its societal responsibilities seriously. Therefore, the company takes action in different fields like healthcare (e.g. "Pulse Polio Immunization Campaign") and disaster relief (e.g. Tsunami Rehabilitation in 2004 or Bihar Floods in 2008).[107] Greening logistics is another sustainable field Safexpress is involved in. Several measures have been implemented in order to reduce the environmental impact of the company's operations[108]:

1) Besides the replacement of vehicles every two years, which is supposed to ensure lower carbon emission levels, smoke filtration devices have been installed in the fleet's vehicles.
2) Furthermore, Safexpress has introduced special software which enables the majority of the company's transactions to be carried out electronically. This way, the amount of paper used can be greatly reduced.
3) Safexpress also takes green action in its logistics parks. Thus, rain water is harvested to nourish plants and green areas around the parks.
4) To save electricity, the inside of Safexpress' logistics parks is illuminated by sunlight during daytime.

**Godrej & Boyce Manufacturing Company Limited and Godrej Industries Limited.**

Godrej is an Indian group with presence in 60 countries with seven companies operating in various fields, for example real estate, FMCG, industrial engineering, appliances, furniture, security and agri-care.

Understanding the group's social responsibility, Godrej developed a vision called "Brighter Living", exclusively dedicated to greening India by "design[ing] and deliver[ing] environmentally superior products which are energy efficient."[109] The group also underlined its green ambition by signing the *CII code for Mission of Sustainable Growth* (MSG) – a programme for ecologically sustainable business growth. Another goal mentioned in the vision statement is "Achieving zero waste, carbon neutrality, positive water balance and a 30% renewable energy source."[110] These goals are confirmed by several distinctions, like a green refrigerator, the *National Energy Conservation Award 2009* from the Indian Government, the *Leader in Energy Efficiency & Sustainability Award* and the *LEED Gold Certification* from the US Building Council.[111]

A further green initiative undertaken by Godrej is the promotion of reduce, reuse and recycle processes. Godrej endeavours to reuse discarded materials for manufacturing instead of new materials.[112] According to Godrej, this saves not only natural resources but also energy, clean air and fresh water.[113]

### 4.4.4 CT APPLICATIONS IN INDIA

In their report by the sub-group on "Passenger and Freight Traffic Assessment and Adequacy of Fleet and Data Collection and Use of IT in Transport Sector in the Twelfth Five Year Plan (2012-17)", the Indian ministry of road transport and highways presented real-world approaches to the application of Intelligent Transport Systems (ITS). In this project, we use the acronym ICTs synonymously with ITS. What both terms mean is the application of IT to collect and analyse data, and furthermore to monitor, plan and control the transport or traffic system or the system's individuals. The benefits of their use are traffic optimisation (in terms of congestion, pollution and accidents) and improved services for traffic participants. Both benefits merge into an increased efficiency of the transportation system.[114]

While developed countries like Germany, the USA or Japan had to spend a lot of money to do research in this field, to buy new and expensive technologies – often finding out, in the process, that the technology is not efficient or reliable enough –developing countries

106 Safexpress 2012a, 2012b.
107 Safexpress 2012c.
108 Safexpress 2012d.

109 Godrej 2012a.
110 Godrej 2012b.
111 Godrej 2012c.
112 Godrej 2012d.
113 Godrej 2012e.
114 MORTH 2011, p. 24.

like India can benefit from these efforts. Access to information technology and infrastructure has never been as easy and cheap as it is today.[115] The following illustrates ICTs used in India:

**Arrival time forecast for public bus users**

In Bangalore, an ICT for Public Transport is used. The Bangalore Metropolitan Transport Corporation rigged its buses so they can be tracked via GPS. Information about the actual location of a bus is collected in the operating centre. This information allows arrival forecasts to be calculated and transmitted to public transport users. Also, problems like defective buses can be detected quickly.[116] This ICT does not reduce congestion or user waiting times, but the credibility and accountability of the system will be improved.[117]

**VAHAN ICT Based Vehicle Registration**

> *"Vahan is a highly flexible and comprehensive system that takes care of all the burdensome vehicle registration. Vahan is three-tier, platform and database independent software, which is customised to cater to the needs of individual States. The software enables the processes at RTOs [Regional Transport Offices] vis-à-vis vehicle registration, fitness, taxes, permits and enforcement to get computerised. Vahan is conceptualised to capture the functionalities as mandated by Central Motor Vehicle Act, 1988 as well as State motor vehicle Rules. Customisation is done in the core product to suit the requirements of all the States/UTs [Union Territories]. The product has been successfully customised and implemented for the 33 States and Union Territories in the country. This will automate all vehicle registration related activities in transport authorities of country with introduction of smart card technology to handle issue like interstate transport vehicle movement and to create state and national level registers of vehicles information."*[118]

**SARATHI Licensing Solutions for RTOs (Regional Transport Offices)**

"SARATHI is a computer based solution that helps RTOs to issue Learning Licences, Driving Licences, and Conductor Licences to the citizens and Licences for the Driving School Establishment. It is designed to process the citizen requests using the work flow based processing. Established with the authority of RTOs, the package can be customised to the various changing needs of RTOs in India."[119]

**Electronic payments for toll collection (ETC)**

In India, several sections of main roads are in private ownership and charge tolls. For payment, toll plazas were installed, where financial transactions are mostly processed manually. "The cash collection method forces road users to stop and pay at the toll plazas sometimes resulting in long queues."[120]

Meanwhile, IT-systems are increasingly implemented for electronic payments either via smart cards or via electronic toll collection. Paying with cash is the most time-consuming method of paying a toll, and thus it causes most congestion in front of toll plazas. The next level is paying via smart card. The card has to be purchased and charged with credit in advance. When reaching a toll plaza, the toll can be charged to the card electronically. This usually saves time because of easier handling. The fastest and highest level of toll payment is paying via electronic toll collection using on-board units. This keeps speed reduction to a minimum. The automated identification and user charging means this method does not produce congestion in front of toll plazas.

On national highway no. 8 from Delhi to Gurgaon, for example, all three payment-alternatives have been offered in parallel since 2008. Among others, further projects for electronic toll collection are planned for a 27 km long section of national highway 22, a 42 km long section of national highway 47 and a 161 km long section of national highway 59. An Austrian company called EFKON AG received the orders in May 2012.[121]

**Road Accident Data Management system (RADMS)**

RADMS is an initiative by the Government of Tamil Nadu, in the most southern part of India, and its software came into operation in 2009. The system aims to collect appropriate accident data, verify and ensure the quality of data, as well as to analyse the data for planning purposes to benefit the public.

> *"RADMS is a comprehensive traffic-management system which helps to study and analyse road accidents in a systematic and scientific way. The successful implementation of this project*

115 MORTH 2011, p. 22.
116 Unfortunately, the GPS devices were removed from the buses currently.
117 MORTH 2011, p. 26.
118 MORTH 2011, p. 28.
119 MORTH 2011, p. 29.
120 MORTH, p. 37.
121 EFKON 2012.

*is a crucial component of our road-safety efforts. The three stakeholders Departments Police, Highways and Transport have access to use the data for analyses and follow up actions in order to reduce accidents."*[122]

### 4.4.5 CONCLUSIONS

As the above analyses show, environmental topics and Green Logistics are a known issue not only in developed countries like Germany but also in less-developed countries like India. Various measures for greening logistics, like modernising the vehicle fleet, are considered in both regions. Also other familiar measures which were mentioned in chapter 3.4.1 as being common measures among Western companies are known in India. This hypothesis is easily verified through white papers and scientific papers from Indian researchers.

Regarding green activities put in place by companies in the Indian sector, it is apparent that large scale and multinational companies receive particular mention. Since in developed countries these are the companies that emphasise green topics notably, too, this is not surprising. There are also smaller, national companies, like Safexpress Pvt Ltd, that are taking action in Green Logistics.

The illustration of activities in ICT-application in India also shows that ICTs themselves are an on-going topic. Nevertheless, the ICTs illustrated above do not pursue green targets, and for this project efforts in road traffic ICT-application should concentrate on green ICTs.

[122] MORTH 2011, p. 37.

# 5 REQUIREMENT ANALYSIS FOR MICPB – URBAN FREIGHT TRANSPORT MANAGEMENT

## 5.1 PURPOSE

The purpose of this document is to identify and list the information, database and functional requirements required for "**Mobility Information and Communication Platform Bangalore (**MICPB**)**" – urban freight transport management.

## 5.2 SCOPE

MICPB – Urban freight transport management is a system which will have the capability to integrate PC / navigation systems, track and trace systems, collect current urban transport data of recipients and the locations of charging stations. The system will integrate a central repository to store spatial and non-spatial data and history.

The urban freight transport system operates on a demand-supply cycle where demand comes from the customer / sender, who needs to transport goods, and supply comes from the carrier who has goods transport vehicles or charges sub-contractors who have goods transport vehicles. We will focus on vehicles with a load capacity of less than two tons.

## 5.3 FEASIBILITY

The Indian system of transport statistics is marked by:

- Decentralised generation of data
- Multiplicity of agencies and time lag

There is no data available for forecasting or understanding the nature of operations.[123]

To understand the feasibility and requirements of MICPB, a survey has been created to capture freight information. Understanding process steps and decision levels in freight transport is extremely vital to understanding the requirements of the actors in this system. The survey obtains information from carriers on:

1) Vehicle specifics
2) Pricing
3) Manpower requirements
4) Area coverage
5) Parking
6) Access and comfort levels with different technologies like SMS, internet applications, GPS devices
7) Financial management
8) Customer access
9) Routing
10) Administration

This information feeds into understanding the data and the functional requirements for developing such a system.

## 5.4 ACTORS

The **actors** involved are:

1) **Customer** – They constitute the demand in the transport supply chain. The customer is responsible for initiating the process of freight transport.
2) **Carrier** – They form a part of the supply in the supply chain. The carrier is responsible for managing the transportation of goods.
3) **Driver** – They provide services at the supply end of the supply chain. The driver transports the goods on behalf of carrier.

The data used for urban freight transport management is different for each of the above actors.

## 5.5 INFORMATION REQUIREMENTS

Arriving at a better intra-urban freight management system requires three kinds of data:

1) **Static data** – These data are filled initially and not updated or changed.
2) **Dynamic data** – These data change constantly and need to be updated with higher frequency.
3) **Real time data** – This database is updated at a very high frequency and is delivered with no delay post collection.

The information requirements for MICPB – small freight transport will be categorised based on the various actors accessing the system.

[123] group 2011.

The data is categorised based on the kinds of data access made by or provided to the following actors:

### 5.5.1 CUSTOMER

| Static data | Dynamic data | Real time data |
|---|---|---|
| ❙ Name of the customer | ❙ From address<br>❙ Destination(s) information<br>❙ Time of delivery<br>❙ Quantity and weight of goods<br>❙ Attributes of goods<br>  ❙ perishable<br>  ❙ hazardous<br>  ❙ fragility<br>Goods dimensions | ❙ Information about vehicle dispatched<br>❙ Current tracking information |

### 5.5.2 CARRIER

| Static data | Dynamic data | Real time data |
|---|---|---|
| ❙ Total number of vehicles<br>❙ Vehicles available for the trip<br><br>❙ Vehicle attributes<br>  ❙ type<br>  ❙ capacity<br>  ❙ dimensions<br>  ❙ last service data<br>  ❙ emissions<br>  ❙ fuel<br>  ❙ registration date<br>  ❙ trips completed<br>❙ Service preferences (the kind of goods, specialisation) | ❙ Dispatch request<br>❙ Average hours/shift<br>❙ Parking related information<br>❙ Cost information based on<br>  ❙ distance<br>  ❙ quantity of goods<br>  ❙ kind of goods<br>  ❙ time of travel<br>  ❙ minimum cost<br>❙ Location<br>❙ Routing information<br>  ❙ area(s) of operations<br>  ❙ radius of operation<br>  ❙ maximum distance per trip<br>  ❙ location of customer<br>❙ Manpower<br>  ❙ for driving<br>  ❙ for loading and unloading | ❙ Current location of vehicle (tracking)<br>❙ Weather data<br>❙ Real time traffic data |

### 5.5.3 DRIVER

| Static data | Dynamic data | Real time data |
|---|---|---|
| ❙ Personal information of driver | ❙ Current capacity of the vehicle<br>❙ Time the customer's location is reached<br>❙ Time of departure from the customer's location (Login time)<br>❙ Time the recipient's location is reached (Logout for trip)<br>❙ Initial traffic model<br>❙ Route information (GIS data on roads, traffic signals etc.)<br>❙ Address details of customer and recipient<br>❙ Information about schedules | ❙ Weather data<br>❙ Traffic forecast<br>❙ Dynamic requests for dispatch<br>❙ Real time traffic data |

In an information communication platform for urban freight transport, some of the key client modules include routing of goods, real time traffic information, traffic modelling/forecast, client communication processes and distribution planning.

Client modules for an urban freight transport management platform can be classified according to the type of actor (e.g. Customer-Requesting a dispatch; Driver-Uploading login/logout information). Also, some modules will be common across actors (e.g. Vehicle tracking by customer and carrier). This platform creates a collaborative environment for freight transport management.

## 5.6 FUNCTIONAL REQUIREMENTS

The following describes the identified functional requirements of the system.

### 5.6.1 CARRIER REGISTRATION

This functionality allows a carrier to register with the system. Only registered carriers will have access to the system. This will allow authorised / authenticated access to the system and will let the system track the captured data.

### 5.6.2 SEARCH CARRIER

This functionality allows a customer to search for a carrier. This requires the customer to enter search parameters such as:

1) Location of customer
2) Location(s) of recipient(s)
3) Radius of operation
4) Goods data
   a. quantity / capacity
   b. type of goods
5) Minimum and maximum time to deliver

### 5.6.3 SELECT CARRIER

This functionality allows a customer to select a transporter for dispatching goods. The customer can select a transporter either from the search results, or from a list of all available transporters. The customer is then required to confirm the dispatch request details. If successful, the transporter is notified of the dispatch requirement.

### 5.6.4 MANAGE INFORMATION

This functionality allows the carrier to manage information related to:

- Users – adding/updating of human resources (driver, labour etc.) information.
- Vehicles – adding/updating of vehicle related information.
- Costs – adding/updating information of trip costs,
- Customers – adding information about customers, their preferences,

The information added/updated has to be reflected in the data warehouse to ensure information consistency.

### 5.6.5 VIEW ROUTING INFORMATION

This functionality allows the driver to view routing information. This requires in-vehicle display units and handheld devices (PDAs, smart phones using GPRS/3G). Also, the driver can be provided information via a trip sheet, which can be a printed timetable generated from this system or constant updates via SMS.

However, a route can be changed at any point during a trip as a reaction to dynamic real time traffic information, weather information and other dynamic dispatch requests.

### 5.6.6 VIEW TRAFFIC INFORMATION

This functionality allows the carrier and driver to view traffic information. This requires a map showing the current and predicted traffic, and certainly helps in better freight management. This information can be made available via a web app or smart phone app.

### 5.6.7 VEHICLE TRACKING

This functionality allows the carrier and customer to track the current location of the vehicle. It requires the vehicle to be equipped with a GPS/GPRS location system.

### 5.6.8 TRIP ANALYSIS

This functionality allows the carrier to analyse and understand trends using the trip history. Some of the patterns that can be identified include:

- Demand periods
  - Peak demand periods during the day
  - Seasonal periods during the year
- Frequently visited locations
- Commonly transported goods

### 5.6.9 GOODS ROUTING

This functionality allows the routing of goods. This will begin after the transporter is notified of the customers' dispatch request details. A vehicle with available capacity will be allocated for delivery. The routing information will be sent to carrier and driver.

### 5.6.10 TRAFFIC MODELLING AND FORECASTING

This functionality supports the system to model and forecast the traffic. It requires MICPB to provide access to external/supplemen-

tary systems for modelling and forecasting the traffic. The results are stored in the data warehouse to act as input for enhancing the routing functionality.

### 5.6.11 COMMUNITY COMMUNICATION

Inter-urban goods transport is a highly informal economic system. This means there is a severe dearth of information about these systems as the operations are small scale and highly fragmented.[124] Designing an integrated management platform is a very hard task under these circumstances. When different actors in the system are allowed to share information (mobility/traffic, vehicle, goods etc.), an efficient and reliable transport management system can be developed. The communication module should aid information flow among various actors of the system by enabling each of the actors to access the required information. This information can be posted through various channels like web applications, smart phone applications, SMS messages, call centres and GPS devices that can be customised to enter information with different attributes (different categories of information).

Different channels of information exchange and the structuring of information like SMS messages in a syntax that conveys the type of information and its location are explained below. For example:

A carrier wishes to send information about a dispatch request to a driver along a particular route. This information can be sent to the driver using various channels.

- An SMS with a structure – <GoodName> <Quantity>-Frm#<doorNumber>,<Street number/name>,<area>-To#<doorNumber>,<Street number/name>,<area>-Time. For example, 'mangoes 2tons-Frm#33,St4,city Mkt-To#444,St6,Elec City-Time 5 pm'
- A call from call centre/carrier
- Sending information to the 'on board' device through the web/smart phone application.
  - A driver wishes to update
- Current capacity of the vehicle to the carrier. This information can be sent using one of above channels by
- A SMS, structured as <Weight of last consignment>,<Current capacity of vehicle>,<Current location>. For example, '2.5tons, 3tons, 221B Baker street'
- A phone call to call centre/transport office
- Using the vehicle's on-board device applications.
- Current traffic information to carrier or to the system using any of the above channels.

### 5.6.12 REPORT GENERATION

The system can create reports for various actors with this functionality. The reports fall under the following categories:

- Customer centric – The system generates a report for the customers. It contains information about the vehicle and driver assigned to their consignment, delivery status of the consignment and delivery confirmation time.
- Vehicle centric – The system generates a vehicle specific report that contains information about the delivery trips, drivers assigned and the consignment information (goods attributes, location).
- Driver centric – The system reports to the driver about the schedule of the day, consignment information (goods attributes, customer information).
- Company centric – The system generates an aggregated report with trips per day, customers serviced, goods attributes, locations visited and financials.

## 5.7 ACTORS AND FUNCTIONAL REQUIREMENTS

The following table shows the functional requirements given above and their corresponding actors.

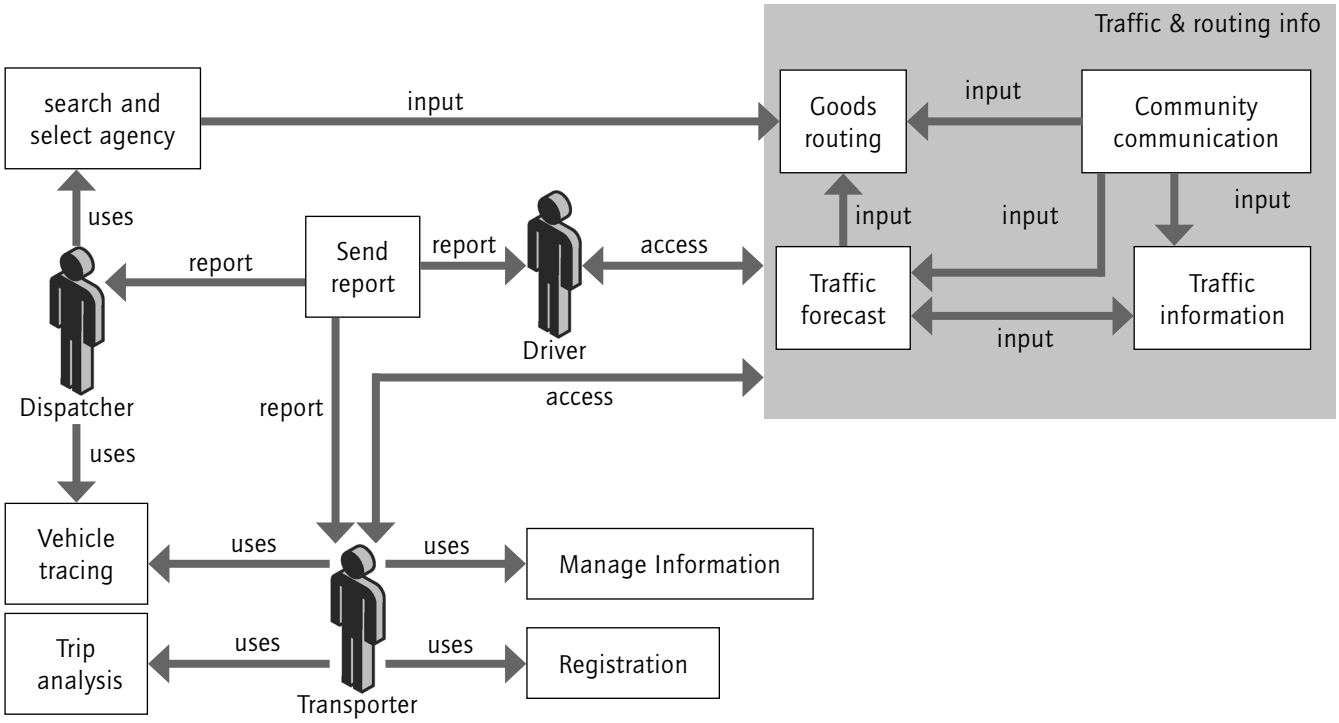
| Functional requirements | Actors |
|---|---|
| Carrier registration | Carrier |
| Carrier search | Customer |
| Select carrier | Customer |
| Manage information | Carrier |
| Trip analysis | Carrier |
| View routing information | Driver, Carrier |
| View traffic information | Driver, Carrier |
| Vehicle tracking | Customer, Carrier |
| Community communication | Carrier, Driver |
| Goods routing | <<system>> |
| Traffic modelling/forecast | <<system>> |
| Send report | <<system>> |

[124] Friedrich 2003; group 2011.

## 5.8 INTERACTIONS AND DEPENDENCIES

In the following figure, the actors' interactions with the various modules and the dependencies between the modules are presented.

Figure 14: Interactions between system modules.




## 5.9 SYSTEM COMPONENTS

Managing freight requires the integration of:

a) A continuous flow of information for routing, tracking, tracing, traffic information and forecasting
b) Centralised data repository/warehouse to store information
c) Applications (web, smart phone, SMS) to manage and monitor activities and integrate external applications

The above tasks in freight management require a set of components. In the following the technical components for MICPB-urban freight management module are identified.

### 5.9.1 DATA WAREHOUSE

The following information is crucial for the MICPB to deliver/implement the following modules. The data warehouse should have the capacity to store both spatial and non-spatial data. It should support storage of user information and transport agency information related to

- routing and traffic (GIS/Spatial data)
- trips
- customer and recipient, etc.
- costs
- client preferences (both carrier and customer)
- transport agencies' trip history

However, real-time traffic data arriving from external connections such as GPS devices needs to be structured into meaningful formats. It then requires parsing, before it can be added to the database. PostGIS is the GIS back-end for PostgreSQL. MySQL has spatial extensions, and is supported in both the MapServer and GeoServer web map servers."[125] Both of these data sources are GIS complaint.

### 5.9.2 APPLICATION SERVER

The application server hosts the client applications related to different actors. External applications (smart phone apps, web applications, on-board devices, call centre etc.) make use of the MICPB functionalities by interfacing with the application server.

### 5.9.3 WEB MAP SERVERS

MICPB requires spatially enabled internet application to deal with GIS related functionalities. A web map server provides functionality and standard OGC services to query and push data into GIS database. There are various servers available, such as GeoServer and MapServer.

GeoServer is Java-based, allowing users to share and edit geospatial data. It is designed for interoperability and publishes data from a major spatial data source using open standards. It is the reference implementation of Open Geospatial Consortium – Web Feature Service and Web Coverage Service.[126]

MapServer is an Open Source geographic data rendering engine written in C'. It allows the creation of 'geographic image maps' that can drive users to content. It supports cross platform, OGC standards.[127]

Both these servers take care of updating both static and dynamic data coming from various clients (smart phone apps, web applications, SMS) into the database, ensuring client requirements are met.

[125] Free and Open Source GIS software http://www.giscorps.org/index.php?option=com_content&task=view&id=13&Itemid=48.
[126] GeoSever: http://geoserver.org.
[127] MapServer: About http://mapserver.org/about.html#about.

## 5.10 SYSTEM ADMINISTRATION

MICPB should provide functionality to administer and manage it. Typically, an administration component has to provide the following functionalities:

- Data management, which includes
  a) Data warehouse management
  b) Data archiving, backup, data deletion
  c) Measuring database performance, etc.

- Server and client module management
  a) Updating the existing modules
  b) Measuring server performance

## 5.11 DATA FLOW

As shown below, the MICPB system can be viewed as a composition of three components.

1) MICPB Client: This interacts with the modules of the MICPB server. It can be represented as:

Table 12: MICPB client.

| MICPB Client | | | |
|---|---|---|---|
| GPS device | Smart phone app | web application | Call center |

2) MICPB Server: The hosts the MICPB modules, which take client requests and process them. Data are taken from data warehouses and to fulfil clients' functional requirements. A client gets acknowledgement for respective requests and gets information related to traffic, routing, vehicle, etc. It can be represented as:

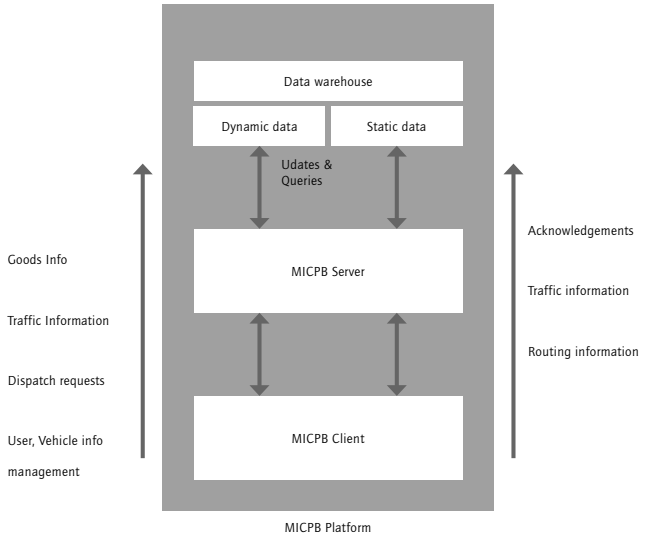
Table 13: MICPB Sever.

| | | | | MICPB Client | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Administra-tion | Communica-tion | Goods routing | Traffic information | Traffic forecast | Vehicle tracking | Registration | Search& select | Trip analysis | Send report |

3) Data warehouse: This is the GIS compliant central repository, which stores the information mentioned in the 'information requirements' section. The MICPB server updates and queries the database to obtain the data required for implementing various modules of the system.

The following image shows the data flow through the system components.

Figure 15: MICPB Platform.




## 5.12 DYNAMIC ROUTING

Dynamic routing can be used to manage freight transport and design the dispatch strategy to maximise delivery capacity. It takes into account dynamic information such as real-time traffic conditions, weather conditions, road network and dynamic requirements of the actors in the system. Hence, a dynamic routing algorithm becomes vital to MICPB.

The dynamic routing problems in our case fall under the combined pickup and delivery problem, which refers to a situation where a fleet of vehicles available to service requests arrive dynamically.[128] The carrier receives these requests real-time and hence has to dynamically route these vehicles manually or using a dynamic routing algorithm. Each dynamic routing algorithm includes various components such as the order and fleet management system, planning system and the observation system.[129]

Order and Fleet Management system – This continuously updates the state of the vehicles, orders, schedules and manages external communication with the clients on both the dispatch and the driver side.

The Observation System – This interfaces with the traffic management system and watches the traffic information and forecast. Based on current orders, it calculates the shortest path.

The Planning System – The planning module assigns the vehicles for delivery.

## 5.13 DATA MODEL

Data upload from clients

The clients upload data that is both static and dynamic in nature, in various formats such as text (goods preferences), numerical (price information) and geo-coded information (location).

GIS data – The Open Geospatial Consortium **Web Feature Service** Interface Standard (**WFS**) provides an interface allowing requests for geographical features across the web using platform-independent

128 Psraftis 1995.
129 Fleischmann 2004.

calls.[130] The spatial data is stored in a GIS-compliant database and the attributes' data model is associated with the topological structure of spatial data.[131] Figure 16 shows a software stack for a typical spatial database. Figure 17 shows the software stack for a spatial database implemented using PostgreSQL Object RDBMS and PostGIS plugin.

Figure 16: Software stack for using a typical spatial database.

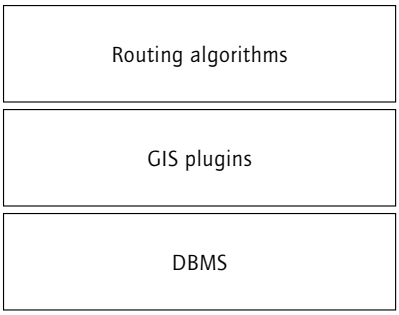
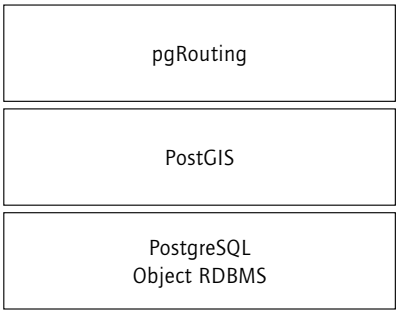



Figure 17: Software stack for a spatial database using PostgreSQL and PostGIS.




GPS data – We can use the GPS eXchange format (GPX), which is a commonly used xml format for GPS data. We can capture waypoints, tracks, route and other metadata such as latitude and longitude. GPX being a basic collection of points, in no sequential order, can be time stamped in order to track a person's route.[132] This XML data can be parsed and stored in a relational database such as PostgreSQL.

A lot of GPS devices transmit data in the NMEA 2000 format. Most computer programs that provide real-time position information understand and expect data to be in NMEA format. This data includes the complete PVT (position, velocity, time) solution computed by the GPS receiver. This data is in the string format and can be parsed to be stored in a GIS-compliant database.

Text and numerical information received needs to be parsed and stored in the database.

## 5.14 CONCLUSIONS

In conclusion, we have identified the requirements (e.g. information, database, functional) for "Mobility Information and Communication Platform Bangalore" (MICPB)". The system is supposed to be used as an urban freight transport management to collect and transfer data related to freight transport. The management system is a multifunctional tool which will be controlled via a centralised monitoring authority to store spatial and non-spatial data. The system includes a navigation-system as well as a track-and-trace-system and collects current urban transport situation and data about the locations of recipients and charging stations.

The tool should improve the communication between the customer/sender, the supplier or the carrier. This system provides the different actors with the current location of the transported goods. Another specific advantage of this tool is the possibility of collecting detailed freight transport movements within the urban area. Based on these data, forecasts for the future can be derived, and the infrastructure as well as the material and transport flows can be optimised.

The requirements for such a system are derived from a survey. The relevant actors of this system are customers, carriers and drivers. The system should be able to optimise the transport supply chain from origin to destination. In this context, it is necessary to consider different types of data (i.e. static, dynamic and real-time data). The data are categorised by the actors.

Within this communication-information platform the different actors are able to access different types of information to improve the communication process and distribution planning: The customer is able to search and select a carrier for dispatching of goods. He can then confirm the dispatch, and the carrier is notified of the dispatched goods. In this way, the carrier is able to manage the order's

130 OpenGIS Web Feature Service (WFS) Implementation specification: http://www.opengeospatial.org/standards/wfs.
131 Buckley D.J, bgis Introduction to GIS http://bgis.sanbi.org/gis-primer/page_27.htm.
132 GPX: The GPS exchange format http://www.topografix.com/gpx.asp.

information. Under the "routing information" view, the driver and carrier are able to view routing information. Thereby, the driver can optimise his route and avoid traffic congestion during the journey. He can also provide information through a trip sheet (timetable, routing etc.) for the carrier and the customer. This flexible handling of goods distribution is only possible with the help of dynamic real-time traffic information. Another use of this tool is vehicle tracking, which allows the customer and the carrier to track the current location of the vehicle. Using the trip history, the "trip analysis" functionality allows the carrier to analyse trends. The system creates reports for the different actors (e.g. report for the customers, vehicle specific report and drivers' report).

Various actors along the supply chain can use the system through different channels (e.g. web applications, smart phone applications, SMS, call centres, GPS devices).

Here, the informal and fragmented transport sector is a big issue in terms of realising of the communication network. If access to this system is easy, the benefit for the sector will be enormous. There are several interactions and communication issues in this field which could be solved by such a system.

# 6 AUTO RICKSHAW STUDY

## 6.1 INTRODUCTION

The following discussion is an extract from an extensive study was carried out by CiSTUP in 2012.

## 6.2 AIM OF THE STUDY

Auto rickshaws ("autos") play an important role as a transport system in Indian megacities. The number of vehicles is growing rapidly. With some 100,000 autos currently in Bangalore, the attraction for customers of a low cost taxi system is unmistakable.

The benefits of auto rickshaws include their on-demand availability, higher speed compared to the bus system, door-to-door connectivity, guaranteed seats compared to standing in crowded buses and the economic advantage over taxes. Also – in spite of their light and open design – they represent a fairly high level of security (6% of all accidents in 2011). In addition, auto rickshaws are a source of employment for a low-income stratum of the population.

On the negative side, there is an (albeit unproven) accusation that auto rickshaws are responsible for a large share of traffic jams. Furthermore, air pollution and high noise level in the streets is held against the auto rickshaws. The former has been falling since conversion to was made mandatory in the city. Public transport companies complain about unfair competition. The auto rickshaw system is less subject to state control. So the role which could be played by auto rickshaws in the city transport system is not predictable.

Although the number of auto rickshaws is growing, the share of all motorised vehicles has dropped significantly. In 1998, 20% of motorised vehicles were auto rickshaws, 20% private cars and 50% scooters. By 2007, those ratios moved to 3% auto rickshaws, 15% passenger cars and 75% scooters. During this period, however, private motorisation levels have tripled.

Conversely, auto rickshaws make up a significant and growing share of the daily traffic, which was already 13% in 2006. This is detrimental to the interests of buses (in 2006 still 46%) and cyclists (2% in 2006).

The number of complaints from users (refusal to pick up passengers, excessive fees, faulty taximeter, defective muffler, etc.) has increased in 2010. Auto rickshaws as a system thus play an ambiguous role which is hard to regulate.

The ownership structure of auto rickshaws is unknown, and the user structure and fields of use have never been studied. For other motorised road users, auto rickshaws, which do not need all the space in lanes and therefore drive in an undisciplined fashion, are more of a nuisance. For the road user who uses the auto-rickshaw for his journey, it is a breezy, fast and flexible mode of transport.

In the past, proponents of the auto rickshaw system argued for specialised lanes with reduced width; opponents argued for the complete abolition of the system in the streets of Bangalore. Customers complain about incomprehensible tariffs, and the emissions from the small 2- or 4-stroke vehicles are very high if the mandated LPG is not used.

This auto rickshaw study was designed against the background of this debate and reflections on the current role of the auto rickshaw system in city traffic, the weaknesses and strengths of the system and how the system could be improved as part of the city transport system. It should first and foremost improve knowledge of this transport system and thus open the door for consideration of how the system could be made better accessible and integrated with other systems, especially via an informational network for fast public transport.

## 6.3 METHODOLOGY

The study results are based on a literature review and on the analysis of quantitative and qualitative interviews.

A total of 250 drivers and 100 users of auto rickshaws were included in in-depth interviews. Qualitative interviews were held with a total of 14 groups of people who interact in any way with the auto rickshaw system. The comprehensive surveys were distributed at stands across Bangalore.

## 6.4 INTERVIEW RESULTS

In the qualitative interviews, the role of various stakeholders dealing with the rules and regulation of the system was examined. The government side (Government of the State of Karnataka, Regional Transport Authority RTA, the regional transport offices RTO and the police departments) regulates the registration and inspection during operation.

Figure 18: Methodology of auto rickshaw study

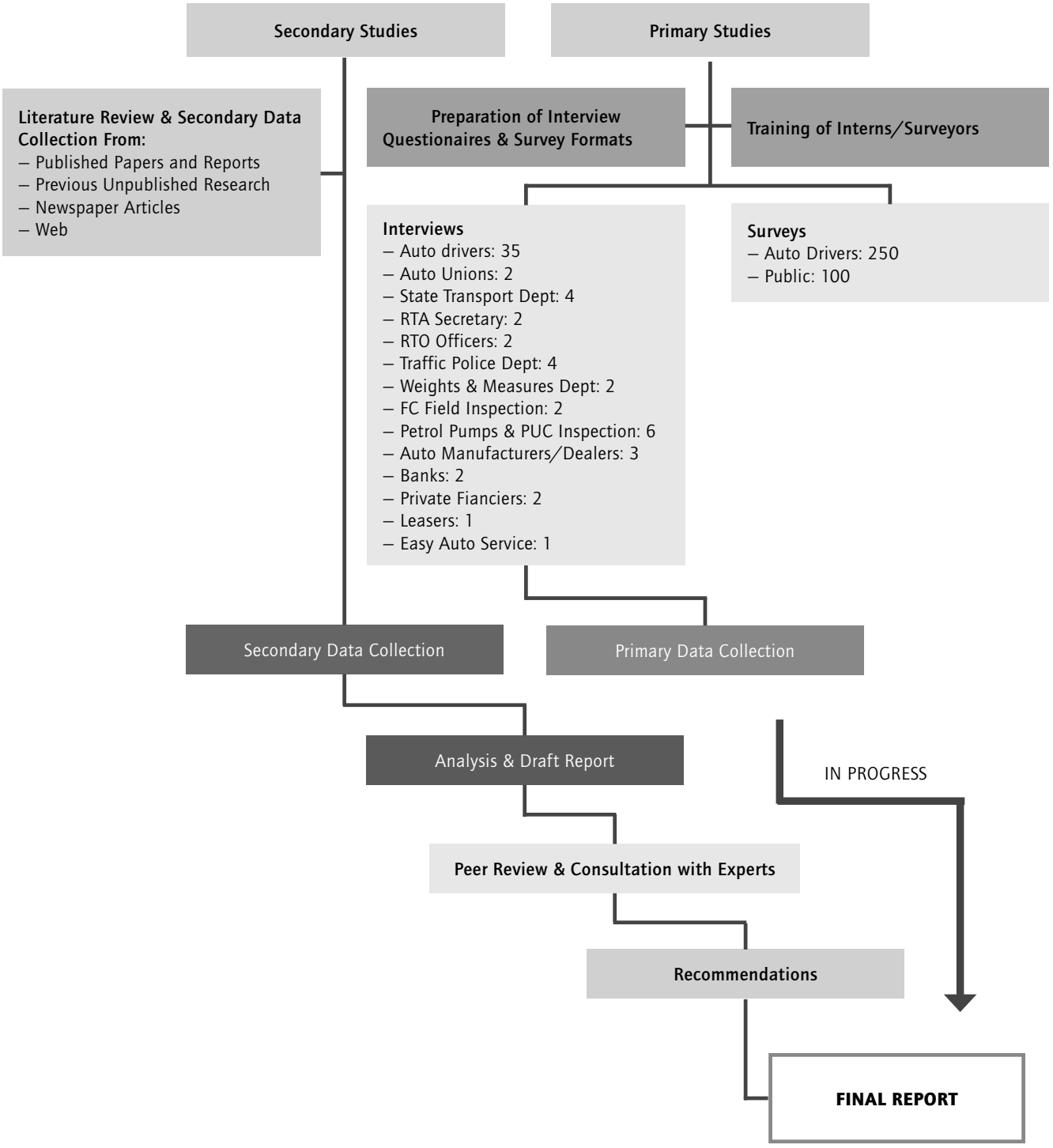


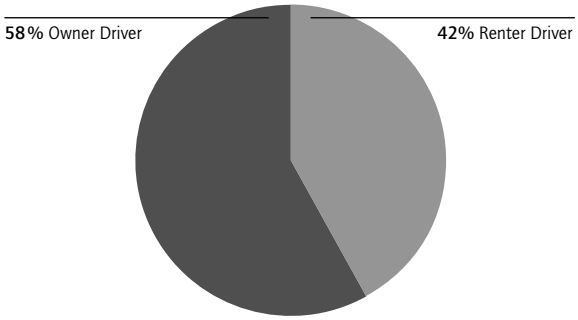
Table 14: Process for obtaining an auto cab driving license and badge.

| FOUR STEP PROCESS TO OBTAIN AUTO CAB DRIVING LICENSE AND BADGE | | | | | |
|---|---|---|---|---|---|
| | **Eligibility/ Qualification** | **Required Documents (along with related RTO Application Forms and passport photos)** | **Associated Cost** | **Time Taken** | **Validity** |
| **STEP 1: LL (general)** Any person wishing to obtain a Driving License (DL) has to first get a Learning License (LL) through a preliminary oral or written test | **Age:** Min. 18 years old<br><br>**Education:** 10th std/ SSLC pass or above (Written Test) In case of others (Oral Test)<br><br>**Address:** Applicant has to be a resident of the same jurisdiction/city | 1. **Age Proof (any one):** School Certificate; Birth Certificate; PAN Card; Registered Medical Practitioner's Certificate; Self Swearing Affidavit<br>2. **Address Proof – same jurisdiction (any-one):** Passport; LIC Policy; Electoral Roll; Telephone/Electricity/Water Bill; Ration Card; Caste and Income Certificate issued by Tahsildar; Pay slip issued by Govt. Office; Self Swearing Affidavit<br>3. **Declaration of Citizenship Status:** Birth Certificate, School Certificate Voter ID, etc. | Rs. 30 | Passed applicants can collect LL same day at RTO<br><br>Failed applicants can reappear next day onwards | 6 months; through-out India |
| **STEP 2: DL (general )** Applicant can appear for a test of compe-tence to drive, only after completion of 30 days from the date of issue of the LL | **Same as in Step 1** | 1. **Same as in Step 1**<br>2. **Valid LL (obtained via step 1)**<br>3. **Vehicle Documents:** in which applicant proposes to appear for driving test (registra-tion, insurance, tax, PUC and FC in case of transport vehicle)<br>4. **Medical Certificate,** if applicant's age is 40 years and above | Rs. 50 (Drive test)<br>Rs. 40 (DL Book)<br>**Or**<br>Rs. 215 (Smart Card) | Passed applicants can collect DL next day at RTO<br>**Or**<br>Within 8 – 10 days by post<br><br>Failed applicants can reappear after 7 days | 20 year period or 50 years of age; through-out India |
| **STEP 3: LL (auto cab)** Any person wishing to obtain an Auto Cab DL has to apply and retake a LL test 1 year after getting the | **Age:** Min. 20 years old<br>**Education:** Min. 10th std/ SSCL pass (Written Test)<br>Min . 8th std pass (Oral Test)<br>**Address:** | 1. **Same as in Step 1**<br>2. **Valid DL (obtained via step 2)**<br>3. **School Certificate**<br>4. **Medical certificate,** necessary in case of transport vehicle | Rs. 30 | Passed applicants can collect LL same day at RTO<br><br>Failed applicants can reappear next day | 6 months; through-out India |

Operation of auto rickshaws is subject to state regulations that provide for a maximum number of approvals. Operating licenses can be transferred, and in times when further approvals are blocked a thriving black market develops where operating permits are sold and bought at premium prices.

Auto rickshaw owners may have multiple auto rickshaws and operate using hired drivers. Employees are represented by a large number of trade union organisations. Drivers are recruited primarily from the lower social classes, because driving an auto rickshaw is not considered socially acceptable.

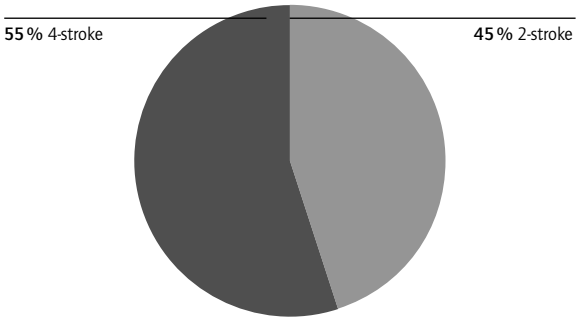
Figure 19: Type of auto drivers in Bangalore City.




Most auto rickshaw drivers rely on agents who perform the necessary administrative procedures (vehicle registration, approval and vehicle inspection).

Auto rickshaws are produced in the country. Even in Bangalore, there are two major production companies (Bajaj and TVS) who produce and sell vehicles with 2- and 4-stroke engines in accordance with ARI standards and EURO III standards.

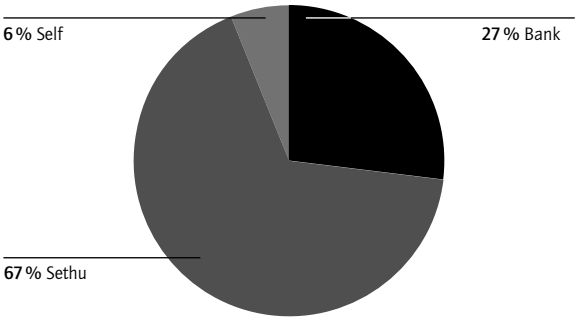
Figure 20: Distribution of types of auto rickshaw.




Financing an auto cab is often a big problem for buyers. Very few are able to buy a cab directly with their own resources. In most cases, third-party financing is involved. After repayment of the loan, the vehicle can be sold and the sale price will be used to buy the next vehicle. In this way, buyers will gradually become the owners of the vehicles.

Vehicles are tested in emissions testing centres for compliance with limits. There are also centres for conversion to LPG. The Department of Legal Metrology is responsible for annual monitoring of taximeters.

Figure 21: Distribution of financing methods.




Stands for auto rickshaws are examined and approved by RTA, Traffic Police and the City Road Safety Committee. BBMP undertakes the maintenance of the stands.

Finally, the users are spread across all social classes, age groups, income groups and gender. However, the focus of the user is in medium-high income groups who use the auto rickshaws for their professional journeys. The system is particularly used by people who do not have access to their own vehicles (no driver's license, health reasons). These people (e.g. women, children, seniors and disabled persons) also form a significant portion of auto rickshaw users.

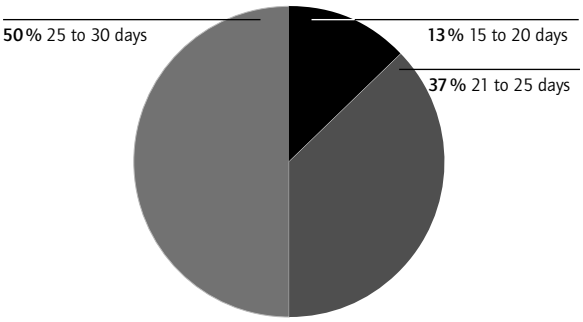
## 6.5 OPERATIONAL CHARACTERISTICS AND ASSOCIATED ECONOMICS

The tariffs for the use of auto rickshaws are currently set at 11 Rs./km. On the basis of a model calculation, the daily net income of 90 paid kilometres and 120 kilometres total, depending on vehicle type and position of the driver (employee or owner), lies between approximately 400 and Rs. 600. But this contradicts the testimony of the drivers in the interviews, where more than half reported a net income of Rs. 250-300.

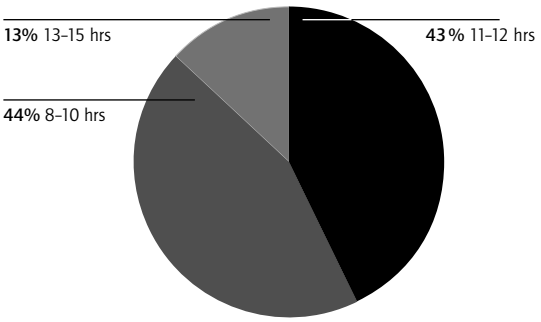
Drivers work an average of 26 days per month and 10 hours per day. On average, a driver spends 2 to 3 hours per day waiting for passengers. Accordingly, he spends 7 to 8 hours per day with passengers. At 90 kilometres per day and an average of 7.5 paid hours driving time per day, the average journey speed for paid kilometre is 12 km/h. The number of empty kilometres is on average 30 km per day.

Figure 22: Main results of quantitative interviews.

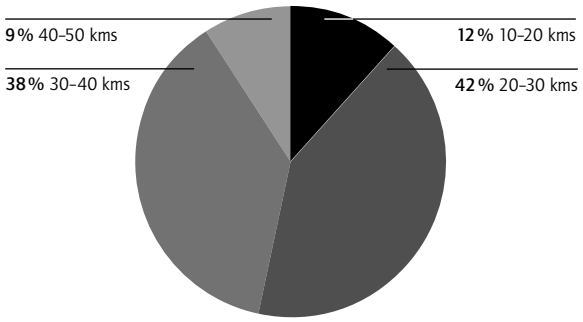
**Working days / month**



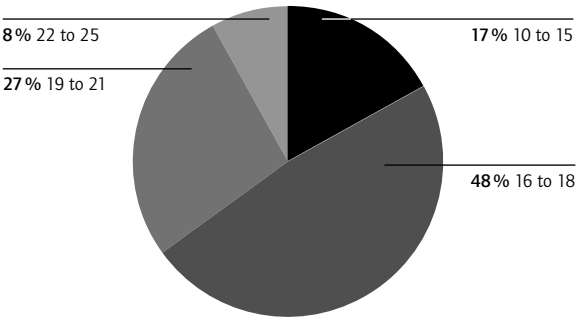

**Working hours / day**



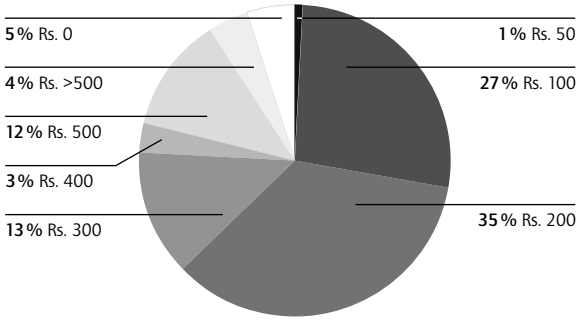

**Empty kms / day**



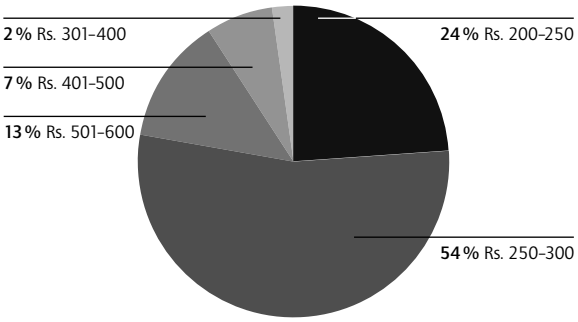

**Mileage (kms / liter)**




**Fine / bribe per month**




**Saving per day**




**Renter Drivers Save – Rs 300-400/day; 7,500-8000/ month**

**Owners Drivers Save – Rs 500-600/day; 11,500-12,000/ month**

Table 15: Recommendations.

A STUDY OF THE AUTO RICKSHAW SYSTEM IN BANGALORE CITY

- Regulations – Permit System, DL-Badge, Renewals, FC, etc. ...
- Monitoring Systems – Computerised, Interlinked Databases (components) &
- Use of Technology ...
- Training/Awareness (auto owners/drivers & public) – Materials for Programmes, Booklets/Brochures, etc ...
- Financing – Innovative Financing Mechanisms for Autos ...
- Other Social/Financial Welfare & Benefit Schemes ...
- Meter Fares/Autos Stands ...
- Feeder/Last Mile Options ...

**CHAPTER 12: Analysis, Important Issues and Recommendations**

- GOVERNMENT AGENCIES (State Govt; Transportation Dept; RTA/RTOs, Traffic Police);
- AUTO DRIVERS/ UNIONS
- SOCIAL ORGs/ ENTREPRENUERS

**Project By:** Radha Chanchani & Fagun Rajkotia ; **Advised By:** Prof. Anantharamaiah & Prof. Ramanayya

## 6.6 RESULTS SUMMARY

The results of the surveys show a range of important information concerning the question of the inclusion of the auto rickshaw system into a dynamic information system for urban traffic. Of great importance will be the existence or not of a dynamic information system that generates additional passengers, reduces idle times and creates an economic advantage. This information system could provide an incentive for auto rickshaw drivers to act as an integrated part of the urban transportation system, which also includes the role of data supplier.

The fitting of an information and communication facility is important. Up to this point, this is not standard in the vehicles.

A second hurdle concerns the fact that drivers and owners are individual competitors. It will be difficult to bring them into an organisational structure, since they avoid state control wherever possible.

In any case, the large pool of vehicles and the fact that the vehicles are most often on the move during work are advantageous. They could prove a fruitful source of information for the current traffic situation, in addition to private data collected from smartphone users.

# 7 INTEGRATION OF THE STUDIES, SUMMARY AND CONCLUSION

## 7.1 JOINT ANALYSIS OF OUTCOMES

The study deals with solutions to solve or reduce the obvious mobility problems in megacities of developing and emerging countries. It covers the areas of "personal mobility" and "mobility of goods and commodities." The hypothesis is that dynamic traffic information systems for passenger and commercial traffic will open up new opportunities to reduce mobility problems in these large cities. With a reliable dynamic traffic information system, existing capacities may be used better. The information system would also enable new services such as integration between public transport systems and individual traffic means (paratransit like taxi, auto rickshaws, rental systems like car sharing and ubiquitously available cycling rental systems) which generate significant benefits for users, operators and society.

This basic hypothesis of the benefits of a reliable dynamic traffic information system is not proven in the present study. A proof would require operational testing and optimisation of such systems in the real world. In this study, however, the tasks of a dynamic traffic information system and the resulting demands on such a system have been developed in a systematic way. The practical example on which the considerations have been based is the megacity of Bangalore. This development can therefore be seen as a first step toward a practical application of ICT-based solutions to mobility problems in this megacity.

Systems for dynamic information about the traffic situation in the networks of road and public transport require extensive static data, dynamic data and models. Some of this data is available and accessible in Bangalore. However, dynamic data needs to mostly be generated fresh. Here, new approaches are available. Private smartphones are increasingly beginning to play a dynamic role in cost-effective data collection. A dynamic information system also requires appropriate models and algorithms that will help to fill the time-space grid of dynamic information.

In the context of a megacity in an emerging country, it will therefore be a matter of developing new mobility solutions in combination with more cost-effective sensing devices and improved information and control strategies. The present study discusses the ability to generate smartphone applications for acquiring the position data of public transportation vehicles and data on road traffic conditions.

A particular challenge is the issue of "integration of transportation methods". This topic has been discussed intensively in the past, but so far there is a lack of realised examples. Experiences with integrated systems are virtually non-existent. The method of integrating rapid public transportation methods (Metro) with individual services (taxis, auto rickshaws, car sharing) and bike rental systems in a mega city needs to be re-thought. The maxim is that the new service must achieve a quality that is at least equal to or better than the commonly used alternatives.

The present study also considers freight mobility. In this field, the knowledge of logistics structures, the volume of goods and supply relationships is significantly restricted. Therefore, research and analysis focused on improving the knowledge and use of this knowledge for new strategies.

The research showed that, in Bangalore, the required static data base of the transportation services is available. For the road network, open source products may be used, processed and attributed. Nevertheless, dynamic information on the road must first be generated. Information on traffic flows and their temporal variance is not available. A transportation model should be developed.

In the area of public transportation, which in Bangalore is composed of suburban trains, the metro network (partly under construction) and the bus networks including the urban and regional bus operators, all important static information about the systems is available. Stops and train stations are geographically coded and schedules are stored in tables. Information about where vehicles are located at any given time can be generated from the scheduled routes and passed on to passengers. But this is only of interest if no delays are encountered. Therefore, the information provided has to be extended to include dynamic data. For the regular passenger it is of real interest to know about fluctuations in arrival times.

In the present study, it is assumed that for the generation of dynamic data, smartphones will be used by passengers on a voluntary basis. Companies that are already active in this market show that this is possible in principle. The forecasts for the development of the smartphone market are also favourable.

Dynamic information systems that incorporate all urban transport methods can also be used for an information network combining "public transportation" with "individual transportation". An integration of transport modes leads to an improvement in the catchment areas for public transport via individual modes of transport, where the latter are used for the last miles at the beginning and at the end of trips. From this, two things are derived: (1) car drivers may

have advantages when using the integrated offering (individual entry and exit, fast public transport in the main run), and (2) public transport operators may benefit from integration due to increased passenger numbers. It is not surprising that a willingness to cooperate in developing the outlined dynamic information system was signalled by the public transport companies.

The study of the auto rickshaw system showed that this system is characterised by a number of features that makes their inclusion in a dynamic urban information system interesting. However, some challenges have to be solved, e.g. the previously simple equipment of vehicles and the lack of organisation. Thus, each owner must be addressed individually. This also makes the inclusion into integrated systems, e.g. for the last miles of trips in combination with the rapid transport, rewarding but difficult.

In the field of commercial traffic, the concept for a dynamic information system has been designed especially for this category of urban mobility. Commercial traffic suffers in particular from the sometimes intolerable traffic flow. Improved information about the current traffic conditions and the identification of possible alternative routes are therefore potential benefits. Therefore, it makes sense to obtain reliable information for commercial traffic on the current traffic situation and then to provide this information to navigation devices.

In summary, the present study shows how a dynamic information system can be designed for urban transport in cities and how it can be used for the integration of public and individual transport. It is assumed that the realisation of such systems is combined with considerable potential benefits which could be increased by such a solution. The actual size of these potential benefits and how they relate to the investment and operational costs can only be derived through applications in the real world.

## 7.2 RECOMMENDATIONS AND CONCLUSIONS

Worldwide, cities are growing, especially in emerging and developing countries. This is due to the influx of population from the rural environment. Natural population growth in the region, however, is often stagnant or declining. Cities offer employment, higher standards of living, better income, education and opportunities for advancement. They are the centres of civilisation. This trend will continue for all forecasts in the coming decades in emerging and developing countries.

However, this rapid growth has brought a plethora of problems. One of the main problems concerns the accessibility of the main destinations in these cities (jobs, education, shopping and recreation). Some cities are already reaching the limits of their development. For many commuters, the time spent on daily travel exceeds 4 or more hours. The transport companies can no longer ensure the proper supply of goods and commodities. The environmental conditions on major roads exceed internationally accepted limits. The increased accumulation of energy consumption for mobility, an increasingly important indicator of sustainable cities, counteracts the savings effort.

Against this background, it is necessary to think about new solutions to the mobility problem. The advances in ICT today allow dynamic information systems with which the existing capacities are better utilised. Also new, integrated services will be realised. Integrated services enlarge the catchment areas of rapid public transport (metro, fast commuter trains). The hypothesis is that more people will benefit from these fast offerings of public transport. Due to the lack of realised applications, genuine experiences of these offers are unfortunately not available.

In general, the benefits will be higher in peak hours than in off peak times. Furthermore, different groups will benefit in different ways from improved information and integrated systems. To explore this, it is necessary to implement those systems in pilot areas. There, they can be subject to further analysis, established on the basis provided by the present study. The implementation of a pilot area in Bangalore would be the next logical step.

The study has shown that such a step can only be successful within an integrated, interdisciplinary cooperation of a wide range of different disciplines. The idea is to define a technical solution in the context of customer claims. The technical solution, however, is not only a question of software and hardware engineers and not only the matter of economic, transportation and social sciences. It is also vital that the public sector is willing to support –or – even better – to participate actively. Ideas about prioritisation of infrastructure or of traffic demand management require the consent of the relevant administrations and, in many cases, from higher political levels. Therefore an integration of local and state governance is indispensable. But the involvement of NGOs will also be necessary and helpful. Without the support of city and state governance, such a project will not succeed. Only a multidisciplinary, policy-supported approach will provide the opportunity to bring solutions to Indian megacities such that they will reduce actual and future mobility problems in a sustainable manner.

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# SMART CITY
# A Study on Technology Innovation for Smart City Initiatives – Opportunities from an Indo-German Perspective

acatech MATERIALIEN

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Project: German Indian Partnership for IT Systems

**Recommeded citation:** K.B. Akhilesh : Smart City: A Study on Technology Innovation for Smart City Initiatives – Opportunities from an Indo-German Perspective, acatech Materialien German Indian Partnership for IT Systems, München/Berlin 2014

**Published by:**
acatech –National Academy of Science and Engineering 2014

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E-mail: info@acatech.de
Internet: www.acatech.de

ISSN: 2191-8481/ISBN: 978-3-942044-37-0

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Coordination: Prof. Dr. Otthein Herzog, Dr. Ulrich Glotzbach
Layout conception: acatech
Conversion und typesetting: work:*at*:book / Martin Eberhardt, Berlin

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# ACKNOWLEDGEMENTS

I am grateful to all those who have helped us put these ideas together and transform them from simple thoughts into model development to finally consolidating the thoughts into a concrete report.

I would like to express my gratitude to acatech, National Academy of Science and Engineering, Germany for giving us the opportunity to conduct this study, titled, "A Study on Technology Innovation for Smart City Initiatives – Opportunities from an Indo-German Perspective" and providing generous funding for the same. I thank Prof. Dr. Otthein Herzog, Executive Board member and project leader for the GRIP IT project at acatech for his full support and cooperation. I would also like to thank Mr. Joseph Mathew, Project Manager, acatech for all his help.

I would like to thank Prof. M.H. Bala Subrahmanya, Chairman, Dept. Of Management Studies, Indian Institute of Science, Bangalore for his extended support. I thank Prof. T.G.Sitharam, Professor, Dept. Of Civil Engineering and Chairman, Centre for infrastructure and Sustainable Transportation & Urban Planning, Indian Institute of Science, Bangalore and Prof. Dr. Jorg Schonharting, CEO, TRC, Transportation Research and Consulting, GmbH for inducing my excitement towards smart cities.

I would like to thank the authorities of the Institute for their support. I thank Mrs. G. Bhanumathi and Mr. Saleem Ahmed, office personnel at the Dept. of Management Studies, for their assistance and timely support.

The Project Assistants, Raksha.A.S and V.Sowmya; and the PhD students, Madhurima Das and Sindhuja.C.V helped me with the paper. I acknowledge their efforts in this study. We have referred to several data sources and image sources in writing the paper. In this world, tied by boundless technology, we have seamlessly covered data across countries and sectors. I thank all the sources concerned. Finally, I extend my regards and best wishes to all those who supported me in every respect to help complete the project.

# 1 CONTEXT

Over the last few decades, India has witnessed unprecedented urban and industrial growth. The economy is in transition, and so is the demographic profile of India, with a steadily growing working population. This has an impact on the psychological, sociological and economic aspects of society. The increasing urban population and with it increasing incomes, has led to increased aspirations and changes in the way of life. This rapid urbanisation has actually come at the expense of economic growth. The demand for basic services has grown, and cities are choking with an increase in vehicle numbers. Cities are growing vertically and the green cover is depleting.

The complexities of urban life also encompass individual stress levels, disputes at the family level, an increase in crime rates in cities and a shortage of resources. The governance in cities and policy making has to consider these changes, which are taking place at a rapid pace. This poses considerable challenges for any economy. While this is a universal issue, it is predominant in India, with its dual facets of an expanding economy and boundless aspirations. While present day cities are both the cause and result of many socio-economic and environmental problems, they are and have always been the repository of knowledge and innovation.

This paper is an attempt to explore issues of smart cities and also to illustrate how pursuing smart city technologies will eventually contribute to increasing innovation and economic prosperity. This process is not the end but the means to sourcing newer opportunities, ensuring newer innovation, optimising collaboration and building a global impact model.

This paper explores this phenomenon through the following sections:
India in Transformation – ISI, Dual Economy and Urbanisation
India – The Innovation Hub and Cauldron of Opportunities
Innovation – Defined and Delineated
Smart Cities
Collaboration – Meaning and Determinants
Open and Inclusive Innovation
Indo-German Collaboration – Strengths and Possibilities
The Vision of Smart Cities through Indo-German Collaboration

# 2 INDIA IN TRANSFORMATION – ISI, DUAL ECONOMY AND URBANISATION

Indian urban cities today are in a phase of transformation. The population is growing, and with it the range of opportunities. There are growing aspirations at one end and changing technology and economy at the other. Various economic reforms guide the industrial and social growth of a country and its cities. To understand the role of innovation in India, it is paramount to understand that the liberalisation policy that opened the economy to greater opportunities is fairly recent. Initially, there was a constant effort to look at developing domestic industry and making the most of indigenous opportunities.

Import substitution industrialization or «Import-substituting Industrialization» (referred to as ISI) is a trade and economic policy that advocates replacing foreign imports with domestic production. This policy gives importance to local production of industrial products. ISI policies were enacted by countries in the global South with the intention of attaining self-sufficiency with regard to product development by creating an internal market.

This leads to an increase in domestic employment opportunities, helps the economy become more resilient to recessions and depressions and also economises and optimises the use of resources. The state then becomes the engine of development and moves along the path toward self-sufficiency.

However, this approach brought some challenges. The industries created in this framework became inefficient and obsolete over time as they lacked the exposure to internationally competitive industries. The local producers faced major disadvantages and there was a misuse of resources.

- It was seen that the goals of higher efficiency, greater productivity and increased competitiveness were not realised. Development of the industries on a social, organisational and technical level was slow. Domestic industry was unable to keep up with the new technical developments and innovations of free world markets.
- The state owned enterprises were over-intrusive and inefficient and led to the emergence of monopolies and oligopolies within the protected market and, over time, became affordable only for the upper classes.
- Bad terms of trade, growing foreign credits and unpaid taxes led to high fiscal deficits and inflationary pressures, making the economy unattractive for foreign investors.

The high rate of protection under the guise of ISI allowed inefficient firms to remain in the industry. ISI, which is an inward approach to trade, thus had many disadvantages. Was the answer to this export-oriented trade? Experts noted that the answer to a progressive economy is not just export-oriented trade, but an attitude of competition and innovation, combined with developed human capital. The 1990s thus saw the gates of the economy open to the world through the liberalisation policy. Since then, India has used its policies and technology to progressively work towards an innovative culture and develop an environment similar to the global economy.

The need for innovation emerged to tackle two unique challenges. India, as a dual economy and in the midst of rapid urbanisation, has the perfect ingredients for an innovation ecosystem. The dualism in the economy is evident across the length and breadth of the country. At one extreme, it is the world's fourth-largest economy in purchasing power parity (PPP) terms. It is also a nuclear and space power, and it is increasingly becoming a top global innovation player in certain key economic sectors–such as biotechnology, pharmaceuticals, automotive components, information technology (IT), software, and IT-enabled services (ITES). At the opposite end, India largely remains a subsistence economy. It is mainly a rural, agrarian economy.

Growth along with innovation is associated with increasing standards of living and a reduction in poverty levels. While some sections of formal and informal sectors have witnessed innovation, it remains limited to a small segment of the economy. A growing workforce has been seen over the decades with increasing numbers in both formal and informal sectors. It is interesting to note that approximately 90 % of the workforce is employed in the informal sector, which is often characterised by activities of low productivity and low skill. Formal enterprises may also face the challenges of low productivity. In the background of this dualism in the economy, what can be done to ensure sustained high growth rates and address the unmet needs of the informal sector and the poor? The role of knowledge and human capital becomes paramount here. By applying new knowledge to the production process, new products can be developed that will in turn meet the needs of all sections of the society.

Innovation involves commitment and efforts from both private and public sectors and collaborations between them, supported by governmental policies. Innovation can be a critical driver, leading to increased productivity and competitiveness and, ultimately, the alleviation of poverty. Innovation in India has to be viewed through a lens that considers this dualism in the economy.

Figure 1: Urban Rural Population in Crores – 1951-2011.

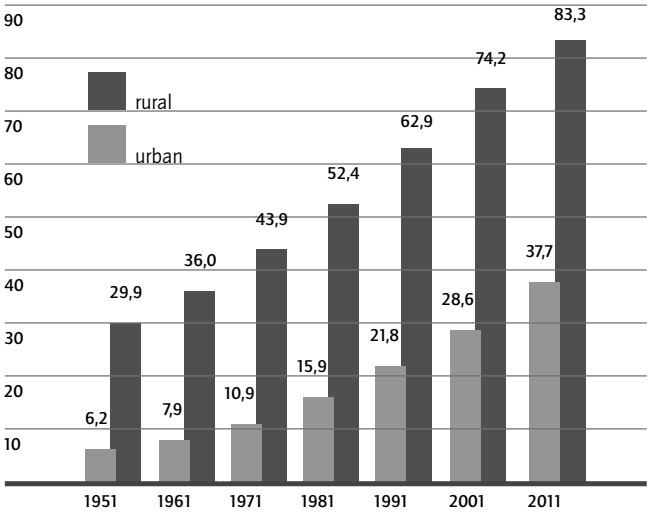
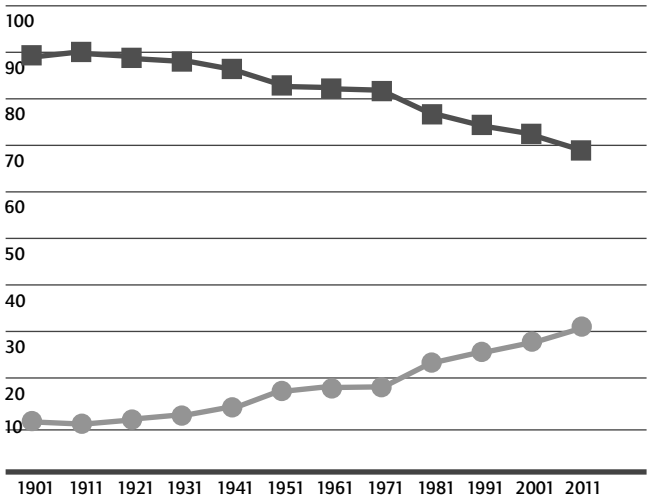



Figure 2: Degree of Urbanisation in India in the last century.




India is at an unprecedented level of urbanisation. It is interesting that only 30 percent of India's population lives in urban areas. This is much lower than in China, Indonesia, South Korea, Mexico, and Brazil. Some of this may be due to much lower per capita incomes in India. It is projected that India's urban population as presently defined will be close to 600 million by 2031, more than double that in 2001. Already the number of metropolitan cities with a population of 1 million and above has increased from 35 in 2001 to 50 in 2011, and this is expected to increase further to 87 by 2031. Existing cities are growing rapidly in all directions, some cities are growing vertically, and many villages now resemble towns. The figures below depict how the urban population has been growing over the years and the increasing degree of urbanisation.

The city of Bangalore, known as the IT hub of the country, is growing faster than ever before. By the end of the year 2012, its head count is likely to cross the one crore (10 million) mark. The city's population currently stands at 9,588,910, according to provisional 2011 census data. Bangalore's population has grown by 46.68 per cent between 2001 and 2011. Current estimates of India's 'urban' population are in excess of 300 million, and likely to reach 600 million by 2030. During the next 20 years, 30 Indians will leave rural India for urban areas every minute. At this rate, India will need some 500 new cities in the next two decades. This brings into sharp focus the need to develop solutions for sustainable cities, consider peripheral expansions and redefine the concept of a metropolitan area. This expansion of cities brings innumerable challenges to the fore. Problems arising from rapid urbanisation impact basic living functionalities like difficulty in waste management, scarcity of resources, air pollution, human health concerns, traffic congestion, and inadequate, deteriorating and aging infrastructure.

Social, organisational, technical, physical and material problems will all arise. Multiple diverse stakeholders come into play, with high levels of interdependence, competing values, and ensuing social and political complexity. Urbanisation has to be converted to an asset rather than being viewed as a crisis.

In that context, making a city smart is the new approach to urban development. This has to be kaleidoscopic in nature, looking at technology, governance, social, political and economic aspects. A smart city in this sense is a prototype of a sustainable and liveable city.

# 3 INDIA – INNOVATION HUB AND CAULDRON OF OPPORTUNITIES

Innovations in the last two centuries have been driven by the needs of the developed world. India has continuing challenges arising across multiple areas like healthcare, education and infrastructure. There are also challenges at the economic and social level that need to be dealt with in a step by step approach. Innovation in such a case is not just a need, but imperative for an economy like this.

India is growing in both the education and the technology sectors; knowledge and human capital has transformed over the years, reaching the level of global competitiveness. We are connected worldwide and this multi-faceted landscape of opportunities, talent, connectivity, networks, openness, technology and collaboration will have a tremendous impact on the nature of business and bring with it unprecedented advantages.

In recent years, India has emerged as a major destination for corporate research and development (R&D), especially for multinational corporations – both large and medium sized. Organisations like the Indian Space Research Organisation (ISRO), Defence Research and Development Organisation (DRDO), and the Centre for Development of Advanced Computing (C-DAC) have with their innovative work set prestigious milestones on a par with international standards. Several collaborations have begun and agreements in the area of science and technology have been signed by the Government of India. Industrial firms in India have recognised their chances and envisioned the future and there is the global mobility of talent, technology and resources. This has mutually benefitted both India and other nations of the world. India today has thus successfully emerged as an innovation hub and a cauldron of opportunities.

# 4 INNOVATION – DEFINED AND DELINEATED

Innovation means renewal or change. It could refer to the development of a new product or to the process followed in making the new product. It happens at an individual, social, business and organisational level. The innovation-decision process was defined by Tarde (1903) as a series of steps that included:

- Gaining some information or knowledge that is new
- Understanding that knowledge and forming an attitude
- Deciding whether to adopt or reject the knowledge
- Discovering how to implement that knowledge and use it
- Confirmation of the decision

Innovation could refer to three different things:

- Novelty – focus is on the object. The uniqueness of certain products, methods or services.
- Change – focus is on the process. The transformation, diffusion and change that takes place.
- Advantage – focus is on a social dimension. Creating new forms of advantage.

The motto is to adopt, adapt, improve and innovate. It is about taking ideas from other environments and adapting them for use in your situation, as one of the best ways of implementing novel solutions.

There are various factors that trigger innovation. They could be social, economic or psychological in nature, triggered by scientific advances and technological developments.

- The rising aspirations and unfulfilled desires of people, and the gaps between needs and the available solutions
- Innovations on grounds of empathy
- The development of skills, knowledge and resources to address the existing problems, with a desire to solve them
- A hunger for change, better utilisation of resources and proper delivery of goods and services in order to sustain the innovation

Innovation is the means to accelerate growth in India and make it more inclusive, ensuring that the vision of environmental sustainability is met. Therefore, innovations are necessary not only in the products developed and the services designed, but also in the manner we approach issues of concern and plan the delivery mechanism. Innovation is a multidimensional concept, and its importance and scope must be viewed in their entirety.

There are various aspects that act as drivers or barriers to innovation.

Innovation Drivers: Drivers could be at the individual, team or enterprise level, depending on processes and scope.

- The Individual – Individuals are the building blocks of an organisation. Individuals are the basic components of teams, groups, divisions and the organisation as a whole. It is essential to strengthen this primary building block to start the process of innovation on firm grounds.
- The Team – Innovation requires skills at multiple levels: invention, development, funding, marketing, patenting, operations, etc. It therefore requires multiple people. It is thus essential for an organisation to develop a strong team that is collaborative in nature and believes in effective communication. Team dynamics are crucial to ensuring a successful innovation process; understanding of the common goal and a strong creative spirit is paramount.
- The Enterprise – While strong and well-formed teams can lead to successful innovations, it is essential to raise the benchmarks, adapt to change and adopt newer methodologies. It becomes important to create and sustain procedures, not just at the team level but at the enterprise level. The policies, metrics and recognition process must all be planned to ensure a smooth innovation journey.

It is thus seen that individuals, teams and enterprise all play a pivotal role in innovation. There has to be interplay between all three to ensure the next two drivers.

- Processes – It is essential to improve the processes that drive innovation at the individual, team and enterprise levels. At the individual level, it is important to have processes to enhance self-awareness, emotional intelligence and cognitive ability. At the team level, the teams could use structured brainstorming or ideation or creative processes to help create innovative solutions. At the enterprise level, the organisational system that is made for creative collaboration becomes important.
- v Expanding scope – The scope of innovation is broad. To see it only as a product is a blinkered view. We have to consider services, business models, alliances, processes, channels etc. We need to have a holistic view of innovation. It is about using change to be able to better meet human needs.

Innovation is driven by high end technology and the research and development carried out by organisations. New approaches and new strategies are synonymous with the process of innovation and important to increase its scale. In this context, the transfer of technology becomes important. Optimal utilisation of resources is required at both the economic and environmental level with sustainability as a vision.

Innovation Barriers: Barriers can be both external and internal.

- External – The most important external barrier to innovation is skill shortage. This happens due to the lack of emphasis on industrial innovation, problem-solving, design, experimentation, etc. It is important to continually build skill sets and be on a par with global standards. Other prominent external barriers include a lack of effective collaboration between research and industry and also between research in universities and R&D institutions. There is also the barrier of excessive governmental regulation and the role of power pricing that impedes the process of innovation from thought to reality.
- Internal – The most important internal barrier as experienced by large firms is the lack of organisational focus on innovation as a strategy for growth and competitiveness. It is essential that organisations take a proactive approach to innovation. Also, inefficient knowledge management systems within the organisations and poor understanding of customer needs and market dynamics cause major problems. For small and medium scale enterprises, prominent internal barriers are skill shortages due to lack of effective in-house training programs. These enterprises also need to work towards understanding how to develop a sustainable model and understanding changing economic dynamics.

Smart cities have their foundation in 'novelty' at every level. It is important to understand their complexity at a technological, social, economic, educational, infrastructural, governance and human level. This is essential for innovation to have far reaching effects.

# 5 SMART CITIES

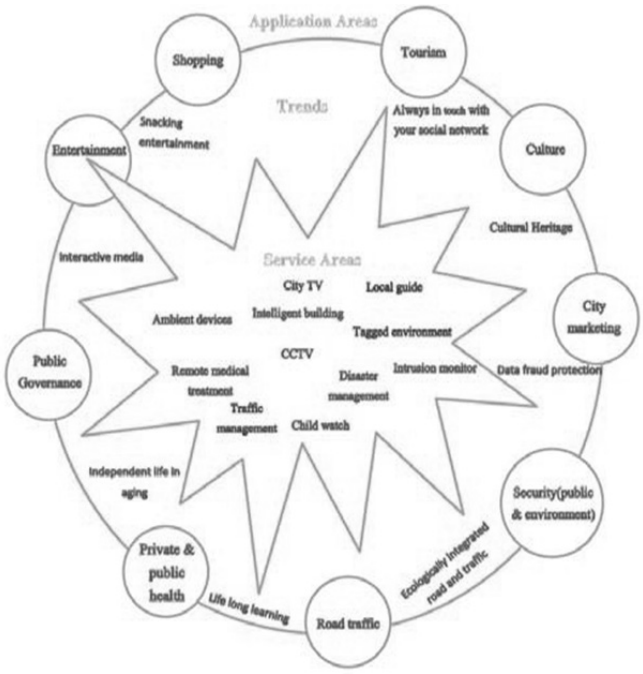
The concept of a 'smart' city emerged as a strategy to mitigate the problems generated by urban population growth and rapid urbanisation. These cities have a futuristic vision. The focus is on safety, and it is environmentally green and efficient. All structures and the use of power, water and transportation are designed, constructed, and maintained by making the use of advanced technologies: integrated materials, sensors, electronics and networks.

All these are interfaced with computerised systems comprised of databases, tracking, and decision-making algorithms. The research and engineering challenges in the realisation of this vision is an amalgamation of various technical fields, including physics, chemistry, biology, mathematics, computing science, systems, mechanical, electronics and civil engineering.

This takes place at several levels, as shown in the figure below.

- "The simplest level is the basic component along with its associated "feedback" or self-monitoring mechanism(s). Each of these must be identified or, if already existing, tailored for the appropriate application."
- "The next level is the design of the system making use of these components. Associated with this would be the interface to the computerized "monitoring" capability for each given function."
- "Next, is the full structure or service supplied, and lastly, the integration of information across all related and seemingly unrelated aspects of an urban centre's essential infrastructure."

Figure 3: The Holistic Mega City Vision.




A city that monitors and integrates conditions of all of its critical infrastructure, including roads, bridges, tunnels, rail/subways, airports, seaports, communications, water, power, even major buildings, can better optimise these resources, plan its preventive maintenance activities and monitor security aspects while maximising services to its citizens. The emergency response management to both natural and man-made challenges to the system must be focused and rapid. With advanced monitoring systems and built-in smart sensors, data can be collected and evaluated in real-time, enhancing the city management's decision-making. For example, resources can be committed prior to a water leak issue and use of technicians reduced by knowing the condition of all the structures.

In the long-term, smart cities' vision, systems and structures will monitor their own conditions and carry out self-repair as necessary. The physical environment, air, water, and surrounding green spaces will be monitored in non-obtrusive ways for optimal quality, thus creating an enhanced living and working environment that is clean, efficient, and secure and that offers these advantages within the framework, with the most effective usage of all resources.

The meaning of smartness in the urban or metropolitan context indicates utilising cutting-edge information and communication technologies (ICTs), and also importantly an invested governance. Investment in ICT infrastructure is one way of stimulating growth in national innovation and economic productivity and this is evident worldwide. At the firm level, it has been seen that the use of ICT can result in good productivity and profitability.

India has a core strength in ICT, and this sector has grown quickly over the past 20 years. However, to fully support the development of an innovation economy, it is essential that this growth must continue and reach all segments of the economy. To achieve this end, it is essential that the government must address a number of policy and regulatory issues to ensure the sector's continued growth and its extension into underserved areas. The availability and quality of ICT infrastructure accessible by research institutes will be increasingly important in fostering innovation. Collaboration between universities and research institutes – both within and outside India – requires investment in high-speed communication networks.

Furthermore, the adoption of technology is a means not an end. Of greater importance is the smart use of technology adopted and the resulting innovations. A smart city is one with a comprehensive commitment to innovation in technology and governance. Innovation for a smart city entails available opportunities and perceived risks simultaneously. It is about finding inclusivity in diversified society parameters. In the existing literature on smart cities, the focus is predominantly on technological aspects. The literature views a smart city as a manifestation of innovative ideas, with little consideration for the policy and managerial side of innovation. When we look at literature from various fields such as e-government, information science, urban studies, and public administration, it can be seen that researchers have identified and discussed challenges, success factors, and impacts of government-driven initiatives that make a city smart.

A smart city should encompass smart economy, smart governance, smart mobility, smart environment, smart people, and smart living.

**Characteristics of Smart Cities:**

Smart Economy (Competitiveness)

- Innovative spirit
- Entrepreneurship
- Economic image and trademarks
- Productivity
- Flexibility of labour market
- International embeddedness
- Ability to transform

Smart Living (Quality of Life)

- Cultural facilities
- Health conditions
- Individual safety
- Housing quality
- Education facilities
- Tourism potential
- Social cohesion

Smart People (Social and Human capital)

- Level of qualification
- Affinity to lifelong learning
- Social and ethnic plurality
- Flexibility
- Creativity
- Cosmopolitanism / Open mindedness
- Participation in public life

Smart Environment (natural resources)

- Attractiveness of natural conditions
- Pollution
- Environmental protection
- Sustainable resource management

Smart Mobility (Transport and ICT)

- Local accessibility
- (Inter-)national Accessibility
- Availability of ICT infrastructure
- Sustainable, innovative and safe transport system

Smart Governance (Participation)

- Participation in decision-making
- Public & Social services
- Transparent governance
- Political strategies & perspectives

**Smart Economy** includes all factors of economic competitiveness such as innovation, entrepreneurship, trademarks, productivity and flexibility of the labour market as well as the integration in the (inter-)national market. The IBM Institute for Business Values, in a series of studies, identified business as one of the core systems of smarter cities, which comprised the city services system, citizen system, business system, transport system, communication system, water system and energy system. The capacities for smart business systems include ICT use by firms, new smart business processes and smart technology sectors. The smart city initiatives are designed to develop information technology capacities and also establish an agenda for change by ensuring industry actions and business development. Thus, creating an environment for industrial and economic development is a primary quality of a smart city. The economic outcomes of the smart city initiatives are numerous. They include creation of both business and job opportunities, the development of the workforce and ensuring improvements in productivity.

**Smart People** not only describes people's level of qualification or education but also by the quality of social interactions, focusing on integration and public life, along with openness towards the outerside world. The qualities of flexibility and creativity also define people's behaviour in a smart city. Considering people and communities as part of smart cities is critical to their development. Traditionally, the focus has always been on technological and policy aspects of smart cities; people and communities were neglected. Smart cities projects have an impact on people's quality of life and aim to ensure that people are better informed, educated and par-

ticipatory in nature. Also, these initiatives allow the members of the city to be more proactive, participate in the governance and management of the city and become active users. The city is not just a reflection of its individuals, but its communities and groups and their respective wants and needs. Thus, a smart city needs to be sensitive in balancing the needs of its various communities and this will ensure success across all segments.

**Smart Governance** comprises aspects of political participation, services for citizens as well as administrative functions. Democratic and transparent governance is also an essential quality. The smart city initiative has multiple stakeholders. This makes the role of governance even more critical. In general, (public) governance has been defined as "regimes of laws, administrative rules, judicial rulings, and practices that constrain, prescribe, and enable government activity, where such activity is broadly defined as the production and delivery of publicly supported goods and services." Managing the stakeholders involves four primary functions: the ability to cooperate among stakeholders, ensuring leadership support, working and maintaining alliances and working under various jurisdictions. The emergence of ICTs has benefitted several cities and has helped improve their governance. This ICT-based governance is known as smart governance. It represents a collection of technologies, people, policies, practices, resources, social norms and information that interact with each other to support the governing activities in the city. Smart governance and leadership is in itself a challenge for initiating a smart city. The participation of people and the manner in which public/private partnership is managed is critical to smart governance. The governance should be accountable, responsive in nature and transparent in its dealings. This helps further collaboration, data exchange, service integration and communication among all components of the smart city.

**Smart Mobility** includes local and international accessibility along with the availability of information and communication technologies and modern and sustainable transport systems. Smart Mobility meets the transportation needs of both people and freight, in turn enhancing the city's economic, environmental and human resources. The Smart Mobility future is possible by applying the following principles:

- Land use planning and transportation planning activities are essential
- Transportation programming at all levels of government
- Evaluation and screening the tools for projects, ensuring detailed planning
- Review of the local development; stringent evaluation of coordination and collaboration activities
- Ensuring and promoting public-private partnerships for investments in infrastructure and land development projects
- The engagement of the community is essential to see the impact of smart mobility, keeping in mind local values, priorities, and conditions

**Smart Environment** entails a description of attractive natural conditions (climate, green space etc.), pollution management, resource management and also efforts made towards environmental protection. At the core of a smart city is the use of technology to better manage natural resources and also increase sustainability. The protection of natural resources is paramount, along with a review of waterways, sewers and green spaces such as parks. All these initiatives ensure sustainability and increase the liveability quotient of a city.

**Smart Living** comprises various aspects of quality of life such as culture, health, safety, housing, tourism, etc. Smart cities encompass urban environments that are liveable, attractive and adaptable. The level of development in a country and future priorities will determine the specific elements of living, but will essentially include all aspects of social, cultural, individual safety, health, and education facilities.

While smart cities are a vision across the globe, they are possible only in a collaborative environment that promotes open and inclusive innovation. Innovation is the cornerstone of a smart city.

# 6 COLLABORATION – MEANING AND DETERMINANTS

Achieving the high-tech, sustainable and smart cities of the future is only possible through partnerships. It is essential to develop a collaborative ecosystem. Collaboration is working together to achieve a common goal. It is a recursive process in which two or more people or organisations work together to realise shared goals. In the case of a smart city, different components have to work together to achieve the goal of developing a smart city.

Collaboration has also been shown to have positive innovation outcomes. There are three components to collaboration. The first is two groups working together: two individuals, two teams, two communities or even two countries. Second, there is the element of transfer and learning. Each can transfer a component of knowledge and receive some in return. Finally, it is important to understand the respective strengths of each party and adopt that knowledge; for example, technology from one country and the social system of another are perfect ingredients for collaboration.

There are some factors that determine a good collaboration:

- The perception of strengths by each of the parties involved
- The importance of setting and understanding the macro picture, delineating the super-ordinate goals and maintaining a holistic view through the entire collaborative process
- The importance of trust – the perception of support is crucial and the belief that neither of the parties will exploit the resources of the other
- Trials and collaboration over a period of time, so that trust is built in a phased manner
- The maintenance of transparent communication at all different levels

Collaboration between two countries or governments is also affected by various drivers. There are three kinds of collaboration driver: external, internal and volition drivers.

- External drivers include the pressures of globalisation, extensive international connectedness and travel, a thorough knowledge of other cultures, information technology (IT) and technological sophistication. Economic pressures also play a crucial role: the push to develop the world markets, enhance global trade and international investment patterns, as well as the development of business aggregations and demand for uniform regulation, competitive neutrality and specialisation. Global environmental, physical and resource pressures have ensured that governments engage in international dialogue and action to manage these problems. Community demands, education, changing demographics and diverse social structures have also changed expectations and understanding.
- Internal drivers refer to the preconditions within the government that include the political demands for public officials to be 'responsive' to the needs of the community. The role of policy is also paramount in terms of reach, accessibility and making outcomes more effective. This can include responsive resource systems, flexible budgetary frameworks and managerial focus on outcomes and performance results.
- Volition drivers refer to the act of developing political strategies for shared goals. They are also about understanding problems across the community, building consensus among players and creating coalitions of support for particular actions. Part of the impetus behind volition is the desire for a new activism in government, to develop new policy agendas, take on wider responsibilities and remake policy frameworks to suit the changing times. This is in line with the governance that is required for a smart city.

Thus, we see that collaboration is essential for the functioning of a smart city and it is collaboration that also leads the way for innovation. For a smart city, it is essential that this innovation is open and inclusive in nature. When there is phenomenal opportunity for collaboration between two countries, and all the necessary and sufficient conditions are present, it will lead to innovation.

# 7 OPEN AND INCLUSIVE INNOVATION

Economies and countries may have free movement of money and technology, but in many cases they lack free movement of people. It is therefore essential to transfer skills and knowledge along with technology and innovation. This is possible with collaboration. Collaboration has an impact on the quality of innovation and gives it a global quality.

"Open Innovation is a paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms look to advance their technology" or "Innovating with partners by sharing risk and sharing reward" as defined by Henry Chesbrough in 2003. He further contends that, "every organization and business unit can benefit from looking both inside and outside for innovative ideas and for assistance in developing and commercialising them to maximise returns from new product development". Thus, open innovation is the phenomenon where innovation moves across spatial and temporal boundaries. It is not restricted to a single R&D unit of an organisation. The new products and services could be developed across R&D networks, which may exist within a single organisation or across organisations. This works in partnership with external engineers, scientists and managers, varied customers, suppliers, governments, universities and other research organisations. This requires the ability to manage across a vast network of innovation activities. Severe talent shortage plagues R&D work in many organisations, thereby affecting innovation. Therefore, it becomes essential to tap other available talent pools, and there is a global competition for garnering scientific, engineering and technology talent. This ensures sustained innovation and sustained financial performance. 91% of the world's 1,000 largest R&D spenders conduct innovation activities outside the countries in which they are headquartered. Innovative ideas are not bound by geographical lines, it is a global phenomenon. Organisations like Procter & Gamble, Unilever, General Motors, Hewlett-Packard, Kraft, Philips and L'Oreal have all successfully implemented open-innovation approaches. India offers the best combination of cost and quality to the global market, and countries in the Asia-Pacific region are also moving in this direction. This will benefit the innovation world.

Open innovation is increasingly a key characteristic of the global innovation network today. It remains a fact that many executives struggle to effectively manage their open innovation initiatives. One of the challenges that management faces in dealing with open innovation is the high demands on management attention, considering all the importance to be given to collaborators' involved with different activities of R&D. The other challenge is generating ideas and mobilising the necessary people and resources to bring these ideas to maturity and exploit the commercial opportunities. It is thus essential to create a culture where such processes are promoted.

Various approaches have been suggested to dealing with the challenges of managing open innovation:

Ensure senior management support: To ensure that open innovation is successfully adopted across the organisation, the support of a senior-level executive who presides over an innovation office is critical. The responsibilities would be at two levels: to seek ideas and opportunities and to establish teams. There would be two kinds of teams, some responsible for managing relationships with external partners and others belonging to different business units that are in charge of developing cross-functional open-innovation processes.

Work beyond 'not-invented here' syndrome: Organisations that make open innovation work have to create a culture that encourages true collaboration among business units and functions and work beyond 'not-invented-here' syndrome. They have to focus on what consumers need and at the same time embrace externally generated ideas.

Processes and tools to be provided: Discipline and frequent communication make open innovation possible. It is essential to move away from ad hoc processes and clearly define the practices, systems and roles for open innovation. It is important to track new ideas, retain the best ones and ensure that the development phase is managed well.

Measurement and reward policy: Organisations have to capture new ideas efficiently to innovate effectively. This is essential to developing a mutually beneficial partnership, the golden rule of collaboration. Organisations need to develop and track key innovation metrics to incentivise innovation efforts.

Open innovation is the goal for organisations, economies and countries. India, which has a dual economy and diversity in every sphere, will be the world's inclusive innovation hub – a place where people can access affordable products and services, actively participate in every activity in their communities and build a better life for themselves and their families.

# 8 INDO-GERMAN COLLABORATION– STRENGTHS AND POSSIBILITIES

This paper highlights the scope of Indo-German collaboration, based on a critical analysis of strengths and possibilities, and realises innovation based on the ideas and proven concepts and action. One should strongly expect that these kinds of collaboration will promote and drive further innovation to meet existing needs and also break new ground. Indo-German collaboration will work as a driver of greater innovation. The development of smart cities through this collaboration will be the catalyst for increased innovation. India is a land of opportunities and Germany a land of ideas. From that perspective, this collaboration has opportunities for both countries to optimise their resources, utilise the rich talent available, share and transfer knowledge, work with the finest technologies and develop products that will have a global presence.

There are huge emerging economies that are focusing on innovation in terms of both upgrading an existing product and introducing a new one. The figure below provides a snapshot of these countries. This also shows that Germany has the opportunity to collaborate with several countries. In that competitive scenario, it is essential to see the positives that India provides. The innovation data in the figure below shows that about 40 percent of Indian firms had developed a major new product, while about 60 percent have upgraded an existing product line. This data suggests that Indian firms have more innovation outputs than firms in China, but less than those in Brazil, Korea and Russia. It has been seen that, post 2005-06, India has focused on increasing its innovation output. The fact remains that innovation is not an end in itself but a means to productivity growth and higher living standards.

Figure 5: Innovation output across various countries (2003-2006).

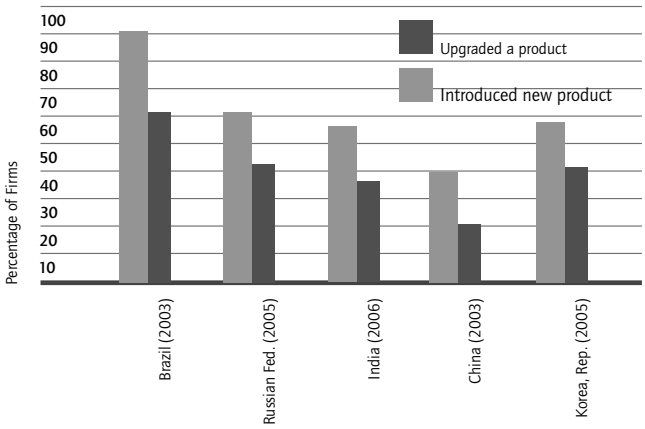



Figure 6: Patents granted in Germany, 2005 to 2009.

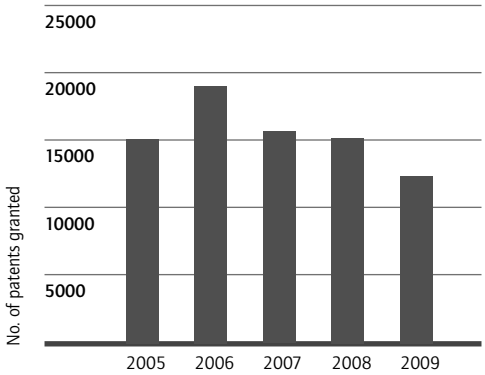
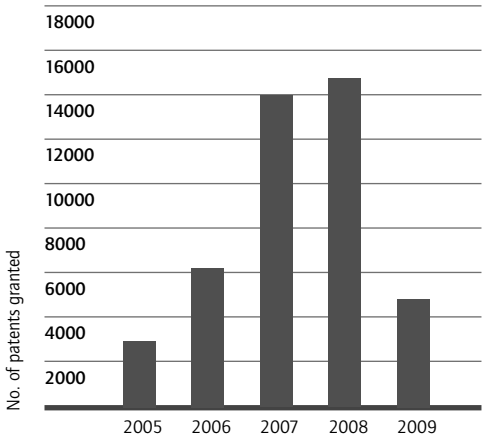


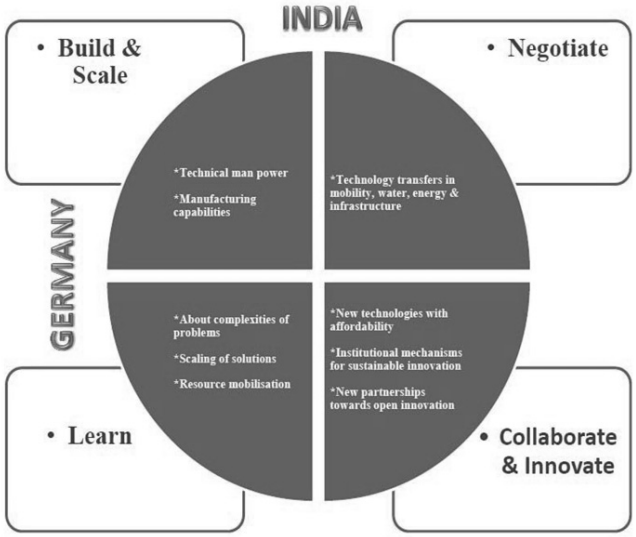

Figure 7: Patents granted in India, 2005 to 2009.




Figures 6 and 7 above show the patents granted between 2005 and 2009. It shows the steady increase in patents for both India and Germany. While Germany is well ahead in total number of patents granted, we do see an incremental increase with regard to India.

To further understand how the Indo-German collaboration can work, we need to identify the strengths and possibilities. These have been presented in the figure below. From the figure, we see that India brings with it the strength of scale and negotiation and Germany gains from the scale and learns. India can provide the technical manpower and manufacturing capabilities. It needs to negotiate for technology transfer in mobility, water, energy and infrastructure. Germany brings with it the solutions to complex problems: the scaling of solutions and resource mobilisation.

Figure 8: Indo-German Collaboration © Prof. K.B. Akhilesh.




The opportunity to collaborate and innovate will ensure:

- New technologies with affordability
- Institutional mechanisms for sustainable innovation
- New partnerships towards open innovation

The different types of collaboration that are possible, particularly in the Indian scenario, are:

- The Industry – Academia relationship, like a Producer-Consumer Interaction: It is essential that academia and industry collaborate and share information. This will help develop a feedback loop, such that industry continually provides feedback to academic institutions regarding their perception or evaluation of their products.
- Research (R&D) Collaboration: Research is the activity of creating new knowledge and innovation is driven by this collaborative knowledge. With academia focusing on research, industry today also has to play an active role in understanding the research that is taking place and work towards it.
- Continuing Education and Collaboration Opportunities: Academic institutions have the resources to provide training for high-end manpower and talent development. These areas are of mutual interest to academia and industry.

There are various areas of Indo-German Collaboration like renewable energy, media and entertainment, hardware and electronics, tourism and automotive industry. The following table presents the strengths of each country in the areas concerned and the possibilities for collaboration.

Table 1: Renewable Energy.

| Areas of Collaboration | Collaborative Scenario & Strengths | | Possibilities |
|---|---|---|---|
| | India | Germany | |
| Renewable Energy:<br><br>Countries worldwide are looking at developing renewable energy and conserving resources. | The existing per capita commercial primary energy consumption in India is about 590 kgoe / year, which is well below that of other developed countries. India has the largest government initiated programs in renewable energy in the world. The Ministry of New and Renewable Energy is planning new incentive schemes to attract private investment of at least 10.9 billion Euros. | In 2008, Germany was the world's sixth largest consumer of energy, and 60% of its primary energy was imported. Government policy promotes energy conservation and renewable energy (oil, coal, lignite, natural gas, hydro- electric and wind power). The government aims to meet the country's electricity demands using only renewable sources by 2050. | An opportunity for India to adopt the German model for the development of renewable energy. The German model ensures the availability of green energy in the market on the distribution network; from a utilities perspective, it reaches from the market to consumers. India cannot fuel its complete future power requirements through fossil fuels (due to limited availability), and so has to look to renewable power. Thus, German technological knowledge and Indian energy requirements can find a joint path. |

Table 2: Tourism.

| Areas of Collaboration | Collaborative Scenario & Strengths | | Possibilities |
|---|---|---|---|
| | India | Germany | |
| Tourism:<br><br>A high priority sector consisting of transport, accommodation, catering, recreation and other ancillary services for tourists. A major employment generator across countries, tourism has seen an annual growth rate of over 5% in the last few decades. | The expected tourism annual growth rate is 9.4% and its contribution in India is 8.78% to total employment and 6.23% to national GDP.<br><br>The number of tourists has tripled in the last decade, increasing from 5.44 million in 2001 to 17.85 million in 2010. Tourism is finding favour with the changing demographics, increasing income and the liberalisation of the aviation sector. It is a growing market. Major tourists come from the USA and UK | One of the leading nations in Europe for hotels and motels. It has a 16.4% share of the regional industry's value. It sees an annual growth rate of 6%. | Opportunities in India:<br>A growing hospitality industry. Increasing investment in the family entertainment and amusement sectors. A few states in India also offer incentives for the development of amusement parks, through relief from entertainment tax and income tax. Increasing number of corporate travel agencies and online travel portals.<br><br>Opportunities in Germany:<br>Indian Spa and Ayurveda centres can set up business in Germany. Indians travel to Germany and other European countries for travel and educational opportunities. |

Table 3: Media.

| Areas of Collaboration | Collaborative Scenario & Strengths | | Possibilities |
|---|---|---|---|
| | India | Germany | |
| Media Entertainment:<br><br>One of the growing sectors worldwide. | Media and entertainment is one of the fastest growing sectors in India. The size of the sector was pegged at about 12 billion Euros in 2010 and is expected to grow at a CAGR of 14% in 4 years (PWC). Animation, gaming and VFX will have one of the highest growths at about 21%. The movie industry is also one of the fastest growing, with many technicians from Europe working in recent movies. | German media industry size: 45 billion in 2009, and it is expected to grow four times to over 70 billion by 2013. | India is Asia's leading cable market and digitisation of broadcasting is on the rise. IPTV has reached almost 45.4 million subscribers with an annual increase of 34.6%. Online / Mobile Gaming is an industry with high revenue and market potential. Animation is a big industry globally. Many countries outsource visual communication products to India. Germany is also a leader in this sector in Europe.<br>India is the destination for high quality and resourceful post production activities. Theatre / Multiplex Infrastructure is significantly growing, with many corporate players entering the field. Given the enduring relationship between India and Germany and the opportunities in India, there is a huge scope for co-operation in the M&E sector. |

Table 4: Automotive industry:.

| Areas of Collaboration | Collaborative Scenario & Strengths | | Possibilities |
|---|---|---|---|
| | India | Germany | |
| Automotive industry:<br><br>This industry is growing worldwide, demanding greater R&D efforts and high technological advancement and efficient utilisation of resources, promoting sustainability. Also, the importance of ecology is being dwelled upon globally. | Emerging areas of imports include solutions for mobility, power-train systems, energy efficiency of car systems, hybridisation of cars and electric vehicles.<br><br>The Tata Nano is a classic example of Indo-German collaboration with Bosch being the brain behind several innovations in the Indian car that changed the way the working class viewed an affordable mode of travel. | The German auto industry was estimated at 316 billion Euros in 2010 and 5.5 million cars were built.<br>The German auto industry views infotronics, IT and intelligent mobility solutions as emerging opportunities for Indo-German collaboration.<br>At present, automotive machine components account for only 3.5% of Germany's total imports of 6 billion Euros from India. | Indian companies in Germany:<br>The biggest Indian player in Germany's automotive sector is Bharat Forge with a manufacturing base in the country; it also plans to expand its footprint in Germany. IT leader Tata Consultancy Services also has a huge presence in Germany and works with several auto leaders. There are 280 Indian companies in Germany, across various industries. Indian investment in Germany in 2010 was 290 million Euros.<br>German companies in India:<br>There are 360 German companies in India, including auto leaders such as Volkswagen and Mercedes Benz and Bosch. Information Communication Technology is India's strength and there is an opportunity to collaborate in this. |

Table 5: Hardware and Electronics.

| Areas of Collaboration | Collaborative Scenario & Strengths | | Possibilities |
|---|---|---|---|
| | India | Germany | |
| Hardware and Electronics :<br><br>Electronics and semiconductor industries have a growing market and scale for opportunities globally. | The Indian domestic market has huge potential and low production costs. It also presents a highly talented workforce, especially for design and engineering services. So, it is an attractive location for electronics manufacturing service providers and semiconductor manufacturing. The electronics industry in India, reported at 1.75 Trillion USD and on record, is the largest and fastest growing manufacturing industry in the world. It is expected to reach 2.4 Trillion USD by 2020. Domestic demand is also expected to increase due to increasing income levels, greater purchase of electronics products, automation demands of corporate sector and the focus of the government on e-governance. While the market is increasing, in two decades demand will surpass the supply, with the government having to look to imports. The Indian electronics hardware production constitutes only around 1.31% of the global production, and the country's imports are expected to rise. | Germany is Europe's largest electronics producing nation and has diversified products. They contribute sizably to the world market. Control and instrumentation is the largest sector, accounting for about 30% of German production in 2008. Computer equipment accounts for 12%, radio communications equipment accounts for 5.8%, telecommunications accounts for 4.9% and medical accounts for 7.6%. The growing automobile industry has also led to a growing electronics industry. | India offers a vast domestic market for semiconductors and electronics companies from Germany. Germany can utilise the cost efficient production capability that India offers, along with the skilled workforce. German production and innovation techniques are of a high technological standard and they are known for efficient business execution and long term commitment. India will have the opportunity to utilise this learning. |

# 9 THE VISION OF SMART CITIES THROUGH INDO-GERMAN COLLABORATION

The above section has shown the various possibilities for Indo-German collaboration across different areas and sectors. Utilising the respective strengths, we can build a smart city that realises all necessary aspects: economy, people, governance, mobility, environment and living. This delineates the importance of basic research; the need to understand technology from different dimensions (scalability, implementation issues, resource issues and governance); the need to promote technologies, implementing the best available technologies; and the need to develop a relevant, sustainable and implementable solution that works not just for India, but globally.

This collaboration is the answer for emerging economies; it is the answer for further innovation.

- It is essential that we believe and trust each other's competencies and skills; work towards increasing cooperation – both South-South and North-South.
- We need to work towards increasing the rate of adoption; it is important to not only learn and share knowledge, but ensure that the transfer of knowledge has been complete and has scope for utilisation.
- The aim is to promote innovation and also sustain innovation in developed countries.
- The holistic vision is to improve people's quality of life by embarking on a collaborative path.

Smart city technologies in the real sense will be the driver of global innovation.

**Build and Scale**

We have to understand the importance of the economy being smart, the availability of resources and the option of scaling. We have to understand the strengths of India and Germany. We have to understand that using smart labour, smarter business systems and ICT enhances people's quality of life. As people grow more qualified and have more technical skills, they can contribute to building the infrastructures in a city. The role of the government is paramount and the governance perspective decides how resources should be optimally utilised. Accessibility and sustainability become core concerns. German cities, as models of sustainable energy, public transportation and optimal resource utilisation, present benchmarks for India to follow.

**Learning**

Learning is a critical factor in collaboration. Resource availability and inclusiveness help pave the way to developing a smart city. Indian resources are affordable and accessible.

**Negotiation**

Negotiation is critical when dealing with competing technologies that are developed, to understand what best suits existing needs and current resource scarcity, along with short-term requirements and long-term demands that may arise. It is essential to forecast and be proactive in unearthing the most suitable technologies. In a case like this India can utilise the technologies available in Germany and ensure technology transfer for product development.

**Collaborate and innovate**

The collaboration with Germany has to be seamless in nature. Through negotiation, it is essential to create a win-win situation, rather than a win-lose or lose-lose situation.
Through this collaboration, it is essential to:

- develop case studies that will work as benchmarks
- write institutional frameworks that can provide guidance for future work
- monitor policies and update them as times change
- sustain resources across sectors
- build citizen partnerships and ensure that they have a say at every level of governance
- document all discoveries and build a knowledge management system

It is only through continuous, sustained and proactive effort that this collaboration can herald in technologies for smart cities, institutionalising innovation at every level.

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# Citizens' Preferences on Governance Structures in Bangalore with Regard to Urban Traffic Management

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Project: German Indian Partnership for IT Systems

**Recommeded citation:** K.B. Akhilesh: Citizen's Preferences on Governance Structures in Bangalore with Regard to Urban Traffic Management, acatech Materialien German Indian Partnership for IT Systems, München/Berlin 2014

**Published by:**
acatech – National Academy of Science and Engineering 2014

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E-mail: info@acatech.de
Internet: www.acatech.de

ISSN: 2191-8481/ISBN: 978-3-942044-37-0

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Coordination: Prof. Dr. Otthein Herzog, Dr. Ulrich Glotzbach
Layout conception: acatech
Conversion und typesetting: work:*at*:BOOK / Martin Eberhardt, Berlin

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# 1 INTRODUCTION

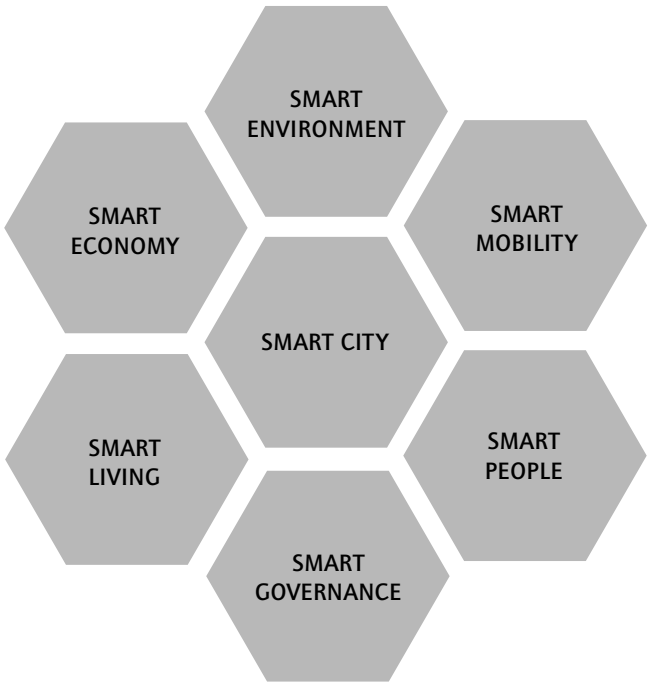
Bangalore has seen a spiral of economic activity and urban growth, with the developed area of the city increasing from roughly 175 square kilometres in 1971 to more than 560 square kilometres in 2006. Bangalore's urban sprawl was aided by the economic boom, during which income levels within certain industries skyrocketed. This rising income, combined with long travel times, poor public transportation facilities and the glamour and hype generated by the automobile industry, powered the vehicular boom on the roads. The government's efforts to make the city more car-friendly had a boomerang effect, with multiplication of private automobiles on the road. In fact, the motorization index nearly doubled from 178 in 1996 to 361 in 2006. Currently, private automobiles – two-wheelers, cars, taxis etc. – make up nearly 88% of the vehicles on Bangalore's streets.

Urban performance not only depends on the city's endowment of hard infrastructure ('physical capital'), but also increasingly on the availability and quality of knowledge communication and social infrastructure ('intellectual and social capital'), the growing importance of Information and Communication Technologies (ICTs), and social and environmental capital in profiling the competitiveness of cities.[1] The significance of these last two assets – social and environmental capital – itself goes a long way to distinguishing smart cities from their more technology-laden counterparts, drawing a clear line between them and what goes by the name of either digital or intelligent cities.

The concept of a smart city itself is still emerging, and the work of defining and conceptualizing it is in progress. The concept is used all over the world with different nomenclatures, context and meanings. A range of conceptual variants generated by replacing the word "smart" with adjectives such as "digital" or "intelligent" are readily used and reused. Some are recognizing the use of *smart city* as an urban labelling phenomenon.[2] Several working definitions have been put forward and adopted in both practical and academic use:

A city performing well and in a forward-looking way in terms of economy, people, governance, mobility, environment, and living, built on the smart combination of endowments and activities of self-decisive, independent and aware citizens.[3] A city that monitors and integrates conditions of all of its critical infrastructures, including roads, bridges, tunnels, railways, subways, airports, seaports, communications, water, power, even major buildings can better optimize its resources, plan its preventive maintenance activities and monitor security aspects while maximizing services to its citizens.[4] A "smart city" is built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens.[5]

Figure 1: Characteristics of a smart city.




Although there is an increase in the frequency of using the phrase "smart city", there is still not a clear and consistent understanding of the concept among practitioners and academia. Only a limited number of studies have investigated and begun to systematically consider questions related to this new urban phenomenon of smart cities. This paper attempts to start filling this gap by identifying important trends and suggesting research agendas about cities as they invest in new ways to become "smart", especially in developing countries like India.

1 Caragliu 2009.
2 Hollands 2008.
3 Giffinger et al.2007.
4 Hall 2000.
5 Giffinger/Kramer/Haindl 2008.

Several cities have started transformational projects and initiatives, called "smart city initiatives", to better serve citizens and improve their quality of life.[6] These projects involve multiple stakeholders. Thus, several cities have felt an increased need for better governance to manage these projects and initiatives.[7]

In general, governance has been defined as "regimes of laws, administrative rules, judicial rulings, and practices that constrain, prescribe, and enable government activity, where such activity is broadly defined as the production and delivery of publicly supported goods and services."[8] Governance, therefore, involves the implementation of processes with constituents who exchange information according to rules and standards in order to achieve goals and objectives[9]. Scholl *et al*. studied challenges of key e-government projects and found that stakeholder relations is one of the critical factors for determining success or failure of such projects.

"Stakeholder relations" refers to four main issues: the ability to cooperate among stakeholders, support from leadership, structure of alliances and working under different jurisdictions. [10]

Several cities have benefited from the emergence of ICTs that improve their governance, as in Bangalore. This ICT-based governance is known as smart governance. It represents a broad collection of technologies, people, policies, practices, resources, social norms and information that interact to support city governance activities. According to Forrester, smart governance is the core of smart city initiatives.[11] Thus, it represents an important challenge for smart city initiatives.

Hafedh Chourabi *et al*.[12] have listed the following factors which influence governance in smart cities:

- Collaboration
- Leadership and championing
- Participation and partnership
- Communication
- Data-exchange
- Service and application integration
- Accountability
- Transparency

Smart governance depends on the implementation of a smart governance infrastructure that should be accountable, responsive and transparent; efficient and reliable urban transport systems are crucial for a city to sustain a high growth rate and alleviate poverty. Hence, a study was undertaken to understand citizens' preferences on governance structures in Bangalore with regard to urban traffic management.

The following provides brief information about Bangalore's urban mobility and its governance structures.

- Bangalore Metropolitan Region Development Authority (BMRDA)
  Area: 8,005 square kilometres and urban: 2,191 square kilometres. BMRDA is an autonomous body created by the Government of Karnataka under the BMRDA Act 1985 for the purpose of planning, co-coordinating and supervising the proper and orderly development of the areas within the Bangalore Metropolitan Region (BMR).
- Population: 8.4 million in the Bruhat Bengaluru Mahanagara Palike (BBMP). The BBMP is the new administrative body responsible for the civic and infrastructural assets of the city of Bangalore, India.
- Bangalore urban: 800 square kilometres.
- Vehicle population: 3.89 million in March 2010
- Road length: 6,000 kilometres

- The Bangalore Metropolitan Transport Corporation (BMTC) is a government agency that operates the public transport bus service in Bangalore.
  - Total buses: 6,083
  - Routes operated: 5,890
  - Total trip lengths: 12.73 lakh km
  - Total trips: 79,754
  - Passengers carried: 4.2 million passengers per day.
  - 583 city and 1,785 sub-urban routes, running 13 lakh kilometres and making 76,266 trips.

- Metro Rail: BMRCL also known as Namma metro (our metro) is a rapid transit rail system for the city of Bangalore.
  - 42 kilometres under construction at the cost of Indian Rupee 8,158 Crores.
- Estimated passengers per day: 16.1 lakh (2021)

6 Giffinger *et al*. 2007.
7 Griffith 2001.
8 Lynn/Heinrich/Hill 2000, p. 235.
9 Johnston/Hansen 2011.
10 Scholl *et al*. 2009.
11 Bellisent 2011, p. 3.
12 Hafedh et al. 2012.

# 2 MATERIALS AND METHODS

A survey was carried out to understand citizens' preferences on governance structures in Bangalore with regard to urban traffic management. A group of 120 Bangalore citizens participated voluntarily in this study. Across the group, the sample was defined with respect to occupations, namely shopkeepers, cleaners and scavengers, elite group, officers and students. Each sub-group was further divided into males and females, three in each sub-group, comprising fifteen citizens from different zones of Bangalore.

Bangalore was divided into four zones: North, South, East and West. In each zone, we defined the characteristics of the population as shown in Tables 1 and 1a below. We assumed that 30 data points from each zone of Bangalore would be a good representative sample. The purposeful stratified random sampling method was adopted for the proposed sample.

Table 1: Demographic characteristics of the proposed sample across the zones.

| Characteristics | Occupation | Male | Female |
|---|---|---|---|
| Gender | Shopkeepers | 3 | 3 |
| | Cleaners/Scavengers | 3 | 3 |
| | Upper-class/Elite Group | 3 | 3 |
| | Officers (Govt, Private) | 3 | 3 |
| | Students | 3 | 3 |
| Total | | 15 | 15 |
| Grand Total | | 30 | |

Figure 2: Map of different zones of the Bangalore urban city.

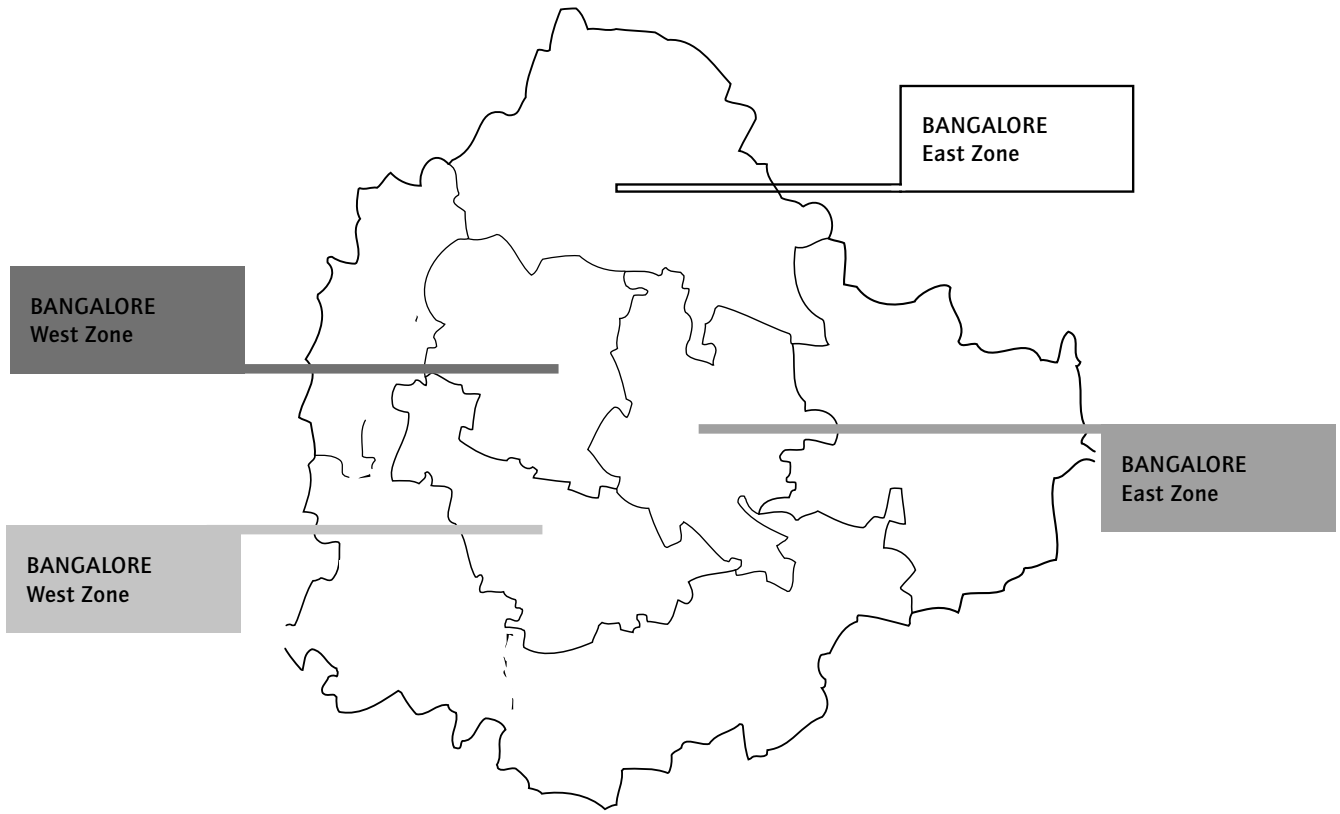


Table 1a: Demographic characteristics of the proposed sample framework across the different zones.

| **Region – Bangalore North (Yelahanka Satellite town, Vidyaranya Pura & HBR layout)** | | | | | | | **Total** |
|---|---|---|---|---|---|---|---|
| Gender | **15** (M) | | | **15** (F) | | | |
| Age Group | 5 (18–30) | 5 (30–45) | 5 (40–49) | 5(18–30) | 5(30–45) | 5 (40–49) | |
| Cleaners/Scavengers | 1 | 1 | 1 | 1 | 1 | 1 | |
| Shopkeepers | 1 | 1 | 1 | 1 | 1 | 1 | |
| Officers (Govt, Private) | 1 | 1 | 1 | 1 | 1 | 1 | |
| Students | 1 | 1 | 1 | 1 | 1 | 1 | |
| Upper-class/Elite Group | 1 | 1 | 1 | 1 | 1 | 1 | 30 |
| **Region – Bangalore South ( Chamrajpet, Hanumanth Nagar & Srinagar)** | | | | | | | **Total** |
| Gender | **15** (M) | | | **15** (F) | | | |
| Age Group | 5 (18–30) | 5 (30–45) | 5 (40–49) | 5(18–30) | 5(30–45) | 5 (40–49) | |
| Cleaners/Scavengers | 1 | 1 | 1 | 1 | 1 | 1 | |
| Shopkeepers | 1 | 1 | 1 | 1 | 1 | 1 | |
| Officers (Govt, Private) | 1 | 1 | 1 | 1 | 1 | 1 | |
| Students | 1 | 1 | 1 | 1 | 1 | 1 | |
| Upper-class/Elite Group | 1 | 1 | 1 | 1 | 1 | 1 | 30 |
| **Region – Bangalore West (Malleshwaram, Yeshwanth Pura & KR Market)** | | | | | | | **Total** |
| Gender | **15** (M) | | | **15** (F) | | | |
| Age Group | 5 (18–30) | 5 (30–45) | 5 (40–49) | 5(18–30) | 5(30–45) | 5 (40–49) | |
| Cleaners/Scavengers | 1 | 1 | 1 | 1 | 1 | 1 | |
| Shopkeepers | 1 | 1 | 1 | 1 | 1 | 1 | |
| Officers (Govt, Private) | 1 | 1 | 1 | 1 | 1 | 1 | |
| Students | 1 | 1 | 1 | 1 | 1 | 1 | |
| Upper-class/Elite Group | 1 | 1 | 1 | 1 | 1 | 1 | 30 |
| **Region – Bangalore East (Shivaji Nagar, Sampangi Ram Nagar & Shanthi Nagar)** | | | | | | | **Total** |
| Gender | **15** (M) | | | **15** (F) | | | |
| Age Group | 5 (18–30) | 5 (30–45) | 5 (40–49) | 5(18–30) | 5(30–45) | 5 (40–49) | |
| Cleaners/Scavengers | 1 | 1 | 1 | 1 | 1 | 1 | |
| Shopkeepers | 1 | 1 | 1 | 1 | 1 | 1 | |
| Officers (Govt, Private) | 1 | 1 | 1 | 1 | 1 | 1 | |
| Students | 1 | 1 | 1 | 1 | 1 | 1 | |
| Upper-class/Elite Group | 1 | 1 | 1 | 1 | 1 | 1 | 30 |
| | | | | | | | **120** |

The above sample framework was used to identify each data point across each region and occupation for the proposed sample. The data was collected from shops, offices, colleges and their respective resident spaces in Bangalore. The duration of each interview was about 15-17 minutes. The survey was conducted from 9th May to 15th May 2012.

**Procedure**

A survey questionnaire was designed to determine the citizens' preferences on governance structures in Bangalore regarding urban traffic management. We administered the questionnaire, including open and closed questions. Question domains included the citizens' demographic characteristics and citizens' preferences on governance structures, mobility and services. The questions identify the citizens' preferences about urban mobility and the role of governance structure in urban transport development in both parastatal (quasi-governmental organization) agencies, Bangalore Metropolitan Transport Corporation (BMTC) and the Metro by the Bangalore Metro Rail Corporation Lt. (BMRCL).

A good rapport was established with study participants and informed consent was obtained before the in-depth interview was carried out. The participants were very briefly told the need and purpose of the study and were assured on the confidentiality of the questionnaire and that no harm or legal consequences would result from the study.

**Analysis of Data**

The exploratory data was analysed by calculating the means, median and ranges to describe the demographic characteristics. The data was further tabulated into frequencies and percentages. The obtained data through open-ended questions were further subjected to qualitative analysis using the thematic network analysis method.

Thematic network analysis is a simple way of organizing salient themes in a text at different levels, thematic networks aim to facilitate the structuring of a text at different levels, and depiction of these themes. Thematic analysis is a general method for qualitative analysis of transcripts or other similar text data sources. The themes are seen based on the response of the subject. A thematic network provides a web-like network as an organizing principle and a representational means, and it makes explicit the procedures that may be employed in going from text to interpretation.[13]

13 Breiger 2004.

# 3 RESULTS AND DISCUSSION

The objective of the study is to understand citizens' preferences on governance structures in Bangalore with regard to urban traffic management. The study was conducted in four different zones of Bangalore, namely Bangalore North, Bangalore South, Bangalore East and Bangalore West. 120 citizens of Bangalore participated voluntarily in the study. Table 3 shows the frequency of citizens' preferences on urban mobility.

Results are presented in the following order: First, we calculated the average age of the group and its corresponding average age across different occupation of the group. Next, we analysed the citizens' preferences on urban mobility and their preference towards the governance structure. Finally, we attempted to give a complete picture across the citizens' preferences on urban mobility and governance structure with respect to occupation, different zones of Bangalore (East, West, North and South) and gender.

Table 2: Average mean values of the demographic characteristics of the group.

| Characteristics | Occupation | Male | Female |
|---|---|---|---|
| Age | Shopkeepers | 35.62 | 10.90 |
| | Cleaners/Scavengers | 33.75 | 8.22 |
| | Upper-class/Elite Group | 35.5 | 9.86 |
| | Officers (Govt, Private) | 34.12 | 9.17 |
| | Students | 32.87 | 8.94 |
| | | 34.37 | 9.36 |

The descriptive data in Table 2 above shows that the group of citizens representing Bangalore city has the average age of 34.37 with a standard deviation of 9.36. Across occupations, we observed an average age of 33.75 with a standard deviation of 10.90 for shopkeepers, an average age of 33.75 with a standard deviation of 8.22 for cleaners, an average age of 35.5 with a standard deviation of 9.86 for the elite group, an average age of 34.12 with a standard deviation of 9.17 for officers and an average age of 32.87 with a standard deviation of 8.94 for students.

Table 3: Frequency of citizens' preferences on urban mobility.

| Preference | Response | Total |
|---|---|---|
| Do you use the bus? | Yes | 89 |
| | No | 31 |
| Can you imagine using the bus in principle? | Yes | 86 |
| | No | 34 |
| Are you proud to have a metro? | Yes | 99 |
| | No | 21 |
| Do you use the metro? | Yes | 23 |
| | No | 97 |
| Would you prefer metro in major? | Yes | 82 |
| | No | 38 |

Figure 3: Percentage of Bangalore citizens' preferences on urban mobility.

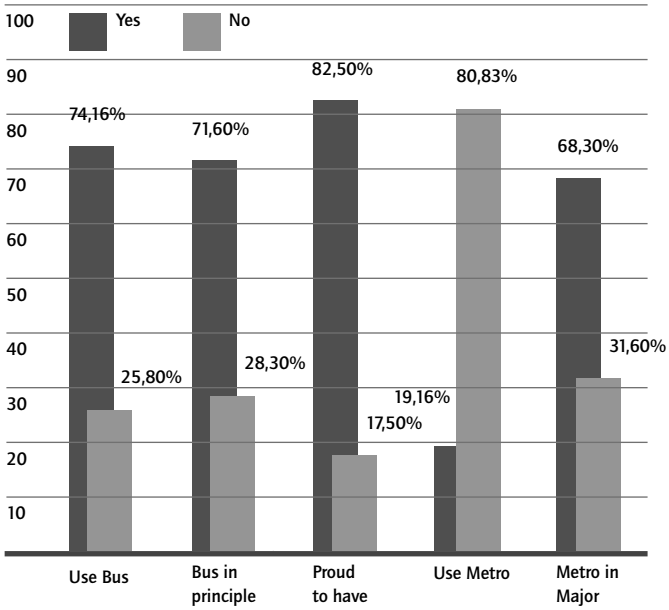



Figure 3 illustrates the percentage of Bangalore citizens' preferences on urban mobility. 74.16% of the group expressed that they use the bus. Among the group, 71.60% reported that they could imagine using the bus in principle for mobility at the present transportation facility in Bangalore city. While 82.50% of the group are proud to have the metro in the city, but only 19.16% of respondents were able to use or access the metro transportation in the city, be-

cause residents of different zones of Bangalore in the group, are yet to have access to metro facility as it is still in construction phase, hence people who can't access metro now are hoping or looking forward to mainly use as a primary mode of transport and hence group of 68.30% expressed their favourable opinion to mainly use the metro as mode of transport in major compared to other mode of transports in future.

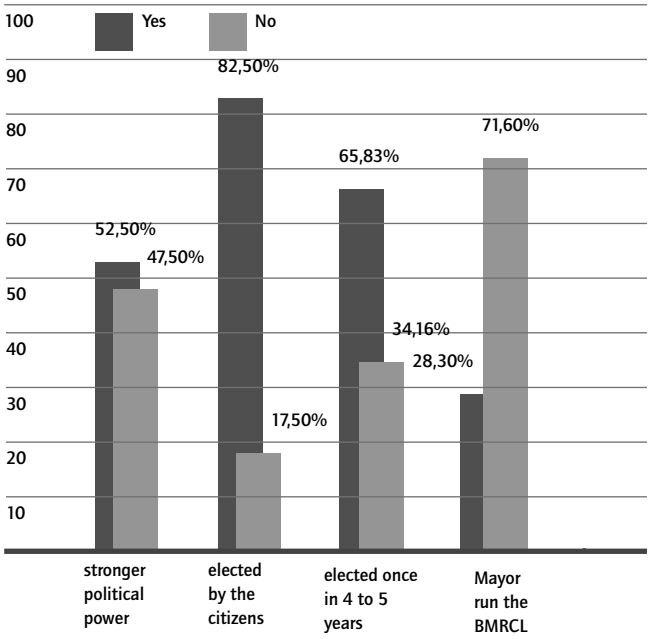
## A. CITIZENS' PREFERENCES ON GOVERNANCE STRUCTURE

Table 4: Citizens' preferences on urban mobility with regard to governance structure.

| Preference | Response | Total |
|---|---|---|
| Should the mayor receive stronger political power? | Yes | 57 |
| | No | 63 |
| Should the mayor be elected by the citizens? | Yes | 99 |
| | No | 21 |
| Should the election take place every 4 to 5 years? | Yes | 79 |
| | No | 41 |
| Should the mayor run the BMRCL instead of the Federal Government? | Yes | 34 |
| | No | 86 |

Table 4 shows the citizens' views on urban mobility regarding the governance structure of the city. 57 people expressed the need for stronger political power for the mayor, while 63 people do not see it as necessary. 99 people expressed the need for the mayor to be elected by the citizens directly and not by the council and 79 people suggested that the election needs to be held every 4 to 5 years instead of annually. Finally, 34 out of 120 favoured the mayor to run the BMRCL instead of the Federal Government in future.

Figure 4: Percentage of citizens' preferences on governance structure.



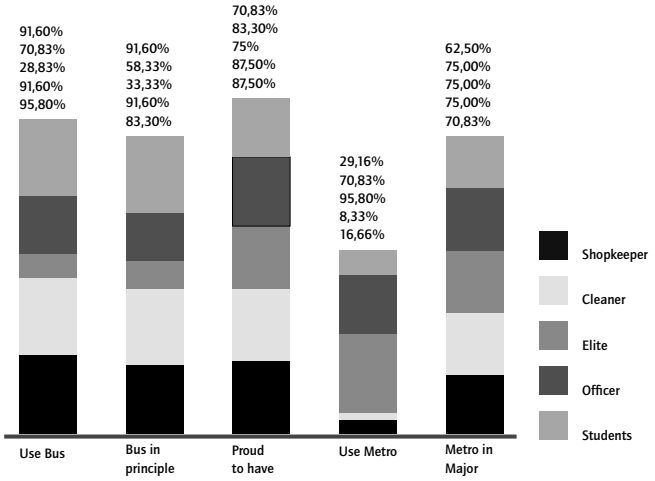

The above graph illustrates the percentage of Bangalore citizens' preferences on governance structure. 52.50% of the group expressed the need for stronger political power. 82.50% of the group expressed the need for the mayor to be elected by the citizens directly and 65.83% of the group reported that the election of the mayor needs to be held every 4 to 5 years. Finally, 28.30% of the group expressed a favourable attitude towards the mayor running the BMRCL instead of the Federal Government in the future.

## B. CITIZENS' PREFERENCES ON URBAN MOBILITY AMONG DIFFERENT OCCUPATIONS

Table 5: Percentage of citizens' preferences on urban mobility among different occupations.

| Preference | Response | Shopkeepers | Cleaners | Elite | Officers | Students |
|---|---|---|---|---|---|---|
| Do you use the bus? | Yes | 96% | 91.60% | 20.83% | 70.83% | 91.60% |
| | No | 4% | 8.33% | 79.16% | 29.16% | 8.33% |
| Can you imagine using the bus in principle? | Yes | 83.30% | 91.60% | 33.33% | 58.33% | 91.60% |
| | No | 16.66% | 8.33% | 66.66% | 41.66% | 8.33% |
| Are you proud to have a metro? | Yes | 87.50% | 87.50% | 75% | 83.30% | 70.83% |
| | No | 12.50% | 12.50% | 25% | 16.60% | 29.16% |
| Do you use the metro? | Yes | 16.66% | 8.33% | 95.80% | 70.83% | 29.16% |
| | No | 83.30% | 91.60% | 4.16% | 29.16% | 70.83% |
| Would you prefer metro in major? | Yes | 70.83% | 75% | 75% | 75% | 62.50% |
| | No | 29.16% | 25% | 25% | 25% | 37.50% |

Figure 5: Percentage of citizens' preferences on mobility among different occupations.



## C. CITIZENS' PREFERENCES ON GOVERNANCE STRUCTURE AMONG DIFFERENT OCCUPATIONS

Table 6: Percentage of citizens' preferences on governance structure among different occupations.

| Preference | Response | Shopkeepers | Cleaners | Elite | Officers | Students |
|---|---|---|---|---|---|---|
| Should the mayor receive stronger political power? | Yes | 58.33% | 62.50% | 33.60% | 58.33% | 50% |
| | No | 41.66% | 37.50% | 66.60% | 41.66% | 50% |
| Should the mayor be elected by the citizens? | Yes | 79.16% | 95.80% | 75% | 79.16% | 83.30% |
| | No | 28.83% | 4.16% | 25% | 28.83% | 16.60% |
| Should the election take place once in 4 to 5 years? | Yes | 66.30% | 70.83% | 58.33% | 75% | 54.16% |
| | No | 33.33% | 29.16% | 41.66% | 25% | 45.83% |
| Should the mayor run the BMRCL? | Yes | 25% | 28.83% | 28.83% | 33.33% | 33.33% |
| | No | 75% | 79.16% | 79.16% | 66.30% | 66.30% |

Table 6 and Figures 6, 7, and 8 show the percentage of citizens' preferences on governance structure among different occupations. Among the different groups, 58.33% of shopkeepers, 62.50% of cleaners, 33.60% of the elite, 58.33% of officers and 50% of students reported that the mayor needs stronger political power towards smart governance. Among the group, 79.16% of shopkeepers, 95.80% of cleaners, 75% of the elite, 79.16% of officers and 83.30% of students expressed the need for the mayor to be elected by the citizens directly, not by the council.

Further, 66.30% of shopkeepers, 70.83% of cleaners, 58.33% of the elite, 75% of officers and 54.16% of students said that the election of the mayor needs to be held every 4 to 5 years. 25% of shopkeepers, 28.83% of cleaners, 28.83% of the elite, 33.33% of officers and 33.33% of students expressed their favourable attitude towards the mayor running the BMRCL instead of the Federal Government in future.

Figure 6: Percentage of citizens' preference for stronger political power.

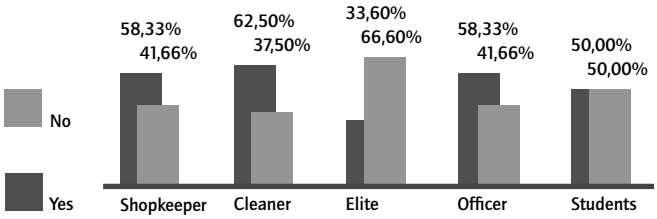



Figure 7: Percentage of citizens' preference regarding election by citizens.

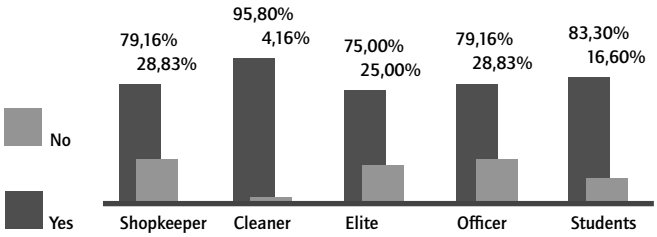


Figure 8: Percentage of citizens' preference on frequency of elections.

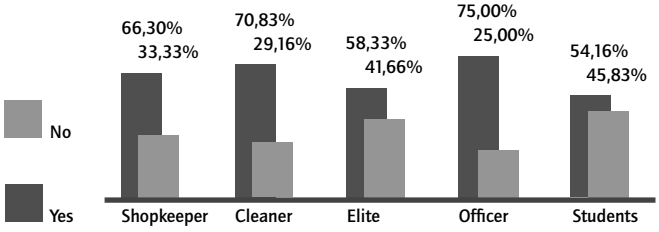
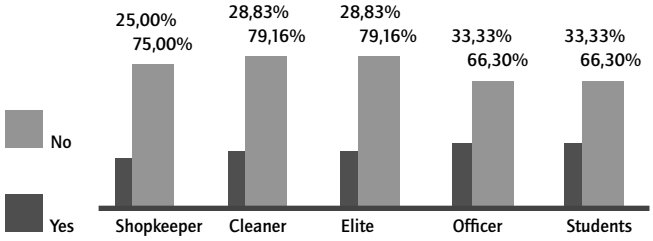



Figure 9: Percentage of citizens' preference on the mayor running the BMRCL.

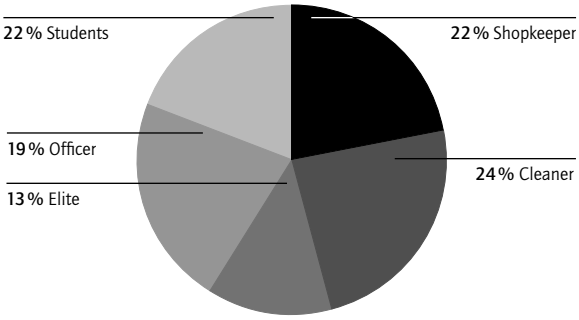



## D PREFERENCE IN GOVERNANCE STRUCTURE

Across the occupations in the group, the pie charts below (Figures 10 and 11) show that 22% of shopkeepers, 24% of cleaners, 13% of the elite, 22% of officers and 19% of students reported that the mayor needs stronger political power towards smart governance. 19% of shopkeepers, 24% of cleaners, 18% of the elite, 19% of officers and 20% of students expressed the need for the mayor to be elected by the citizens directly and not by the council.

Across the occupations in the group, the pie charts below (Figures 12 and 13) illustrate that 20% of shopkeepers, 22% of cleaners, 18% of the elite, 23% of officers and 17% of students reported that the election of the mayor needs to be held every 4 to 5 years and 17% of shopkeepers, 19% of cleaners, 19% of the elite, 23% of officers and 22% of students expressed their favourable attitude towards the mayor running the BMRCL instead of the Federal Government in the future.

Figure 10 & 11: Preferences on governance structure among different occupations.



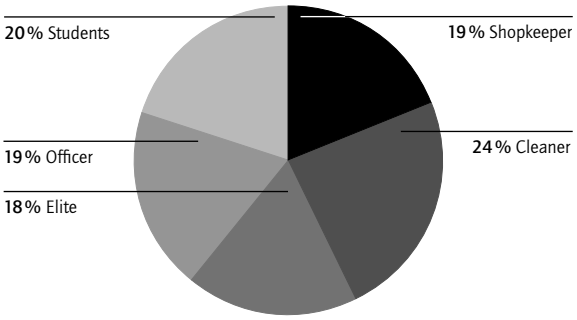
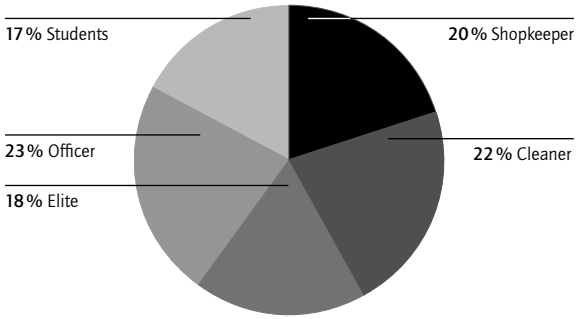
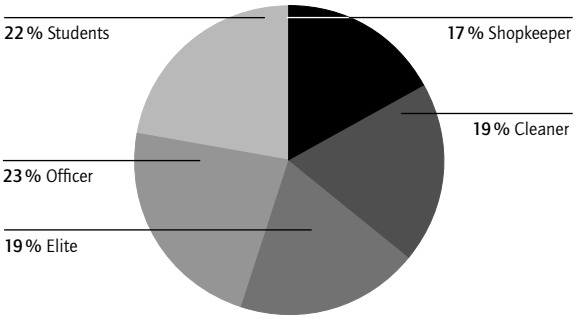




Figure 12 & 13: Preference on governance structure among different occupations.



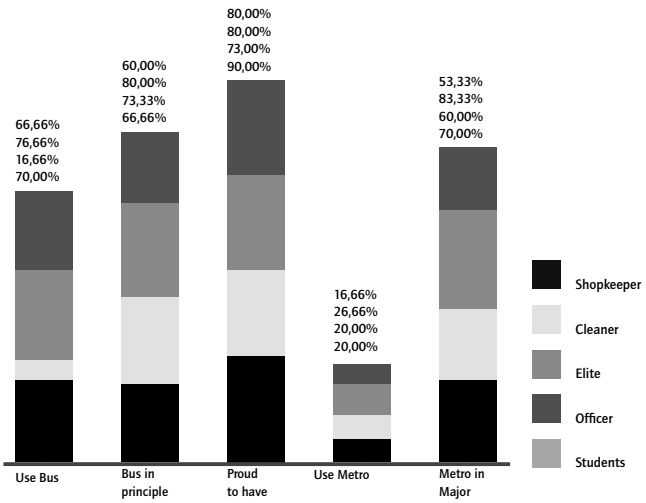
## E. PREFERENCES ON URBAN MOBILITY ACROSS DIFFERENT ZONES OF BANGALORE URBAN CITY

Table 7 and Figure 14 below demonstrate the percentage of Bangalore citizens' preferences on urban mobility across the different zones of Bangalore. 70% from the East, 16.66% from the West, 76.66 % from the North and 66.6% from the South reported that they use the bus. Across the region, 66.66% from the East, 73.33% from the West, 80% from the North and 60% from the South reported that they could imagine using the bus in principle for mobility. 90% from the East, 73.33% from the West, 80% from the North and 80% from the South are proud to have the metro in the city, but only 20% from the East, 20% from the West, 26.6% from the North and 16.6% from the South use the metro in the city, and further, 70% from the East, 60% from the West, 83.33% from the North and 53.33% from the South expressed their favourable opinion to mainly use the metro.

Table 7: Percentage of citizens' preferences on urban mobility across different zones.

| Preference | Response | East | West | North | South |
|---|---|---|---|---|---|
| Do you use the bus? | Yes | 70% | 16.66% | 76.66% | 66.66% |
| | No | 30% | 83.33% | 23.33% | 33.33% |
| Can you imagine using bus in principle? | Yes | 66.66% | 73.33% | 80% | 60% |
| | No | 33.33% | 26.66% | 20% | 40% |
| Are you proud to have a metro? | Yes | 90% | 73.33% | 80% | 80% |
| | No | 10% | 26.66% | 20% | 20% |
| Do you use the metro? | Yes | 20% | 20% | 26.66% | 16.66% |
| | No | 80% | 80% | 73.33% | 83.33% |
| Would you prefer metro in major? | Yes | 70% | 60% | 83.33% | 53.33% |
| | No | 30% | 40% | 16.66% | 23.33% |

Figure 14: Percentage of citizens' preferences on urban mobility across different zones.



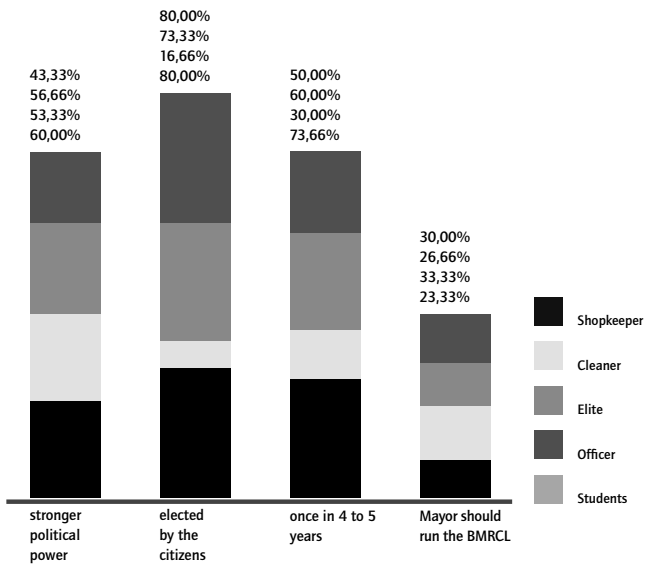
## F. PREFERENCES ON GOVERNANCE STRUCTURE ACROSS DIFFERENT ZONES OF BANGALORE URBAN CITY

Table 8 and Figure 15 show the percentage of citizens' preferences on governance structure across different zones of Bangalore city. Among the different zones, 60% from the East, 53.33% from the West, 56.66% from the North and 43.33% from the South reported that the mayor needs stronger political power towards smart governance. 80% from the East, 16.66% from the West, 73.33% from the North and 80% from the South expressed the need for the mayor to be elected by the citizens directly, not by the council. Further, in the group 73.66% from the East, 30% from the West, 60% from the North and 50% from the South reported that the election of the mayor needs to be held every 4 to 5 years and 23.33% from the East, 33.33% from the West, 26.66% from the North and 30% from the South expressed their favourable attitude towards the mayor running the BMRCL instead of the Federal Government in future.

Table 8: Percentage of citizens' preferences on governance structure across different zones of Bangalore urban city.

| Preference | Response | East | West | North | South |
|---|---|---|---|---|---|
| Should the mayor receive stronger political power? | Yes | 60% | 53.33% | 56.66% | 43.33% |
| | No | 40% | 23.33% | 43.33% | 56.66% |
| Should the mayor be elected by the citizens? | Yes | 80% | 16.66% | 73.33% | 80% |
| | No | 20% | 83.33% | 26.66% | 20% |
| Should the election take place once in 4 to 5 years? | Yes | 73.66% | 30% | 60% | 50% |
| | No | 26.66% | 70% | 40% | 50% |
| Should the mayor run the BMRCL? | Yes | 23.33% | 33.33% | 26.66% | 30% |
| | No | 76.66% | 66.66% | 73.33% | 70% |

Figure 15: Percentage of citizens' preferences on governance structure across different zones.



## G. CITIZENS' PREFERENCES ON URBAN MOBILITY BY GENDER

Table 9 and Figure 16 show the percentage of citizens' preferences on urban mobility by gender. 70% of males and 78.33% of females in the group reported that they use the bus. Among the group, 71.60% of males and 71.60% of females use the bus in principle for transportation among other transportation. Further, 71.60% of male and 93.33% of female reported that they are proud to have the metro, but only 21.66% of males and 16.66% of females use the metro, as majority of city residents are yet access metro facility and hence 76.66% of males and 60% females expressed their favourable opinion to mainly use the metro in future.

Table 9: Percentage of citizens' preferences on urban mobility by gender.

| Preference | Response | Male | Female |
|---|---|---|---|
| Do you use the bus? | Yes | 70% | 78.33% |
| | No | 30% | 21.66% |
| Can you imagine using bus in principle? | Yes | 71.60% | 71.60% |
| | No | 28.30% | 28.30% |
| Are you proud to have a metro? | Yes | 71.60% | 93.33% |
| | No | 28.30% | 6.66% |
| Do you use the metro? | Yes | 21.66% | 16.66% |
| | No | 78.33% | 83.33% |
| Would you prefer metro in major? | Yes | 76.66% | 60% |
| | No | 23.33% | 40% |

## H. PREFERENCES ON GOVERNANCE STRUCTURE ACROSS GENDER

Table 10 and Figure 17 demonstrate the percentage of citizens' preferences on governance structure by gender. 43.33% of males and 61.66% of females in the group said that the mayor needs stronger political power towards smart governance. Among the group, 78.33% of males and 86.66% of females expressed the need for the mayor to be elected by the citizens directly, not by the council.

35% of males and 36.66% of females reported that the election of the mayor needs to be held every 4 to 5 years and 28.30% of males and 30% of females expressed their favourable attitude for the mayor running the BMRCL instead of the Federal Government in the future.

Figure 16: Percentage of citizens' preferences on urban mobility among gender.

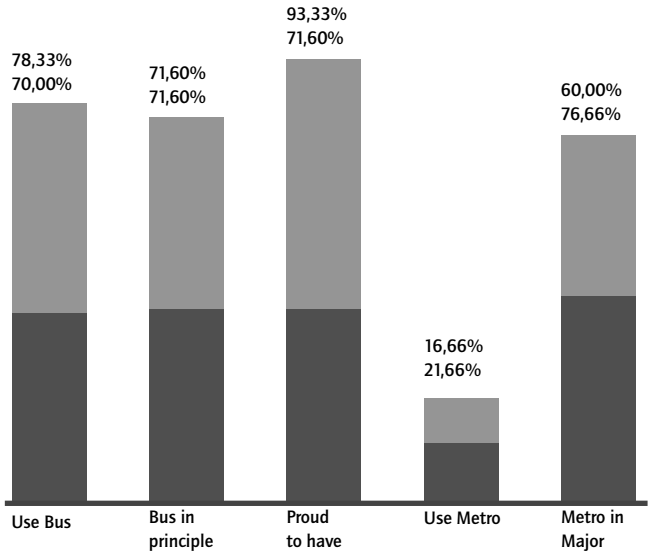



Figure 17: Percentage of citizens' preferences on governance structure among gender.

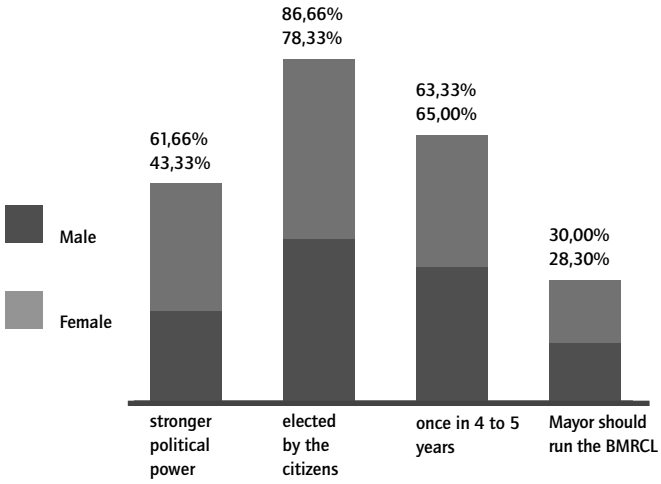


Table 10: Percentage of citizens' preferences on governance structure across gender.

| Preference | Response | Male | Female |
|---|---|---|---|
| Should the mayor receive stronger political power? | Yes | 43.33% | 61.66% |
| | No | 56.66% | 38.33% |
| Should the mayor be elected by the citizens? | Yes | 78.33% | 86.66% |
| | No | 21.66% | 13.33% |
| Should elections take place once every 4 to 5 years? | Yes | 65% | 63.33% |
| | No | 35% | 36.66% |
| Should the mayor run the BMRCL? | Yes | 28.30% | 30% |
| | No | 71.60% | 70% |

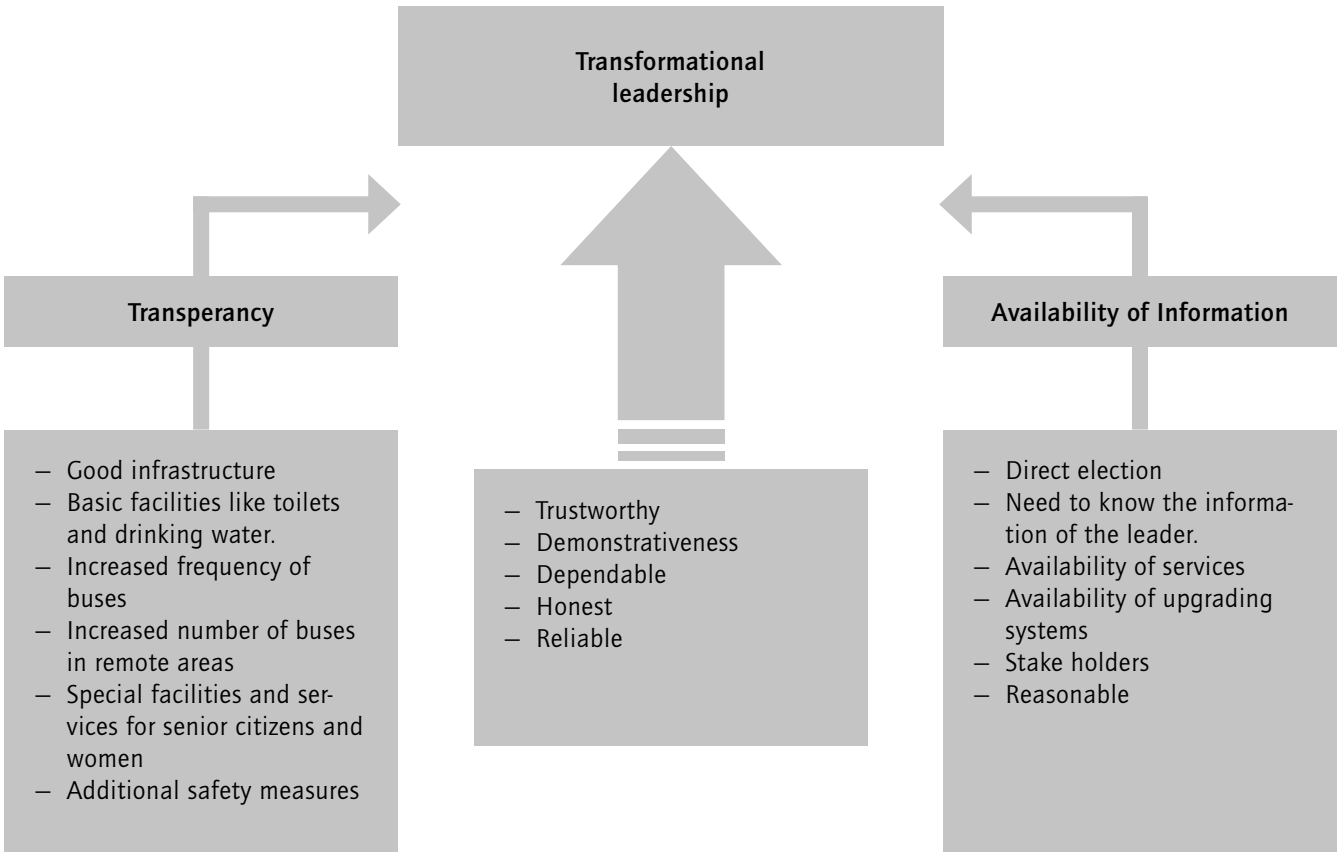
The aim of the study was to understand citizens' preferences on governance structures in Bangalore regarding urban traffic management. The data obtained through open-ended questions were subjected to qualitative analysis using the thematic network analysis method. The table below illustrates basic themes observed from the citizens' perspectives on urban mobility and governance structure.

As shown in Figure 18, below, the majority of the group emphasised the need for stronger political power for the mayor and transparent governance through direct election by the citizens of the city rather than by council members of each ward. Furthermore, the majority of the group said that the election needs to be conducted every 4 to 5 years. From these observations, it is evident that citizens of Bangalore are looking forward to a change in governance structure, transparency, accountability of information and transformative political leadership.

Table 11: Themes that emerged on the citizens' preferences on urban mobility with regard to governance structure.

| Basic Themes | Organizing Themes | Global Theme |
|---|---|---|
| ❙ Good infrastructure<br>❙ Basic facilities like toilets and drinking water.<br>❙ Increased frequency of buses<br>❙ More buses in remote areas<br>❙ Special facilities and services for senior citizens and women<br>❙ Additional safety measures | TRANSPARENCY | Transformational leadership |
| ❙ Trustworthy<br>❙ Demonstrativeness<br>❙ Dependable<br>❙ Honest<br>❙ Reliable | ACCOUNTABILITY | |
| ❙ Direct election<br>❙ Need to know more information about the leader<br>❙ Availability of services<br>❙ Availability of upgrading systems<br>❙ Stakeholders | AVAILABILITY OF INFORMATION | |

Figure 18: Themes emerging to understand the citizens' preferences on urban mobility with regard to the governance structure.



# 4 SUMMARY AND FINDINGS

The aim of the study is to understand the citizens' preferences on governance structures of Bangalore with regard to urban traffic management. The study was conducted in the four different zones of Bangalore, namely Bangalore North, Bangalore South, Bangalore East and Bangalore West. 120 citizens of the city participated voluntarily in the study.

**Citizens' preferences on urban mobility**

74.16% of group expressed that they use the bus. Among the group, 71.60% reported that they could imagine using the bus in principle for mobility. While 82.50% of the group expressed their opinion that they are proud to have metro in the city, only 19.16% use metro in the city, and further, 68.30% of the group expressed their favourable opinion to use mainly the metro.

**Citizens' preferences of governance structure**

52.50% of the group expressed the need for stronger political power. Further, 82.50% of the group expressed the need for the mayor to be elected by the citizens directly and 65.83% of the group said that the election of mayor needs to be held every 4 to 5 years. Finally, 28.30% of the group expressed a favourable attitude towards the mayor running the BMRCL instead of the Federal Government in future.

**Citizens' preferences on urban mobility by occupation in the group**

95.80% of shopkeepers, 91.60% of cleaners, 28.83% of the elite, 70.83% of officers and 91.60% of students reported that they use the bus. 83.30% of shopkeepers, 91.60% of cleaners, 33.33% of the elite, 58.33% of officers and 91.60% of students would use the bus in principle for transportation. Further, 87.50% of shopkeepers, 87.50% of cleaners, 75% of the elite, 83.30% of officers and 70.83% of students are proud to have the metro, but only 16.66% of shopkeepers, 8.33% of cleaners, 95.80% of the elite, 70.83% of officers and 29.16% of students use the metro in the city, and 70.83% of shopkeepers, 75% of cleaners, 75% of the elite, 75% of officers and 62.50% of students expressed their favourable opinion to use mainly the metro in future.

**Citizens' preferences on governance structure by occupation in the group**

Among the group, 22% of shopkeepers, 24% of cleaners, 13% of the elite, 22% of officers and 19% of students reported that the mayor needs stronger political power towards smart governance. Further, 19% of shopkeepers, 24% of cleaners, 18% of the elite, 19% of officers and 20% of students expressed the need for the mayor to be elected by the citizens directly, not by the council.

**Citizens' preferences on urban mobility across different zones of the city**

70% in the East, 16.66% in the West, 76.66% in the North and 66.6% in the South reported that they use the bus. 66.66% in the East, 73.33% in the West, 80% in the North and 60% in the South reported that they could imagine using the bus in principle for mobility. While 90% from the East, 73.33% from the West, 80% from the North and 80% from the South are proud to have the metro in the city, only 20% from the East, 20% from the West, 26.6% from the North and 16.6% from the South use the metro, and further, 70% from the East, 60% from the West, 83.33% from the North and 53.33% from the South have expressed their favourable opinion to use mainly the metro in future.

**Citizens' preferences on governance structure across different zones of the city**

Among the different zones, 60% from the East, 53.33% from the West, 56.66% from the North and 43.33% from the South reported that the mayor needs stronger political power towards smart governance. Among different zones, 80% from the East, 16.66% from the West, 73.33% from the North and 80% from the South expressed the need for the mayor to be elected by the citizens directly and not by the council. Further, 73.66% from the East, 30% from the West, 60% from the North and 50% from the South 79.1% answered that the election of the mayor needs to be held every 4 to 5 years, and 23.33% from the East, 33.33% from the West, 26.66% from the North and 30% from the South expressed their favourable attitude toward the mayor running the BMRCL instead of the Federal Government in future.

**Citizens' preferences on urban mobility by gender in group**

70% of males and 78.33% of females in the group reported that they use the bus. Among the group, 71.60% of males and 71.60% of females would use the bus in principle for transportation. Further, 71.60% of males and 93.33% of females reported they are proud to have the metro, but only 21.66% of males and 16.66% of females use the metro in the city, and further, 76.66% of males and 60% of females expressed their favourable opinion to use mainly the metro.

**Citizens' preferences on governance structure by gender in group**

43.33% of males and 61.66% of females in the group reported that the mayor needs stronger political power towards smart govern-

ance. Among the group, 78.33% of males and 86.66% of females expressed the need for the mayor to be elected by the citizens directly, not by the council. Further, 35% of males and 36.66% of females in the group reported that the mayoral elections needs to be held every 4 to 5 years, and 28.30% of males and 30% of females expressed their favourable attitude toward the mayor running the BMRCL instead of the Federal Government in the future.

# 5 CONCLUSION

The majority of the group still depends on Public Transport Services like BMTC, and the majority of them are looking forward to accessing the metro service in the future, but only a few groups of Bangalore citizens benefit from the metro services. This is because only one terminal of the metro service is currently available while the others are still under construction. Hence, it is still not accessible to every member of the city.

In terms of preferences on governance structure, the majority of the group emphasised the need for stronger political power for the mayor and transparent governance through direct election by the citizens of the city rather than from council members of each ward. Further, regarding the duration of elections, the majority of the group observed that the election needs to be conducted every 4 to 5 years. From these observations, it is evident that citizens of Bangalore are looking forward to a change in governance structure, transparency, accountability of information and transformative political leadership.

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# The Framework of Political Institutions in the Context of Smart Mobility Projects in Bangalore

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**Recommeded citation:** Jörg Himmelreich: The Framework of Political Institutions in the Context of Smart Mobility Projects in Bangalore, acatech Materialien German Indian Partnership for IT Systems, München/Berlin 2014.

**Published by:**
acatech – National Academy of Science and Engineering 2014

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Internet: www.acatech.de

ISSN: 2191-8481/ISBN: 978-3-942044-37-0

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Coordination: Prof. Dr. Otthein Herzog, Dr. Ulrich Glotzbach
Layout conception: acatech
Conversion und typesetting: work:*at*:book / Martin Eberhardt, Berlin

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# THE FRAMEWORK OF POLITICAL INSTITUTIONS IN THE CONTEXT OF SMART MOBILITY PROJECTS IN BANGALORE

The implementation of every technological innovation for managing traffic systems and reducing $CO_2$ emissions in Bangalore requires the involvement of the bodies and agencies of the State of Karnataka, of city municipalities of Bangalore and of Bangalore's civil society and citizens in accordance with the rules of "Good Urban Governance". Whether it concerns new traffic data management systems or the introduction of electronic motor cars or car-sharing projects, the government bodies and agencies of the State of Karnataka and the city of Bangalore are involved as administrations – either by granting licences or through public private partnerships or as directly responsible administrations in the case of public transport management, planning and the provision of traffic infrastructure. "Good Urban Governance" in the traffic and transport sector requires the involvement of all stakeholders, be they the state, civil society or the private sector.

This study will look at the relevant framework of the relevant state and city government bodies and agencies and analyse the administrative and legal responsibilities of these government institutions involved in the planning and implementation of technological traffic projects in the context of "Smart Mobility". In particular, the study tries to describe the difference between the legal and constitutional theory in terms of relevant legislation versus practical political reality, which is significantly characterized by an absence of local urban autonomy and meaningful participation of citizens and civil society. For a practical political and administrative reality, legislation seems to be a major obstacle for the implementation of many technological and infrastructural innovations in India in general and in Karnataka and Bangalore in particular. To make an initial approach to this research objective, this study is based on relevant scientific literature only; it must also be proven and checked by interviews with the civil servants and citizens and research on the ground in Bangalore.

A brief account of the present traffic situation in Bangalore is followed by a description of the institutional framework of the State of Karnataka, and in a separate section, the institutional framework of the Bangalore municipality. This is followed by a very brief overview of major institutions involved with traffic systems and services. In the conclusion, a few suggestions for the implementation of new technological projects in a first test phase will be given.

# 1 THE TRAFFIC SITUATION IN BANGALORE

Environmentally sustainable and efficient urban transport and traffic systems are essential to maintain India's and Bangalore's high economic growth rates and thus to reduce poverty. For a long time, Bangalore had been India's "Garden City" and considered to be the country's most pleasant and hospitable urban town. Since the IT boom in the early 90s, which turned Bangalore into India's "Silicon Valley", this image has been suffering.[1] Bangalore has attracted significant international investment in IT industries and services, but it has failed to meet the similarly growing demand for urban infrastructure and for efficient transport systems in particular. Software workers' morning commutes to work are now reported to take over two hours in some cases.[2]

Bangalore has experienced a growth of population, economy and spatial area in the past 10 years that puts an extraordinary strain on its transport and traffic infrastructure and services. The population of Bangalore has increased by 46.68% between 2001 and 2011 according to the first provisional figures of the Indian Census data from March this year; it is currently the fastest growing Indian City.[3] The Bangalore metropolitan area has a population of 6.5 million.[4] Motor vehicle ownership is increasing very rapidly. Bangalore has 298 vehicles per 1,000 people; motorized two-wheelers are the main growth category with more than one million registered compared to about a quarter million cars.[5] Despite these figures, overall mobility rates are low, just above one trip per capita per day. The passenger markets are very heterogeneous, reflecting great inequality of income and wealth. Walking and cycling account for 17% of daily trips in Bangalore, and more than 40% of daily trips take place on public transport services. Bangalore still relies on street buses only, although the construction of a metro system has started after a planning period of 18 years. Due to modal shifts to two-wheelers, the trend for the use of public transport services has not substantially risen in the past decade, despite population increases and expected higher travel rates.

1 Woldemariam 2010, p. 1.
2 The Economist, March 3, 2005.

3 Census of India 2011.
4 ibid.
5 These are still figures from March 2005 based on the World Bank Report: Towards a discussion of support to Urban Transport development in India, p.6. The 2011 figures will be significantly higher.

# 2 INSTITUTIONAL FRAMEWORK OF THE STATE OF KARNATAKA

Bangalore is the capital of the State of Karnataka, which was founded as a federal state of the Indian Union on November 1st, 1956 by the States Reorganisation Act. Karnataka is governed by a parliamentary system. It has two houses: the Legislative Assembly, with 224 members who are elected for 5 years, and the Legislative Council, with 75 members of whom one third are elected every two years.[6] The government of Karnataka is headed by the Chief Minister, who is elected by the majority of the Legislative Assembly, formed by the party or a coalition of parties that have won the elections. The Chief Minister heads the council of ministers, consisting of members that he has appointed. The Chief Minister and Council run the legislative agenda and exercise most of the executive power of the state.

The constitutional and formal head of the state, however, is the Governor. The Governor is appointed by the President of India who follows a proposal by the government of the Indian Union. The Governor of Karnataka, as in any other Indian state, institutionally and politically represents the political will of the federal government in Delhi in Karnataka and is usually a politician from the ruling party in Delhi. The constitutional position of a Governor in the single Indian state indicates the centralistic structure of the Indian constitution and the Indian political system. The duality of a Chief Minister and a Governor in Karnataka is a source of political rivalry, often leading to political deadlocks, particularly if the state is ruled by a different party than the Union in Delhi. This is one more systemic reason for the failure of Karnataka governments to cope with adjusting traffic services and infrastructure in its capital Bangalore in response to the growth of Karnataka's economy and population since the early 1990s.

The State of Karnataka consists of 27 districts, with Bangalore by far the most populous.[7] The administration in each district is governed by a District Commissioner who belongs to the Indian (Federal) Administrative Service and is assisted by a number of officers belonging to Karnataka state service. The districts of Bangalore and of other towns in Karnataka are headed by a mayor (see below, Section 3.).

In the state government of Karnataka, the already constitutionally embedded rivalry between Chief Minister and Governor is further sharpened by the rivalry between the political parties in political reality. As in other Indian states and in the Union, the Congress Party and the Bharatiya Janata Party (BJP) are the main competitors apart from the Janata Dal (JDS) and other regional parties. Particularly in regional political parties, the political ties of the legislators with their party are not as close as in Western parliamentary systems. Civil society groups in Bangalore complain about the high degree of corruption in the two parliamentary houses of the state. Members of the parliament consider their position as a platform to earn money and repay those who supported their election.[8] Thus, it is not very unusual for single members of the opposition in the Legislative Assembly (MLA) to leave their party camp and vote with the ruling party. That is how the former Chief Minister of Karnataka BS Yeddyurappa was elected. His BJP won the state election, but did not receive sufficient seats in the Legislative Assembly, while the Congress and the most important regional party, the Janatha Dal (JDS), were pushed into opposition by the voters. In "Operation Lotus", BS Yeddyurappa, as leader of the BJP, "convinced" eight MLAs from Congress and six from JDS to resign the assembly seats and get elected under the BJP banner, thus achieving a majority in the assembly that elected him as Chief Minister. Since then, the Karnataka government has been in an ongoing crisis where trust votes in the parliament are raised by the opposition via the dirtiest political means and are somehow rejected by the Chief Minister. Now, the Governor of Karnataka from the Congress Party has even called to suspend the government.

This constant political standoff at the state level has serious and immediate political consequences for the city of Bangalore and its planning and management capabilities for the improvement of traffic infrastructure and services. The recent developments are only a final culmination of decades' long political impasses that have repeatedly contributed to the delay and blocking of reforms in Bangalore. Only the period from 1999 to 2004 under the Chief Minister S.M. Krishna from the Congress Party is considered to be different, due to his close ties to the Gandhi family at the Union level. During this period, his party had clear majorities in the state legislature and in the Bangalore City Council.[9]

6 Pylee 2003, pp. 357.
7 India 2010.
8 Ravichandar 2010, p. 1.
9 Woldemariam 2010, p. 2.

# 3 INDIAN MUNICIPALITIES

The 74th Constitutional Amendment Act of the Indian constitution (CAA) from 1992, that passed the National Parliament in 1993, granted Indian municipalities a constitutionally guaranteed independent status for the first time. The CAA sought to strengthen the existing municipal institutions with respect to (a) the autonomy of municipal/urban local bodies, (b) the promotion of decentralization of power, finance and political structures, and (c) the formation of appropriate structures, guidelines and functions.[10] The amendment stipulates that cities like Bangalore have to be constituted as Municipal Corporations and must establish a third executive tier on the local level within a Greater City Corporations; these are the ward committees.[11] The more detailed description of administrative rights and authorities of municipalities were mainly left to the State.

In addition, City Corporations had to establish ward committees for the local administration in districts of more than 300,000 dwellers.[12] For Bangalore, the number of ward committees was limited to 30. After considerable delay they were finally established in Bangalore in April 1999, but failed to work.[13]

Karnataka State law provides Bangalore's own elected officials with rather limited authority. The mayor serves for a one-year-term; he is elected by the City Council, which is the city parliament, and not by the citizens directly. Power within the Council, which consists of 100 members, is diffuse and reflects all the weakness of an Indian parliament mentioned above. Executive power rests with commissioners who – like all the heads of municipal departments – are appointed by the Chief Minister. Due to Bangalore's failure to conduct municipal elections in the early 1990s and as late as 2007, the state government has periodically administered Bangalore without deferring to any elected council or mayor. In terms of Bangalore's finances, state government transfers are its single most important source of funds. As the Chief Minister bears the ultimate responsibility for these transfers, he has an indirect veto power over large expenditures by the city. For these reasons, any real reform effort in Bangalore always hinges on Karnataka's Chief Minister.[14]

Although the 74th Constitutional Amendment intended to strengthen the political independence of municipal local bodies and to limit the political authority of a Chief Minister in a state, Karnataka's Chief Ministers since 1992 have done little to follow the rationale of this amendment in order to preserve their own political strength.

After an organizational restructure in 2006, Greater Bangalore City Corporation (Bruhat Bengalooru Mahanagara Palike, BBMP) has become the key "urban local body" (ULB), replacing the former local bodies, Bangalore City Corporation, 8 neighbouring Municipal Councils and 111 outlying villages. BBMP is only a new local administrative government structure. It has not been granted adequate powers by the state to plan and administer the city. Furthermore, against the rationale of the amendment, the state has created numerous parastatal bodies that are controlled by the state government in order to deliver basic urban services that would usually be a task for the local municipalities, such as water supply, energy, police and traffic infrastructure and services.[15]

This policy of the state of Karnataka concerning Bangalore led to an existence of a surfeit of municipal and parastatal bodies and agencies with overlapping responsibilities around urban traffic infrastructure and services. Urban traffic planning and management in Bangalore lacks the coordination of different activities and initiatives; even basic information relating to different sectors is extremely difficult to collect, collate and correlate. As a consequence, Bangalore has rather weak urban governance. "The city planners and administrators have clearly failed to anticipate and cope with the expansion of Bangalore".[16]

Apart from the official bodies, civil society in Bangalore is known for its vibrant community participation. As a response to the urban governance failure in Bangalore, its civil society has contributed considerably to shaping the policies and governance structures and has always interfered whenever there has been any apathy on the part of the administration towards activities of interest to society at large. Meanwhile, improving urban governance and infrastructure is the objective of quite well-known NGOs like Citizens Voluntary Initiative for the City (CIVIC) and Janaagraha. Bangalore Agenda Task Force (BATF) was a much praised experiment to promote public private partnership and bring together citizens, NGOs, industry representatives and local bodies.[17]

10 Nallathiga 2008, p. 2.
11 Hamid 2004, p. 3.
12 Rani/Roy 2009, pp. 37.
13 ibid.
14 Woldemariam 2010, p. 3.
15 Centre for Ecological Sciences, Indian Institute of Science 2007, p. 2.
16 Paul 2002, p. 32.
17 Woldemariam 2010, p. 5.

# 4 MAJOR BODIES AND INITIATIVES

As Bangalore has a more fragmented institutional network for urban transport than found in most other places[18], it is necessary to give a brief overview about the most import bodies and agencies:

- The BBMP or Bangalore Municipal Corporation (BMC) administers the city government. Specifically, its Department of Public Works is responsible for the maintenance and improvement (including broadening) of local roads; in addition, the national/state roads within city limits are handed over to the BBMP for maintenance, traffic and parking management, and law enforcement.
- The Bangalore Development Authority (BDA) was founded in 1976 to undertake the planning and development of land use. It acquires the land and develops it as residential lay outs which eventually are handed over to the city corporation, often involving the extension of city limits. Its jurisdiction comprises the Bangalore Metropolitan Region (BMR), consisting of Bangalore Urban District Area/Bangalore Metropolitan Area (BMA), Bangalore Rural and Ramanagaram.[19] It is an authority of the state of Karnataka.
- The Bangalore Metropolitan Region Development Authority (BMRDA) is an autonomous body created by the Government of Karnataka under the BMRDA Act 1985.[20] It has jurisdiction over the ring beyond the BDA's jurisdiction. Its purpose was to act as an umbrella agency for coordinating planning and development, but it never took off.
- Karnataka Road Development Corporation Ltd. (KRDCL), founded in 1999, registered under the Companies Act, is entirely owned by the Government of Karnataka. Its objective is to mobilize private sector funds for the construction and operation of roads and bridges where tolls can be charged. In addition, it has to develop and implement road traffic infrastructure schemes in Bangalore.
- Bangalore Mass Rapid Transit Ltd. (BMRTL) was set up in 1994 to support rapid transit projects (metro, railway) like KRDCL does for roads.
- Karnataka Urban Infrastructure and Development Finance Corporation (KUIDFC), entirely owned by the Government of Karnataka. Its task is interaction with the private sector; it is a model agency for the Megacity Fund.
- The Bangalore Metropolitan Transport Corporation (BMTC) is an independent company, entirely owned by the State of Karnataka, and managed by a Board of Directors, all appointed by the State. It runs the public bus transport in Bangalore. Technical performance indicators place BMTC among the top 2-3 urban transport companies in India.
- The Regional Transport Office (RTO) is responsible for vehicle tax collection and for issuing vehicle licenses.
- There are other ad hoc bodies like the Transport Advisory Forum and Task Force on Traffic and Transport.

18 World Bank 2005, p. 57.
19 TERI University 2009, p. 12.
20 Nallathiga 2008, p. 12.

# 5 CONCLUDING RECOMMENDATIONS FOR SUBSEQUENT IMPLEMENTATION STEPS

With regards to the various technical projects that were presented at the GRIP IT Workshop in Bangalore on May 20th, 2011, in the context of "Smart Mobility", the following suggestions can be made, by drawing conclusions about the highly fragmented institutional framework for urban transport that characterizes Bangalore's weak urban governance, as described above:

For the initial phase of testing the viability of every technological project, a sub-district of the city should be identified where the project could be tested. The selection of the sub-district should follow the criteria that best suit the initial test and will depend on the income structure of the inhabitants of this sub-district, land use, preferred journey distances of the users etc.

Depending on the kind of technology used for the project, all relevant city and state government bodies and agencies that could eventually become relevant for its implementation should be approached and involved early.

Any government fund eventually related to the project should be approached, as well as any private company that could be interested.

It is important to also include the local ward committee[21], even if it has almost no responsibility.

Relevant NGOs and local civil society groups should be identified and included, to ensure that the project is not only accepted by the government at the top, while being rejected by civil society groups. The plans for a TATA group construction plant for the production of the new Nano in Singur in the State of West-Bengal were finally abandoned in September 2008, after serious protests from the citizens against the decision of the State Government to provide the company with land for the construction plant. This should serve as an example and a warning of how not to proceed.

21 The importance of the ward committees in Bangalore for local administration issues is underlined in Benjamin 2000, pp. 35 – 56, (52); Rani 2009, pp. 40.

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# PLaSMA
# Multiagent Simulation

# Last-Mile Connectivity Bangalore

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**Recommeded citation:** Stefan Edelkamp et al.: PLaSMA Multiagent Simulation Last-Mile Connectivity Bangalore, acatech Materialien German Indian Partnership for IT Systems, München/Berlin 2014.

**Published by:**
acatech – National Academy of Science and Engineering 2014

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E-mail: info@acatech.de
Internet: www.acatech.de

ISSN: 2191-8481/ISBN: 978-3-942044-37-0

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Coordination: Prof. Dr. Otthein Herzog, Dr. Ulrich Glotzbach
Layout conception: acatech
Conversion und typesetting: work:*at*:book / Martin Eberhardt, Berlin

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# 1 INTRODUCTION

This *Last-Mile Connectivity Study for Bangalore* was conducted for the National Academy of Science and Engineering (acatech) by the Center for Computing and Communication Technologies (TZI) at the University of Bremen in cooperation with Centre for Infrastructure, Sustainable Transportation and Urban Planning, Indian Institute of Science (CiSTUP).

The study documents the outcome of the implementation effort for addressing last-mile connectivity in the city of Bangalore, India within the multiagent simulation system PlaSMA. It reports on the simulation setup and its outcome in form of a feasibility assessment. It comes with a description on the agent model and its routing infrastructure. The multiagent model is generic in the sense that different transport agencies and autonomous vehicles can be added. It integrates planning and execution, research topics which are currently in vogue.

The study is based on the User Needs Study executed by CiSTUP that was presented at the full-day symposium *Socio–Economic Challenges for Smart Cities in India* by the National Academy of Science and Engineering. It also refers to the 2010 *Draft Final Report of the Comprehensive Traffic and Transportation Study for Bangalore Metropolitan Region* and the 2010 *Traffic Management Plans for Major Towns in Bangalore Metropolitan Region* conducted by WilburSmith Associates for the Bangalore Metropolitan Region Development Authority.

Eventually, the simulation should become the basis for travel information and route planning to be integrated into an internet platform for urban mobility in mega-cities.

The current study was presented in the context of a full–day symposium on *Smart City Technologies as Innovation Drivers* on Wednesday, April 25, 2012 at the Faculty Hall, Indian Institute of Science, Bangalore. The Symposium was organized by CiSTUP and acatech.

## 1.1 GOAL OF THE STUDY

In the study, we show that the multiagent framework PlaSMA[1] is appropriate for modelling and simulating the logistics of passengers in a public transport network (later for other sorts of goods), in the city of Bangalore, India with the focus on studying options for last-mile connectivity.

The study implements a simulation scenario, starting at a higher level of abstraction drilling down to a running program. As the multiagent simulation is obtained from a computer science perspective, we provide some IT aspects like configuration files, finite-state machine models of the agent, and source code.

In the context of a joint German-Indio Initiative on improved eMobility, the solutions should eventually consider different scenarios for urban mobility, including eBikes and other sorts of electrification.

We are aware that at the current point in time the traffic needs in Bangalore (and similar mega-cities in India) are very different to European metropolitan areas, as a different mixture of vehicles and road infrastructure applies: besides cars, and buses there are many motorbikes and auto-rickshaws and fewer bicycles operating on the street. The control of traffic flow is not enforced strictly, and the number of vehicles is increasing such that it is not difficult to predict that throughput will drastically decrease in the next few years. In rush hours, it is even difficult for pedestrians to cross streets. More-over, pollution makes life in the mega-city increasingly less enjoyable.

We are aware that this study is only a very preliminary step towards a rich simulation of the interactions that happen in urban mobility. The accuracy, scale and complexity of the model can be significantly increased. Thus, the study does not provide any conclusive report on how to improve traffic in Bangalore.

## 1.2 LAST-MILE CONNECTIVITY

Last Mile Tour Planning is an established objective in Operation Research, especially in (Distribution) Logistics applications, where one is concerned with the planning and controlling of Transport and Logistics Systems. Within this research domain, the Delivery Problem is encountered most frequently. In the Delivery Problem the number of costumers and their requirements is known. Given a number of vehicles of different capacity the task is to deliver the requested goods while fulfilling all side constraints (usually time and capacity restrictions) and minimizing total transport costs.

Instead of a delivery, we might be confronted with the Dual Collection Problem, where goods have to be collected from their produc-

1 Website: http://plasma.informatik.uni-bremen.de.

ers (e.g. mail boxes). Also hybrids like Pick-Up and Delivery Problems are frequently encountered. In the case of our study for last-mile connectivity, we are concerned with the transportation of people (often called the School Bus Problem). Sometimes tours have to be rescheduled while they are already in progress, such as in Dial-a-Ride Problems. Time constraints in the form of time windows take high priority. Traffic may have an important impact on executing a tour plan.

Usually, the entire problem is too complex to be solved optimally off-line. Therefore, multiagent simulation can help to cover the dynamics of a system model and to evaluate and optimize key measurements.

Algorithmically, Dijkstra's Single-Source Shortest Path algorithm (or the A* variant of it that includes goal distance estimates), Floyd & Warshall All-Pair Shortest Paths algorithm, as well as solutions to the Travelling Salesman or Chinese Postman Problems are of core interest. There are more involved variants like the Canadian Traveller Problem that can help to solve tour planning problems. Additionally, assignment optimization problems of goods into vehicle time tabling (e.g. Temporal Networks) and Project Scheduling (e.g. PERT) are concerns. In most cases, the entire task is too complex to be solved as a whole, and partitioning, abstraction, or simulation has to be applied. For mapping query locations to an existing routing infrastructure, a spatial data structure has to be constructed that promptly answers nearest neighbour queries. We will see that Voronoi diagrams and Delaunay triangulations are most appropriate.

In our study, we will see that even in the restricted scenario of last-mile connectivity for air passengers there is a dynamic change in the number and status of the simulation agents and their requirements. We will also see that the Single-Source Shortest Path algorithm (or a sequence of calls to it) is the most important subroutine, both for planning and subsequent plan execution.

## 1.3 OVERVIEW

In the following chapter we drill down to the scenario and requirement analysis and present the data we obtained from CiSTUP and post-processed. In Chapter 3, we consider how to configure the PlaSMA system, and how to define the infrastructure needed for a simulation. We take the bus infrastructure as an example, explain how to run a simulation, and uncover the underlying concept of the PlaSMA simulator. In Chapter 4, we introduce the design of the agent model in the form of displaying and discussing the finite state machines that underlie the implementation and provide the stubs for the Java source code. In Chapter 5, we conduct a feasibility assessment on our implementation, starting from the database infrastructure and the computational requirements, via the implementation of the agents and simulation results (in the form of screen shots) and reports on key measurements. Chapter 6 considers our implementation refinement for shortest path search that was necessary to execute the simulation in real- time. Chapter 7 proposes an approach for nearest neighbour search that has been implemented but not integrated into the PlaSMA system because of insufficient performance. Better implementations are discussed. In Chapter 8, we wrap up our results and consider some research and implementation avenues for future work.

# 2 SCENARIO AND REQUIREMENTS ANALYSIS

The BMTC bus routes and associated information on travel fares and fleet sizes were supplied by the CiSTUP authorities via Prof. Dr. Sitharam. They refer to real-life BMTC and taxi data. After some initial rounds of discussion, we decided to look at the last-mile connectivity problem of passengers at the airport first.

## 2.1 BUS ROUTES

Table 1 shows 12 bus routes from the airport to the city (and back) as a real-world snapshot of a specific day. It shows the name of the route, where it starts and ends, the length of the route, the sequence of stops, as well as the cost of transport together with the number of schedules and depots.

With the help of Google Maps, we looked for the GPS coordinates of all listed bus stops (as precisely as possible). The subsequent list of GPS-annotated stops (whitespace eliminated) is given below.

```
JeevanBimaNaga 12.967633,77.654707
ChinmaiahHospital 12.978422,77.646039
CMHRoad 12.978422,77.638577
Halsuru 12.976331,77.626727
TajResidency 12.975788,77.606599
LakesideHospital 12.988249,77.617911
StJohnsRoad 12.991135,77.613813
JCNagara, 13.001547,77.612042
MekhriCircle 13.014489,77.583879
Hebbala, 13.20034,77.660011
JnOfKogiluCross 13.20034,77.660011
RVDCollege 12.925139,77.499354
Jnr5thBlock 12.91715,77.583511
Jnr4thBlock 12.928402,77.584326
AshokaPillar 12.943605,77.58463
ShanthinagraBusStn, 12.954041,77.592523
RichmondBClub 12.965552,77.603204
GeneralPostOfficeGPO 12.984047,77.597076
HighgroundsPS 12.984653,77.583983
WindsorManor 12.993853,77.585253
PalaceGuttahalli 12.999958,77.584369
HopeFarm 12.9839,77.751997
WhitefieldPostOfficee12.969724,77.749854
Siddapura, 12.95632,77.731637
Marathhalli Bridge 12.956529,77.701274
HAL 12.958474,77.665772
HotelLeelaPalace 12.959979,77.646639
Domlur 12.961694,77.638485
CommandoHosptl 12.962656,77.627885
Koramangala 12.92493,77.634444
StJohnsHospital 12.929615,77.615529
Forum 12.932417,77.612822
DairyCircleRd 12.947056,77.594454
ShanthiNagaraBusStand 12.947129,77.594427
RichmondCircle 12.965688,77.602903
IndianExpress 12.984057,77.597217
Vasanthnagara 12.992808,77.594994
RMGuttahalli 12.999707,77.583836
BDAComplex 12.912862,77.637869
KoramangalaSonyWorld 12.936976,77.626623
InnerRingRoad 12.935094,77.623984
Dell 12.954542,77.641447
TrinityCircleM 12.973111,77.617106
MGRoad 12.976624,77.601449
Bommanahalli 12.898389,77.618031
CentralSilkBoard 12.916648,77.621663
Agara 12.961297,77.636107
MarathhalliRingRoad 12.956529,77.701253
KRPuramRailwayStation 13.000753,77.674302
KalyanaNagara 13.026614,77.638468
Nagavara 13.043651,77.60695
MarathalliBridge 12.956989,77.701802
HotelGrandAshoka 12.992431,77.582442
Vijaynagar 12.972463,77.538285
Basaveshwara Nagar 12.991783,77.538496
ModiHospital 12.997825,77.545788
Navarang 12.998118,77.551585
MalleshwearamBusStand 13.000878,77.563391
PadmanabhaNagra 12.918321,77.559589
Kathriguppe 12.925484,77.549699
HosakerehalliCross 12.931037,77.542723
BankColony 12.964893,77.52339
Chamarajpet 12.960335,77.56358
MysoreCircle 12.960126,77.556417
MCTC 12.943867,77.526612
Deepanjali 12.951238,77.537144
Nagara 12.974742,77.548792
Vijaya Nagara 12.972463,77.538303
SadashivNagaraBashyamCircle 13.008551,77.580253
JPNagara3rd Phase 12.928402,77.584541
Jayangara9thBlock 12.911043,77.578654
JayanagarBusStation 12.928318,77.584412
MysoreBankVSD 13.000167,77.55249
BasaveshwaraCircle 12.984593,77.588276
```

Table 1: BTMC Route Details on 20-01-2012.

| ROUTE | from | to | Via Places | length | cost | schs | depots |
|---|---|---|---|---|---|---|---|
| BIAS-4 | HAL OLD AIRPORT | BIAL | Jeevan Bima nagar, Chinmaiah Hospital , CMH Road, Halsur, Taj Residency, Lakeside Hospital, St.Johns Road, J.C.Nagara, Mekhri Circle, Hebbala, Jn.of Kogilu Cross | 46 | 180 | 8 | 7 |
| BIAS-5 | JP NAGARA 6TH PHASE | BIAL | RV D College, Jnr 5th blk, Jnr 4th Block, Ashoka Pillar, Shanthinagra Bus Stn, Richmond (B Club), GPO, Highgrounds PS, Windsor Manor, Guttahalli, Mekhri Circle, Hebbala, Jn. of Kogilu Cross, | 47 | 180 | 8 | 13 |
| BIAS-6 | KADUGODI BUS STATION | BIAL | Hope Farm, Whitefield Post Office, Siddapura, Marathhalli Bridge, HAL, Hotel Leela Palace, Domlur, Commando Hosptl, Taj Residency, Lakeside Hospital, St.Johns Road, J.C.Nagara, Mekhri Circle, Hebbala, Jn.of Kogilu Cross, | 55,3 | 200 | 5 | 7 |
| BIAS-7 | H.S.R. LAYOUT BDA COMPLEX | BIAL | Koramangala, St.Johns, Forum/Checkpost, B Dairy, Shanthi- nagara Bus Stand, Richmond Circle, Indian Express, Vasanth- nagara, R.M.Guttahalli, Mekhri Circle, Hebbala, Jn.of Kogilu Cross, | 50 | 180 | 4 | 25 |
| BIAS-7-A | H.S.R. LAYOUT BDA COMPLEX | BIAL | Koramangala, BDA Complex, Koramangala Sony World , Inner ring road, Dell, Domlur, Commando Hosptl, Trinity Circle, M.G.Road, GPO, Windsor Manor, .M.Guttahall Mekhri Circle, Hebbala, Jn.of Kogilu Cross, | 48 | 180 | 4 | 25 |
| BIAS-8 | ELECTRONIC CITY | BIAL | Bommanahalli, Silk Board, Agara, Marathhalli Ring Road, K.R.Puram Railway Station, Kalyana Nagara, Nagavaara, Hebbala, Jn.of Kogilu Cross. | 66 | 240 | 8 | 7 |
| BIAS-8A | KUVEMPU NAGARA (BTM LAYOUT) | BIAL | Central Silk Board, Agara, Marathalli Bridge, Kalyan Nagar, Hebbala, Jn.of Kogilu Cross. | 58 | 200 | 4 | 25 |
| BIAS-9 | KEMPEGOWDA BUS STATION | BIAL | Hotel Grand Ashoka, Mekhri Circle, Hebbala, Jn.of Kogilu Cross | 35,5 | 165 | 9 | 7 |
| BIAS-10 | CHIKKALASANDRA BUS STATION | BIAL | Vijaynagar, Basaveshwaranagar, Modi Hospital , Navarang , Malleshwearam, Mekhri Circle, Hebbala | 52,2 | 200 | 1 | 13 |
| BIAS-11 | CHIKKALASANDRA BUS STATION | BIAL | Padmanabha Nagra, Kathriguppe, Hosakerehalli Cross, Bank Colony, Chamarajpet, Mysore Circle, MCTC, Deepanjali Nagara,Vijayanagara, Navarang, Malleshwaram Bus Stand, Sadashiv Nagara Bashyam Circle, Mekhri Circle, Hebbala, Jn.of Kogilu Cross | 52,2 | 200 | 4 | 13 |
| BIAS-12 | KUVEMPU NAGARA (BTM LAYOUT) | BIAL | J.P.Nagara 3rd Phase, Jayangara 9th Block, Jayanagar Bus Station, Ashoka Pillar, Shanthi Nagar Bus Station, Corporation, Mysore Bank, VSD, Basaveshwara Circle, Mekhri Circle, Hebbala, Kogilu Cross. | 50 | 200 | 6 | 25 |
| TOTL | 11 | | | | | | |

## 2.2 FARES, FLEET STRENGTH, AND TRANSPORTED PASSENGERS

Table 2 displays the cost of bus and taxi transportation both on a per km basis and for the entire journey (end-to-end). The assumed taxi rate is Rs 17.5 per km, where BMTC bus prices are calculated for one to four people. The total number of passenger transports for the BMTC measured for one particular week (partitioned into single and return travel as well as into single ticket or bus pass ticket) is shown in Table 3, while the taxi fleet strength and the trips per day are shown in Table 4. These tables show that there are about 6,000 people using the bus and about 10,000 people taking a taxi on a given day.

To model the people in the system requires statistical data on where people live, work and shop – in other words their daily schedule. We are aware that this data is difficult to acquire and has to be statistically approximated. Indirect parameters like the number of passengers boarding and disembarking can be measured in the real world, but were not accessible for this study. Our approach to generating passengers and vehicles still needs to be refined but is a rough approximation, choosing the start and end location at random. A slightly more complex model uses a random walk strategy starting at a random stop to ensure that transport requests are not far from the encoded bus stations.

We decided to simulate the flow of humans and vehicles along edges in the routing graph. We did not model the traffic itself (jams etc.) on a microscopic level, so that each passenger and each vehicle is one agent in the system. To avoid scalability issues (Bangalore has approx. 10 million inhabitants), we plan to cluster groups by exploiting the option for abstraction within the PlaSMA toolkit.

Table 2: BMTC cost comparison with Taxi Service.

| ROUTE | from | to | length | BMTC 1 Person | | BMTC 2 Person | | BMTC 3 Person | | BMTC 1 Person | | TAXI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | FULL | PER KM | FULL | PER KM | FULL | PER KM | FULL | PER KM | |
| BIAS-9 | KEMPEGOWDA BUS STATION | BIAL | 35,5 | 165 | 4,65 | 330 | 9,3 | 495 | 13,94 | 660 | 18,59 | 621 |
| BIAS-4 | HAL OLD AIRPORT | BIAL | 46 | 180 | 3,91 | 360 | 7,83 | 540 | 11,74 | 720 | 15,65 | 805 |
| BIAS-5 | JP NAGARA 6TH PHASE | BIAL | 47 | 180 | 3,83 | 360 | 7,66 | 540 | 11,49 | 720 | 15,32 | 823 |
| BIAS-7-A | H.S.R. LAYOUT BDA COMPLEX | BIAL | 48 | 180 | 3,75 | 360 | 7,5 | 540 | 11,25 | 720 | 15 | 840 |
| BIAS-7 | H.S.R. LAYOUT BDA COMPLEX | BIAL | 50 | 180 | 3,6 | 360 | 7,2 | 540 | 10,8 | 720 | 14,4 | 875 |
| BIAS-12 | KUVEMPU NAGARA (BTM LAYOUT) | BIAL | 50 | 200 | 4 | 400 | 8 | 600 | 12 | 800 | 16 | 875 |
| BIAS-10 | CHIKKALASANDRA BUS STATION | BIAL | 52,2 | 200 | 3,83 | 400 | 7,66 | 600 | 11,49 | 800 | 15,33 | 914 |
| BIAS-11 | CHIKKALASANDRA BUS STATION | BIAL | 52,2 | 200 | 3,83 | 400 | 7,66 | 600 | 11,49 | 800 | 15,33 | 914 |
| BIAS-6 | KADUGODI BUS STATION | BIAL | 55,3 | 200 | 3,62 | 400 | 7,23 | 600 | 10,85 | 800 | 14,47 | 968 |
| BIAS-8A | KUVEMPU NAGARA (BTM LAYOUT) | BIAL | 58 | 200 | 3,45 | 400 | 6,9 | 600 | 10,34 | 800 | 13,79 | 1015 |
| BIAS-8 | ELECTRONIC CITY | BIAL | 66 | 240 | 3,64 | 480 | 7,27 | 720 | 10,91 | 960 | 14,55 | 1155 |

Table 3: BMTC Commuter numbers.

| Date | Day | Departure from BIAL to City | | Departure from City to BIAL | | Total commuters |
|---|---|---|---|---|---|---|
| | | Ticket | Pass | Ticket | Pass | |
| 05.02.2012 | Sunday | 2954 | 349 | 2528 | 566 | 6397 |
| 06.02.2012 | Monday | 2251 | 523 | 2061 | 1220 | 6055 |
| 07.02.2012 | Tuesday | 1902 | 508 | 2151 | 1430 | 5991 |
| 08.02.2012 | Wednesday | 1715 | 452 | 2079 | 1273 | 5519 |
| 09.02.2012 | Thursday | 1899 | 512 | 2187 | 1146 | 5744 |
| 10.02.2012 | Friday | 2213 | 498 | 2673 | 1289 | 6673 |
| 11.02.2012 | Saturday | 2502 | 362 | 2668 | 711 | 6243 |

Table 4: Taxi Fleet Strength.

| Sl No. | Service Provider | Fleet strength | Trips per cab per day | Total trips per day |
|---|---|---|---|---|
| 1 | EASY-CAB | 650 | 4 | 2600 |
| 2 | MERU | 650 | 4 | 2600 |
| 3 | KSTDC | 500 | 4 | 2000 |
| 4 | CELL-CAB | 200 | 4 | 800 |
| 5 | CARZONE | 100 | 4 | 400 |
| 6 | AKBAR-TRAVELS | 80 | 4 | 320 |
| 7 | Unauthrized Operations | 500 | 4 | 2000 |
| **TOTAL** | | **2680** | **4** | **10720** |

Including traffic information is subject to current research in our group. There are initiatives in PlaSMA to include traffic jams into the simulation, but so far edge following is mainly determined by the speed of the human or vehicle and the type of road.

## 2.3 IMAGES

Using images for the agents can ease control of the simulation in the PlaSMA Aurora GUI. As shown in Figure 1, we designed icons for taxis, bikes, people, buses, bus stops, and auto-rickshaws. Remember that the GUI is mainly a tool for understanding the flow of the simulation on a given infrastructure. For large-scale studies the frontend is not needed.

Figure 1: Images for the PlaSMA GUI.

# 3 MULTIAGENT-BASED SIMULATION WITH PLASMA

PlaSMA is an event-driven multiagent simulation system which has been designed to solve and evaluate scenarios within the logistics domain. In particular, the system allows the simulation of autonomous logistic processes, where autonomous agents perform planning and decision processes. The platform is based on the FIPA-compliant Java Agent Development Framework (JADE). JADE offers components for agent communication and coordination. PlaSMA extends this architecture as a simulation middleware for discrete event time progression.

Downloads for the PlaSMA System are available at http://plasma.informatik.uni-bremen.de/download.html

The user guide can be found at
http://plasma.informatik.uni-bremen.de/download/release_12.02/plasma_userguide_12.02.pdf

For interaction with partners there are installation and developer guides and scenario generators available for PlaSMA (these can be made accessible in the context of or subsequent to the study). There are on-going integration efforts addressing PlaSMA's scalability.

PlaSMA refers to a Server-Client architecture, so that the server can run on a different machine than the client. The GUI Client is called Aurora.

PlaSMA requires JDK 1.6 to run. The following libraries are currently in use:

1) Java Agent DEvelopment Environment (JADE) (version 4.1)
2) Nasa WorldWind (version 2.1)
3) PostgreSQL (version 9.1)
4) PostgreSQL JDBDC 4 Driver (version 9.1)
5) SQLite (version 3.7.4)
6) Google Guava (version 11.0)

The advantages of the multiagent framework, in contrast to other forms of logistic models, are that the approach is inherently distributed, as agents act as individual or are clustered in groups, and there is ontological knowledge encoded in the relations between transport goods. Simulation experiments are thus defined by OWL ontology and user-implemented software agents, which represent the individuals defined in the ontology. Although the main focus is on logistics simulation, the system is suitable for other domains as well.

In general, the PlaSMA architecture consists of the following components: world model, physical objects, infrastructure, action triggers, behaviour definitions, and agents. The agents in a PlaSMA simulation scenario have methods for, e.g., sending and receiving messages, as well as executing actions within defined behaviours. The simulation agent is a logical simulation process that represents an environmental process, an organization, or a set of physical objects.

A PlaSMA scenario's world model can be modelled as a graph so the infrastructure of the logistics domain can be mapped accordingly. Graph nodes represent, e.g., traffic junctions or logistic sources and sinks. Graph edges represent roads, rails, waterways, etc. For modelling real transport infrastructures, it is possible to import a graph from OpenStreetMap.

The PlaSMA application is platform-independent. It runs with the Java Virtual Machine on Windows and Linux. To run PlaSMA, one can simply get it from our download page,
http://plasma.informatik.uni-bremen.de/download.html
unpack the file and start both the server and the client. To learn more about PlaSMA, one should have a look into the PlaSMA User Guide and the Javadoc API documentation. Both documents provide information on how to use the PlaSMA System and how to create a scenario from scratch.

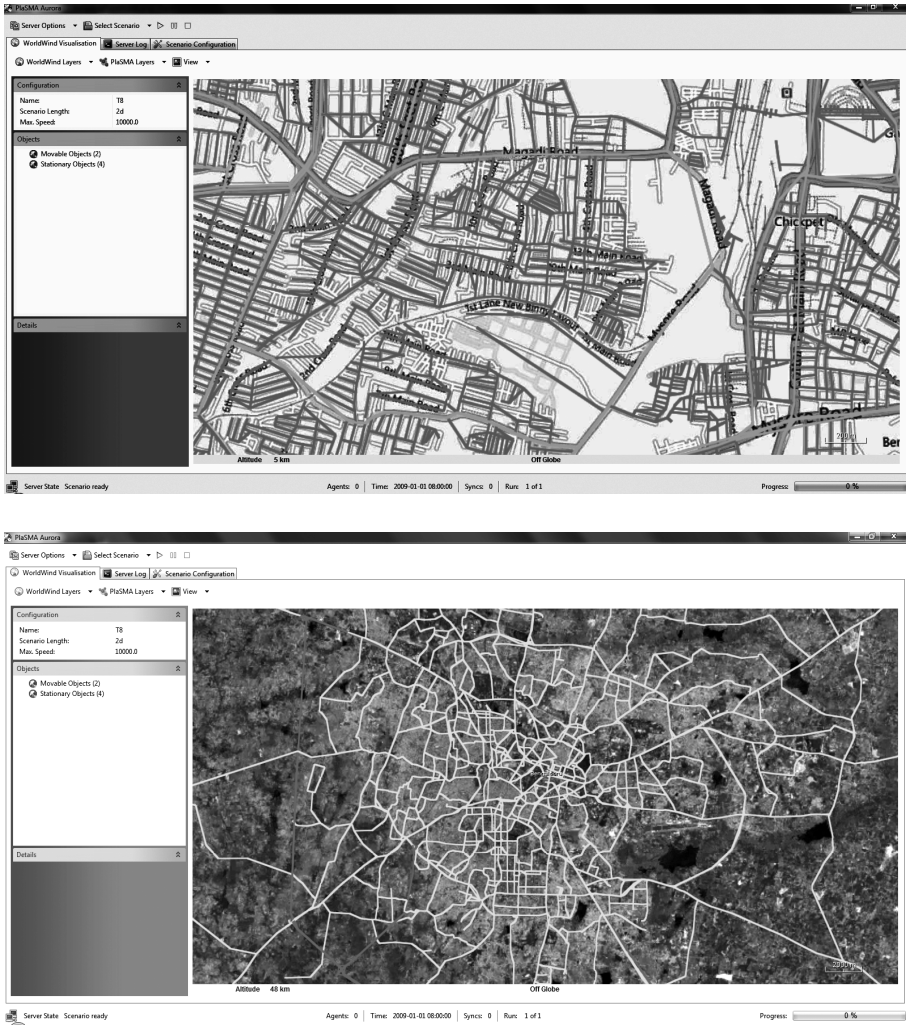
The PlaSMA software package contains a server application and two different client applications. The PlaSMA server runs the simulation either on a local machine or on multiple computers in parallel. The client (GUI or console) starts simulation scenarios and provides information about simulation progress. The GUI allows the configuration of simulation parameters and shows simulation entities on a 3D world map. The command line client for the console is for advanced users and only shows the percentage of simulation progress.

## 3.1 CONFIGURATION OF PLASMA SCENARIOS

Configuring a scenario in PlaSMA is simple. After installing the user configuration, the file has to be adapted.

```
#  SCENARIO USER CONFIGURATION
#  Location of the PlaSMA Core System
#
#  For Windows  users please note that in the specification of the path to the
#  PlaSMA installation  directory,  single backslashes ' \ '  must be substituted
#  with double backslashes  ' \ \ '  as in:
#  plasma.location=C : \ \Users \ \myUser \ \Plasma
#
#  Furthermore,  please specify an absolute rather than a relative path.
plasma.location=C : \ \Users \ \edelkamp \ \workspace \ \plasma_core \ \app
#
If the scenario depends on jars from other scenarios, the latter need to
be deployed properly to your Plasma installation. Afterwards,  you can
configure the build process such that the deployed jars from the scenarios
you depend on, are used during compilation.  You do this, by uncommenting the
following line in case of dependencies:
scenario.hasDependencies
#  PlaSMA Core Libraries Required to build the Scenario
plasma.libs=$ { plasma.location } / lib
#  Scenario Build Structure
scenario.src=src
scenario.build=build
scenario.test=test
scenario.lib=lib
```

Figure 2: Infrastructure as extracted from OpenStreetMap and shown in PlaSMA's Aurora GUI.




## 3.2 DEFINING THE INFRASTRUCTURE

To perform the simulation, we extracted route navigation data from OpenStreetMap in OSM-format. Limited information on real-life bus schedules are added manually based on the data provided by CiSTUP and BMTC. For the bus stops GPS coordinates have to be found, for which we used the facilities of Google Maps. We do not have a lager study.

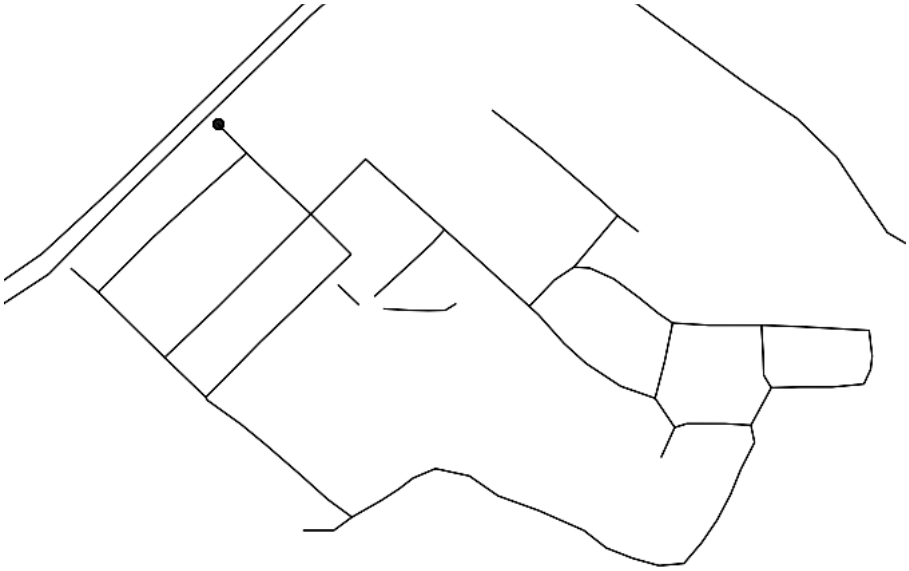
One possible download server for extracting the OpenStreetMap data that we used is located at http://download.geofabrik.de

As Bangalore was not predefined, we defined a bounding box on the city and included streets if they crossed the boundaries instead of clipping them. The GPS/GIS data on the road infrastructure of Bangalore was exported to a Postgres database that can be imported directly into a database using a PlaSMA tool.

Figure 2 shows the parts of the road infrastructure that we used in the PlaSMA GUI Aurora at two different zoom levels. The top picture shows (parts of) Bangalore's inner city roads, while the bottom picture shows (parts of) Bangalore's truck roads. This also shows the effect of zooming in the world-view of the scenario's road infrastructure, and the integration of different visibility layers.

In some cases, we observed problems with the connectivity of the Bangalore graph in OpenStreetMap. Figure 3 provides an example of a magnified part of the graph that splits into several connected components. If the start and end locations of a query are contained in different components of the graph, our shortest path search module detects that there is no possible solution.

Figure 3: Connectivity problems in an OpenStreetMap graph.



## 3.3 MODELLING EXAMPLE

In the context of this study, we first implemented a bus agent realizing a driving behaviour with multiple stops. The bus is invoked with and follows a predefined daily time table (its schedule with arrival and departure times at each stop on his route). If stops are not on the map, they are attached to it by adding an edge to the nearest intersection. The bus agent computes shortest paths between stops using the road infrastructure. Since routing seemed to be a bottleneck, we refined the A* search algorithms that computes the shortest path from each stop to the next.[2]

For modelling buses, we wrote a new behaviour that is able to follow a predefined sequence of stops. First, we needed a mapping from GPS coordinates to stops within the scenario ontology:

```
<tlo:Coordinates rdf:ID="BangaloreBIAL">
    <tlo:latitude rdf:datatype="&xsd;float">13.198889</tlo:latitude>
    <tlo:longitude rdf:datatype="&xsd;float">77.705556</tlo:longitude>
</tlo:Coordinates>

<trans:BusStop rdf:ID="BangaloreBIAL_Stop">
    <tlo:positionedAt rdf:resource="#BangaloreBIAL"/>
</trans:BusStop>

<tlo:Coordinates rdf:ID="JeevanBimaNaga">
    <tlo:latitude rdf:datatype="&xsd;float">12.967633</tlo:latitude>
    <tlo:longitude rdf:datatype="&xsd;float">77.654707</tlo:longitude>
</tlo:Coordinates>

<trans:BusStop rdf:ID="JeevanBimaNaga_Stop">
    <tlo:positionedAt rdf:resource="#JeevanBimaNaga"/>
</trans:BusStop>

...
```

2 We found that computing the fastest route was slow, so we stuck to computing the shortest route.

Next, we needed to provide the IDs, starting points, and velocities of the buses.

```
<trans:Bus rdf:ID="Bus.01">
<rdf:type rdf:resource="&tlo;StorageFacility"/>
<tlo:storageCapacity rdf:datatype="&xsd;float">1.0</tlo:storageCapacity>
<trans:maximumVelocity rdf:datatype="&xsd;integer">100</trans:maximumVelocity>
<tlo:maximumPossibleVelocity rdf:datatype="&xsd;integer">110</tlo:maximumPossibleVelocity>
<tlo:positionedAt rdf:resource="#BangaloreBIAL"/>
</trans:Bus>
<trans:Bus rdf:ID="Bus.02">
<rdf:type rdf:resource="&tlo;StorageFacility"/>
<tlo:storageCapacity rdf:datatype="&xsd;float">1.0</tlo:storageCapacity>
<trans:maximumVelocity rdf:datatype="&xsd;integer">100</trans:maximumVelocity>
<tlo:maximumPossibleVelocity rdf:datatype="&xsd;integer">110</tlo:maximumPossibleVelocity>
<tlo:positionedAt rdf:resource="#BangaloreBIAL"/>
</trans:Bus>
</rdf:RDF>
```

As defining the ontology for a static model of each bus individually is inflexible and tedious, we later decided to generate bus instances by the bus company agent dynamically within the simulation, so that only one ontological representation of a bus, its parameters, and its pictorial representation remained.

### 3.4 IMPLEMENTATION FOR BUS INFRASTRUCTURE

Having specified the bus stops, we need to read their timetable. For ease of specification, we chose a comma-separated text file with a sequence of starting times for buses operating on a line and the relative (expected) times to get from one bus station to the next. We selected four of the above 11 bus lines and split each of them into their outward and return directions.

```
# Line=BIAS-4
# Start_Times=07:00, 08:00, 09:00, 10:00, 10:30, 11:00, 11:30, 12:00, 12:30, 13:00, 13:30, 14:00, 14:30, 15:00,
      15:30, 16:00, 16:30, 17:30, 18:00, 18:30, 19:00, 20:00, 21:00, 22:00
JeevanBimaNaga_Stop | 00:01 | 00:01
ChinmaiahHospital_Stop | 00:04 | 00:01
CMHRoad_Stop | 00:05 | 00:01
TajResidency_Stop | 00:04| 00:01
LakesideHospital_Stop | 00:03 | 00:01
StJohnsRoad_Stop | 00:07 | 00:01
JCNagara_Stop | 00:05 | 00:01
MekhriCircle_Stop | 00:06 | 00:01
Hebbala_Stop | 00:04 | 00:01
JnOfKogiluCross_Stop | 00:03 | 00:01
-----------------------------------------------------------------------
#Line=BIAS-4R
#Start_Times=08:00, 09:00, 10:00, 10:30, 11:00, 11:30, 12:00, 12:30, 13:00, 13:30, 14:00, 14:30, 15:00, 15:30, 16:00,
      16:30, 17:00, 17:30, 18:00, 18:30, 19:00, 20:00, 21:00, 22:00
JnOfKogiluCross_Stop | 00:01 | 00:01
Hebbala_Stop | 00:03 | 00:01
MekhriCircle_Stop | 00:05 | 00:01
JCNagara_Stop | 00:06 | 00:01
StJohnsRoad_Stop | 00:07 | 00:01
LakesideHospital_Stop | 00:06 | 00:01
TajResidency_Stop | 00:05 | 00:01
```

```
CMHRoad_Stop | 00:04 | 00:01
ChinmaiahHospital_Stop | 00:06 | 00:01
JeevanBimaNaga_Stop | 00:05 | 00:01
————————————————————————————————————————————
#Line=BIAS-5
#Start_Times=07:10, 08:10, 09:10, 10:10, 10:40, 11:10, 11:40, 12:10, 12:40, 13:10, 13:40, 14:10, 14:40, 15:10, 15:40,
      16:10, 16:40, 17:10, 17:40, 18:10, 18:40, 19:10, 20:10, 21:10, 22:10
AshokaPillar_Stop | 00:06 | 00:01
ShanthinagraBusStn_Stop | 00:04 | 00:01
RichmondBClub_Stop | 00:07 | 00:01
GeneralPostOfficeGPO_Stop | 00:04 | 00:01
HighgroundsPS_Stop | 00:08 | 00:01
WindsorManor_Stop | 00:05 | 00:01
RMGuttahalli_Stop | 00:04 | 00:01
MekhriCircle_Stop | 00:07 | 00:01
Hebbala_Stop | 00:04 | 00:01
JnOfKogiluCross_Stop | 00:03 | 00:01
————————————————————————————————————————————
#Line=BIAS-5R
#Start_Times=08:10, 09:10, 10:10, 10:40, 11:10, 11:40, 12:10, 12:40, 13:10, 13:40, 14:10, 14:40, 15:10, 15:40, 16:10,
      16:40, 17:10, 17:40, 18:10, 18:40, 19:10, 20:10, 21:10, 22:10
JnOfKogiluCross_Stop | 00:06 | 00:01
Hebbala_Stop | 00:07 | 00:01
MekhriCircle_Stop | 00:04 | 00:01
RMGuttahalli_Stop | 00:07 | 00:01
WindsorManor_Stop | 00:04 | 00:01
HighgroundsPS_Stop | 00:07 | 00:01
GeneralPostOfficeGPO_Stop | 00:04 | 00:01
RichmondBClub_Stop | 00:08 | 00:01
ShanthinagraBusStn_Stop | 00:04 | 00:01
AshokaPillar_Stop | 00:04 | 00:01
————————————————————————————————————————————
#Line=BIAS-6
#Start_Times=07:20, 08:20, 09:20, 10:20, 10:50, 11:20, 11:50, 12:20, 12:50, 13:20, 13:50, 14:20, 14:50, 15:20, 15:50,
      16:20, 16:50, 17:20, 17:50, 18:20, 18:50, 19:20, 20:20, 21:20, 22:20
HopeFarm_Stop | 00:04 | 00:01
WhitefieldPostOffice_Stopp| 00:06 | 00:01
Siddapura_Stop | 00:04 | 00:01
HAL_Stop | 00:07 | 00:01
HotelLeelaPalace_Stop | 00:05 | 00:01
Domlur_Stop | 00:04 | 00:01
CommandoHosptl_Stop | 00:06 | 00:01
TajResidency_Stop | 00:03 | 00:01
LakesideHospital_Stop | 00:04 | 00:01
StJohnsRoad_Stop | 00:06 | 00:01
JCNagara_Stop | 00:05 | 00:01
MekhriCircle_Stop | 00:03 | 00:01
Hebbala_Stop | 00:07 | 00:01
JnOfKogiluCross_Stop | 00:04 | 00:01
————————————————————————————————————————————
```

```
#Line=BIAS-6R
#Start_Times=08:20, 09:20, 10:20, 10:50, 11:20, 11:50, 12:20, 12:50, 13:20, 13:50, 14:20, 14:50, 15:20, 15:50, 16:20,
      16:50, 17:20, 17:50, 18:20, 18:50, 19:20, 20:20, 21:20, 22:20
JnOfKogiluCross_Stop | 00:05 | 00:01
Hebbala_Stop | 00:04 | 00:01
MekhriCircle_Stop | 00:07 | 00:01
JCNagara_Stop | 00:03 | 00:01
StJohnsRoad_Stop | 00:04 | 00:01
LakesideHospital_Stop | 00:06 | 00:01
TajResidency_Stop | 00:04 | 00:01
CommandoHosptl_Stop | 00:06 | 00:01
Domlur_Stop | 00:07 | 00:01
HotelLeelaPalace_Stop | 00:05 | 00:01
HAL_Stop | 00:04 | 00:01
Siddapura_Stop | 00:03 | 00:01
WhitefieldPostOffice_Stopp| 00:07 | 00:01
HopeFarm_Stop | 00:04 | 00:01
-----------------------------------------------
#Line=BIAS-7
#Start_Times=07:25, 08:25, 09:25, 10:25, 10:55, 11:25, 11:55, 12:25, 12:55, 13:25, 13:55, 14:25, 14:55, 15:25, 15:55,
16:25, 16:55, 17:25, 17:55, 18:25, 18:55, 19:25, 20:25, 21:25, 22:25
Koramangala_Stop | 00:04 | 00:01
StJohnsHospital_Stop | 00:06 | 00:01
Forum_Stop | 00:05 | 00:01
DairyCircleRd_Stop | 00:03 | 00:01
ShanthiNagaraBusStand_Stop | 00:08 | 00:01
RichmondCircle_Stop | 00:04 | 00:01
IndianExpress_Stop | 00:06 | 00:01
Vasanthnagara_Stop | 00:07 | 00:01
RMGuttahalli_Stop | 00:04 | 00:01
MekhriCircle_Stop | 00:06 | 00:01
Hebbala_Stop | 00:07 | 00:01
JnOfKogiluCross_Stop | 00:04 | 00:01
-----------------------------------------------
#Line=BIAS-7R
#Start_Times=08:25, 09:25, 10:25, 10:55, 11:25, 11:55, 12:25, 12:55, 13:25, 13:55, 14:25, 14:55, 15:25, 15:55, 16:25,
16:55, 17:25, 17:55, 18:25, 18:55, 19:25, 20:25, 21:25, 22:25
JnOfKogiluCross_Stop | 00:04 | 00:01
Hebbala_Stop | 00:06 | 00:01
MekhriCircle_Stop | 00:05 | 00:01
RMGuttahalli_Stop | 00:03 | 00:01
Vasanthnagara_Stop | 00:08 | 00:01
IndianExpress_Stop | 00:04 | 00:01
RichmondCircle_Stop | 00:06 | 00:01
ShanthiNagaraBusStand_Stop | 00:07 | 00:01
DairyCircleRd_Stop | 00:04 | 00:01
Forum_Stop | 00:06 | 00:01
StJohnsHospital_Stop | 00:07 | 00:01
Koramangala_Stop | 00:04 | 00:01
```

It is possible to add or delete bus lines and individual bus instances by simply changing this text file. PlaSMA agents and their behaviours are implemented in Java. This requires computer scientists to do the modelling, but affords highest expressiveness to the abilities of the agents. In PlaSMA, the agent model breaks down into a number of finite-state machines. Each agent has some time of activation in which it changes states. The activity of agents is scheduled by the underlying multiagent scheduler along the time line.

To get a feeling of what has to be done to implement agents for the multi-agent system, we provide an example source code for the sub-

behaviour DriveToNextStop to the multi-step bus driving behaviour BehDriveByTimetableFSM. The behaviour drives a vehicle to its next destination. The destination has to be saved in

`DSKeyChain.KEY_CURRENT_ROUTE`

or

`DSKeyChain.KEY_NEW_ROUTE_TO_ADAPT`

The velocity has to be saved in

`BehDriveByTimetabelFSM.VELOCITY_TO_NEXT_STOP`

If no velocity is defined, the action takes the default velocity of the vehicle.

```
package org.tzi.plasma.behaviours.general; import org.tzi.plasma.analysis.logging.LogLevel; import org.tzi.plasma.control.
SimulationAgent; import org.tzi.plasma.control.UserBehaviour; import org.tzi.plasma.util.DSKeyChain;
import org.tzi.plasma.toolkit.util.vehicleRouting.vehicle.Vehicle;
import org.tzi.plasma.worldmodel.graph.Path;
import org.tzi.util.Velocity;
import jade.core.behaviours.DataStore;

public class BehDriveToNextStop  extends BehDrive {

public BehDriveToNextStop(SimulationAgent controller, DataStore datastore, Vehicle vehicle) {
    super(controller, datastore, vehicle);
}
public static enum Result {
    DRIVE_COMPLETE, DRIVING;
};

private Result res = Result.DRIVING;
public static final String LABEL = BehDriveToNextStop.class.getName();
private boolean isDone = false;
private Path route;

public void onStart() {
    res = Result.DRIVING;

    isDone = false;
}

          public void action() {
    this.controller.log("'Start of drive action'", LogLevel.TRACE); this.topLevelBehaviour = (UserBehaviour) this.par-
    ent; this.setVelocity((Velocity) this.getDataStore().get( BehDriveByTimetabelFSM.VELOCITY_TO_NEXT_STOP));
    this.route = (Path) this.getDataStore().get(DSKeyChain.KEY_CURRENT_ROUTE);
    if (route == null || route.isEmpty()) {  this.res = Result.DRIVE_COMPLETE; this.isDone = true;
    }  else {
          super.action();
    }
    this.controller.log("'End of drive action'", LogLevel.TRACE);
}

public void startNewRound() {  }

public int onEnd() {
    this.reset();
    return this.res.ordinal();
}
public boolean done() {
          return this.isDone;
}
```

We see that agents are resumed (on start) at specific points in time by the overall agent scheduler. After invoking their behaviour they execute parts of the duties and are subsequently suspended (on end). As bus agents communicate with the bus company (according to a fixed communication protocol) on their time table and with the passengers on signing the final trip contract and executing the pick-up, the final Java agent implementation of a bus is far more complex.

### 3.5 STARTING THE PLASMA SIMULATION SYSTEM

After starting the PlaSMA simulation system and Aurora, the PlaSMA GUI, connecting it to the server, and choosing the simulation, the connection to the database is complete and the infrastructure is loaded.

```
[INF].[System][Sync:#0][AID/simman] PlaSMA changed to state: Loading scenario [INF].[System][Sync:#0][AID/simman]
PlaSMA changed to state: Scenario loaded [INF].[System][Sync:#0][AID/simman] Finished command selectConfig [INF].[Syste
m][Sync:#0][AID/simman] PlaSMA changed to state: Initializing [INF].[System][Sync:#0][AID/simman] Simulation state:
scenario = Bus Traffic Scenario run = 1 of 1
start sim time = 2009-01-01 08:00:00
[INF].[System][AID/DBGraphGenerator] Found 49399 vertices and 134222 edges in 44741 [INF].[System][Sync:#0][AID/sim-
man] Initialized simulation run "Bus Traffic
Scenario" (without agents)
[INF].[System.WorldModel][AID/ClientWorldModel] Connected to central world model
(locally)
[INF].[System][Sync:#0][AID/simman] Current random seed: 1230796800000 [INF].[System][Sync:#0][AID/simman] PlaS-
MA changed to state: Scenario ready [INF].[System][Sync:#0][AID/simman] Finished command initSimRun [INF].[System.
WorldModel][AID/CentralWorldModel] Registering client with UUID
6e0433cd-b2e7-41ba-9023-51f7018db371 [INF].[System][Sync:#0][AID/simman] PlaSMA changed to state: Running [INF].[Sy
stem][Sync:#0][AID/simman] Finished command startSi
```

We see that the Bangalore graph, on which routing takes place, has 49,399 nodes and 134,222 edges. Loading it on a modern computer took about 50s. The default starting time of the simulation is 1st January 2009 at 8 o'clock, but this can be changed on demand. In general, a multiagent simulation system can combine distributed discrete event or time-stepped simulation with decision-making encapsulated in agents as separate and concurrent logical processes.

### 3.6 SIMULATION TIME

In classical simulation systems, the logical processes involved and the interaction links have to be known in advance and must not change during simulation. This is not the case in multiagent simulation systems, where each agent may interact with all other agents. Agents may join or leave the simulation during execution, e.g. depending on a stochastic simulation model or human intervention. This flexibility, however, complicates simulation time management.

To start off, it is necessary to distinguish different notions of time related to multiagent-based simulation. Generally, physical time refers to the time at which simulated events happen in the real world. Simulation time (or virtual time) models physical time in simulation. In scenarios where the advancement of local virtual (simulation) time (LVT) is directly coupled with the progress of each individual agent in executing its behaviours, heterogeneities in the computational demands of agents in the simulation and the distribution of agents across host platforms with varying computational power can create a problematic divergence of LVTs, leading to the so-called *causality problem*. In order to guarantee correct and reproducible simulations, the simulation system must ensure that agents process events in accordance to their time-stamp order. This requirement is addressed by synchronization, which can be either optimistic or conservative in character.

The choice of synchronization mechanism is an important design decision for the implementation of a multiagent system. Based on the identification of important quality criteria for multiagent systems, a coordinated conservative synchronization approach has been adopted in PlaSMA, which is handled concertedly by the simulation controller hierarchy.

# 4 SIMULATION MODEL

The classification of agent types adopted in PlaSMA and the association of these software agents with entities within the simulation environment is of particular importance when it comes to simulation execution. The adopted modelling approach conceptually introduces a partition of all software agents, which constitute a simulation into distinct agent communities, namely simulation actors and environmental agents.

The former community, made up of object and service agents, constitutes the multiagent system, which has been deployed in the simulation environment in order to evaluate global performance, patterns of interaction or the design of particular agents. Object agents in PlaSMA act as artificial autonomous decision makers on behalf of particular physical entities.

The simulation world model allows simulation agents to dynamically create additional agents over the whole course of a simulation run. In autonomous logistics, the runtime creation of new agents is often motivated by dynamic production or transport order inflow. For instance, an agent that manages incoming transport orders for a warding agency might want to delegate the supervision of particular orders to specialized agents. These can be instantiated on demand rather than creating a fixed pool of handling agents upon simulation start.

## 4.1 NOMENCLATURE

In the following, we will look at a graphical representation of the PlaSMA models we designed, before actually implementing them in Java.

The agents consist of *behavioural states* that have a one-to-one correspondence to the actual Java implementation of the agent. The subscript "u" attached to a node refers to the lifespan of a behaviour for the agent for which it may be scheduled. In our scenario, the lifetimes of the behavioural states are potentially unlimited.

We distinguish simple behaviours (like Init or HandleInformation-Requests or Driving) and complex behaviours (like TransportPassengers) that themselves consist of an arrangement of behavioural states. The text that labels a behaviour (indicated by BEH) gives insights into what the behaviour actually does and attaches semantics to the model that has to be implemented.

Note that these complexity types (simple, FSM, etc.) do not necessarily mean that a behaviour's implementation is simple or not, but whether or not it is decomposed. Complex behaviours are called FSM behaviours. FSM behaviours are labelled transition systems with a starting state (indicated with an incoming arc) and some terminal state (encircled node) and state transition governed by additional conditions. In contrast to FSM transitions, we employ transitions that spawn and create new behaviour states.

Communication arcs (dashed) show whether or not a behaviour is able to communicate with other agents. In these cases, communication parameters (e.g., ArchieREResponder) are provided at a behaviour state to refer to the protocol on which the parameters exchange internal data.

As a feature, we have indicated which agent is posing shortest path queries. Even though this is not a behaviour but a call to the routing handler, it affects the running time of the simulation significantly.

## 4.2 SCHEDULED TRANSPORTATION COMPANY AGENT

The *scheduled transportation company agent* is an implementation of a transportation company like BMTC (or vehicle-specific branches of BMTC) that

- provides an information infrastructure for answering initial transport queries (HandleInformation- Requests)
- sets up and maintains a list of people to be transported at stops for a specific vehicle (Handle- BoardingQueries)
- receives, answers, and commits transport requests from people at stops (HandleTransportRequest)

Its agent model is shown in Figure 4 (top). The agent is constructed once the scenario is started and starts with the Behaviour Init (matching to all other agents). After fulfilling the registration duties and receiving all timetabling information (from a file), it invokes all individual agents of its fleet. The three sub-behaviours are spawned and run in parallel.[3]

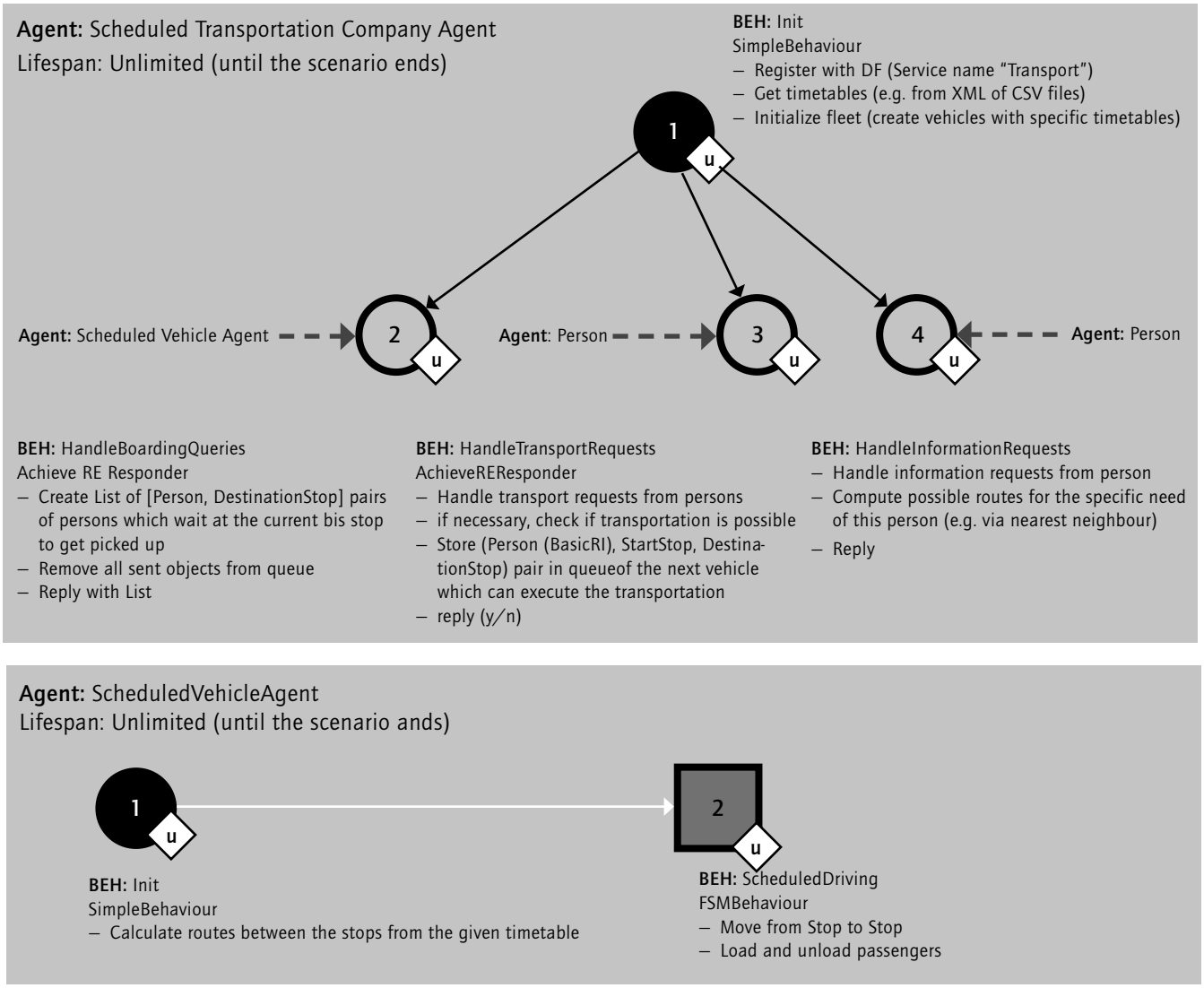
More formally, a query of a person with regards to a routing graph infrastructure $G$ with node set $V$ is assumed to consist of a start lo-

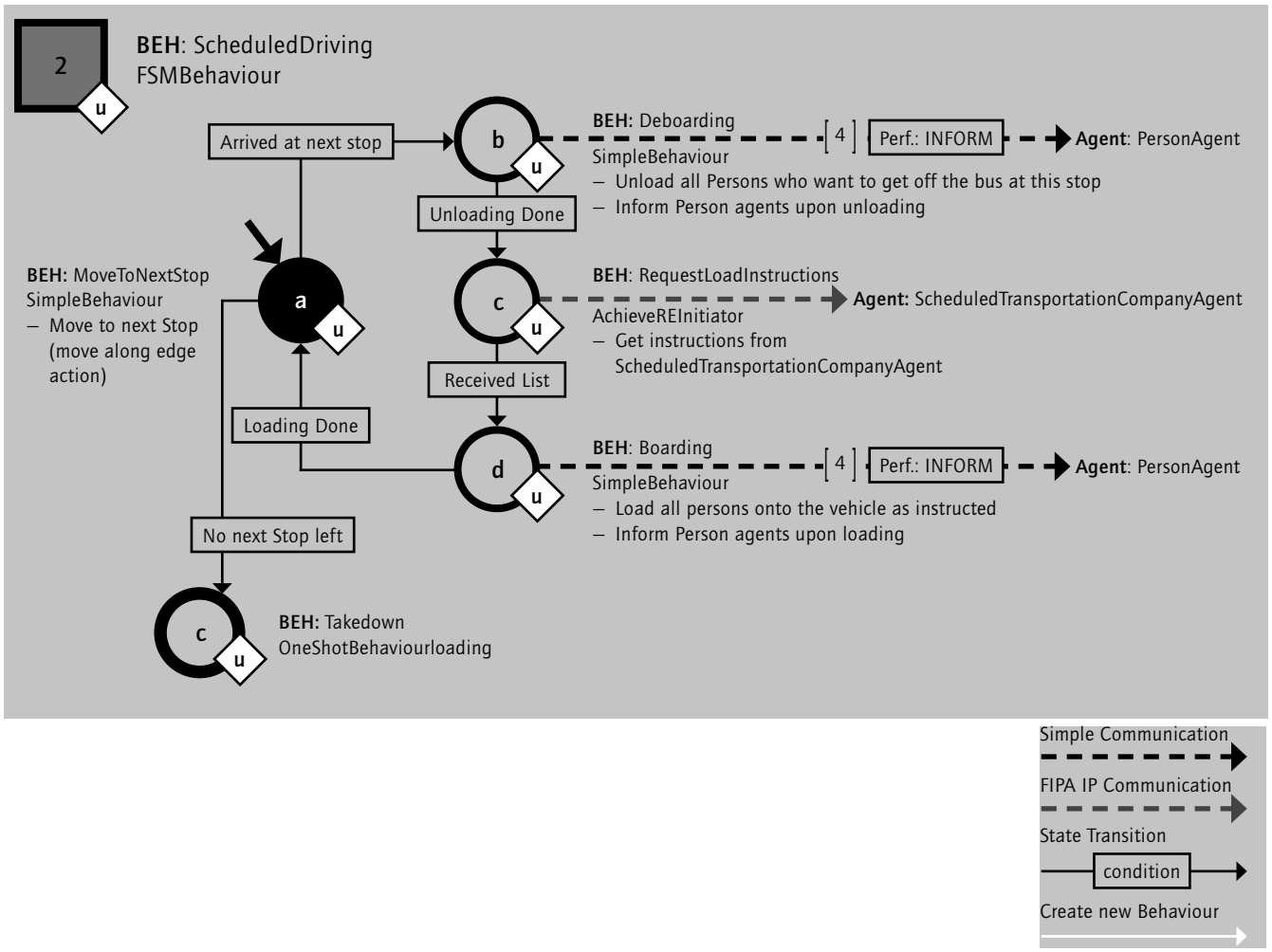
[3] Parallelism is only with the logical framework. In fact all parallel behaviors are time-stamped and thus executed sequentially.

cation $v_0 \in V$ and an end location $v_* \in V$ of the journey. Moreover, a time stamp can be associated to the journey, which in the simplest assumption is the current simulation time. To answer the query, the scheduled transportation company agent provides a selection of transport options that each contains the first stop $h_0 \in V$ to be picked-up and the last stop $h_* \in V$ of the transport. If $h_0 \neq v_0$ there is remaining effort needed for the human to reach the stop and if $h_* \neq v_*$ remaining effort is needed to reach the final destination of the journey.

It is possible that the trips offered by a multi-vehicle transport agency like BMTC consists of different transportation options (bus, tram, underground and overground trains). In our first approximation, we only use one vehicle to be routed. In complex settings, it is possible to recursively plan the prefix and suffixes of a trip with a different transport agent.

Figure 4: PlaSMA model of the Scheduled Transportation Company and Vehicle Agents.









## 4.3 SCHEDULED VEHICLE AGENT

The *scheduled vehicle agent* is a member of a transportation company and on its invocation; it receives a schedule from the agency that it then has to follow on a daily basis. The timetable information contains the arrival and departure time of each stop on the tour. If a vehicle is running late it usually tries to catch up with its schedule, reducing waiting times. In the case of a bus company this will be a bus. Other examples are underground and overground trains, and in case of bike rental companies, (motor) bikes.

Its model is shown in Figure 4 (bottom). The FSM behaviour for scheduled driving mainly implements a cycle of boarding, disembarking, and moving, interrupted by communication with the transportation company agent to receive new instructions.

## 4.4 AUTONOMOUS TRANSPORTATION VEHICLE AGENT

The *autonomous transportation vehicle agent* is a complex agent that is able to sign contracts with costumers and follow routes. It combines the functionality of a scheduled transportation agent and a scheduled vehicle agent. An example is an individual taxi or an individual rickshaw.

Its model is shown in Figure 5. On the top level of the specification, the autonomous transportation vehicle agent has three states: one where it is invoked and one where it receives its timetable. Unlike the transportation agency, it does not handle boarding queries on the top level to maintain a list of passengers, but immediately and individually executes transport requests. The third behaviour is a transport passenger FSM behaviour which is similar to the sched-

uled driving in terms of boarding and disembarking the passenger, but does not iterate over a sequence of stops. The FSM behaviour is invoked whenever a transport contract was sealed.

The answer from the scheduled vehicle agent to a transport query ($v_0$, $v_\sim$) is usually a single transport option with the human having to reach the first stop and no efforts to reach the final destination of the trip.

### 4.5 BIRTH GIVER AGENT

The *birth giver agent* generates a person agent at a given start location and initializes it with a certain budget in time and cost, as well as a target location. All values are random numbers, drawn according to a given probability distribution. The simple model with only one state that iteratively creates person agents for the simulation is shown in Figure 6.

Realistic modelling of the random process is crucial for the applicability of the simulation outcome. The better the model, the better its prediction. These data might be indirectly inferred by information on where people live and where they work, or by monitoring their current use of vehicles. In the end, a fairly complex probability distribution for transport request humans and their queries is derived. We are happy to include additional information from CiSTUP. So far, we have assumed that the starting and target locations exist on the map. Otherwise, the nearest map point has to be sought.

### 4.6 PERSON AGENT

The human, known as the *person agent*, is a very complex agent. It communicates with transportation agencies as well as with vehicles, with which it is transported. It plans and executes routes, and a person is additionally able to actively execute the transportation task without any vehicle by walking.

The PlaSMA model is shown in Figure 7. We see a hierarchy of complex FSM behaviours. Moreover, it shows that a person lives in a loop of planning and executing these plans. Based on the dynamics of the simulation systems, plans can fail and replanning might be required.

For the generation of plans (Planning behaviour), shortest plans have to be generated for walking and transportation agencies have to be contacted for options. While the start and goal locations are assumed to be vertices on the map, not all transportation requests can be satisfied to this level of precision, so planning includes augmenting vehicle use with walks to or from the vehicles' stops. Once the plan is fixed it goes to execution (ExecutePlan behaviour).

For the execution of plans, there is a distinction between active behaviours like walking and passive behaviours like being transported.[4] The starting point of the behaviour looks at the (next step in the) plan and decides whether it is an active or a passive behaviour. Passive transport has to be monitored and can fail (e.g. by a timeout on the waiting time), so that the planning behaviour has to be reinvoked on termination. In case of success, people are removed from the simulation once they reach their final destination.

We have finalized the implementation of birthgiver, bus, person and scheduled transportation company.

4 While riding a bike might be attributed as being an active option in real-life, in this model it can also been viewed as a being passive behavior in the form of a rental service with a contract.

Figure 5: PlaSMA model of Autonomous Transportation Vehicle Agent.

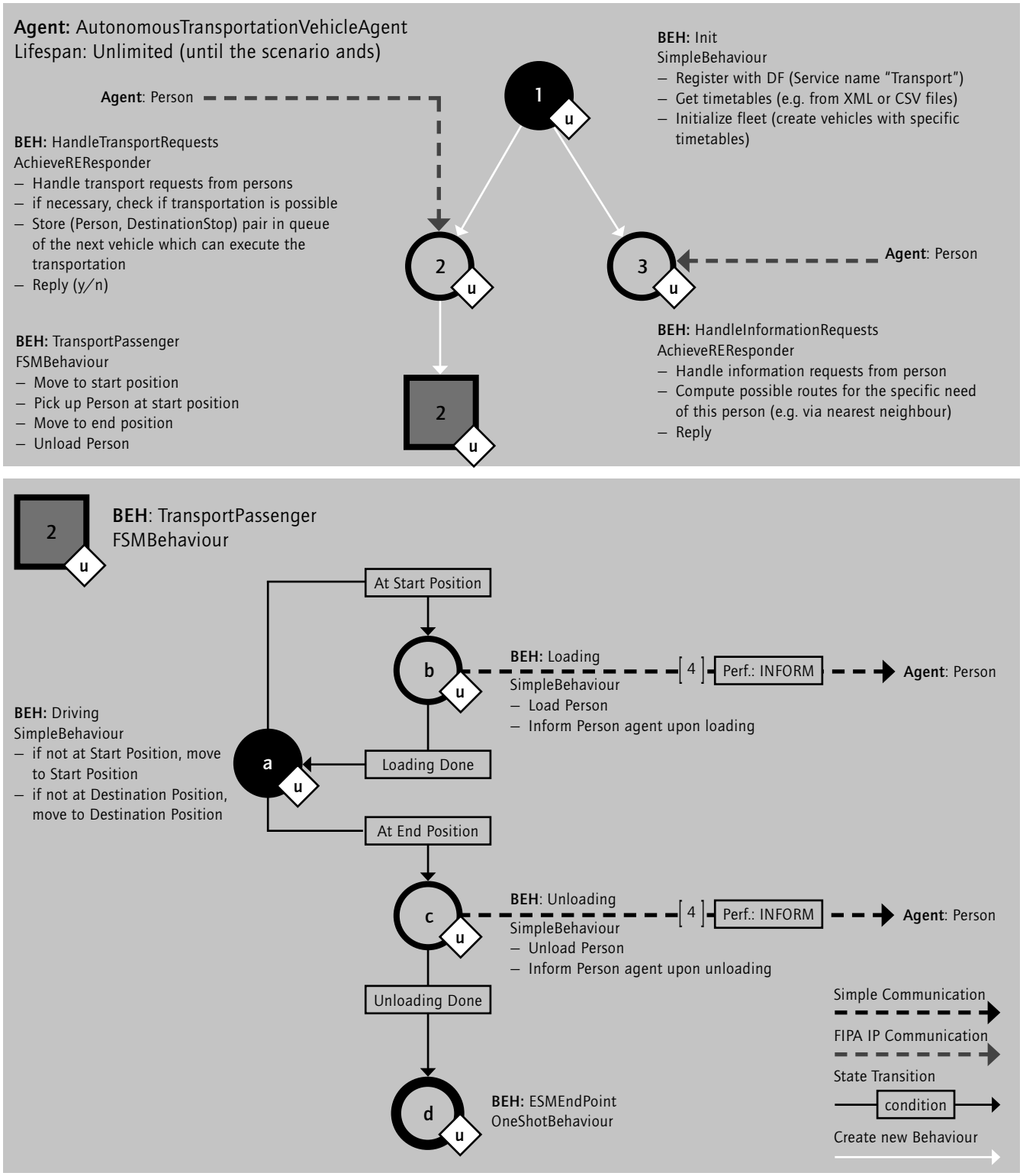


Figure 6: PlaSMA model of Birth Giver Agent.

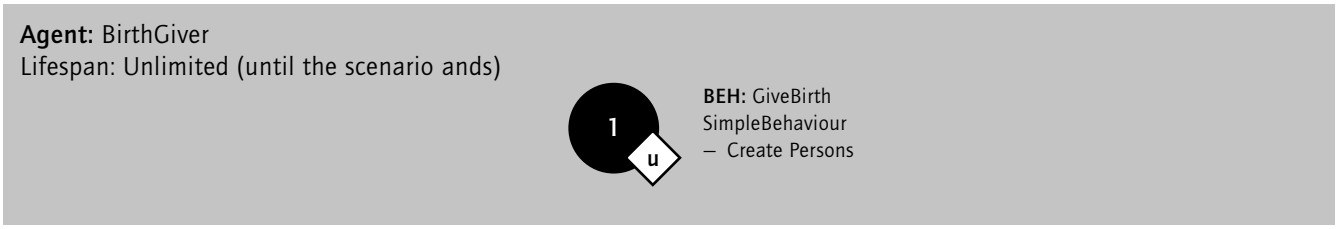
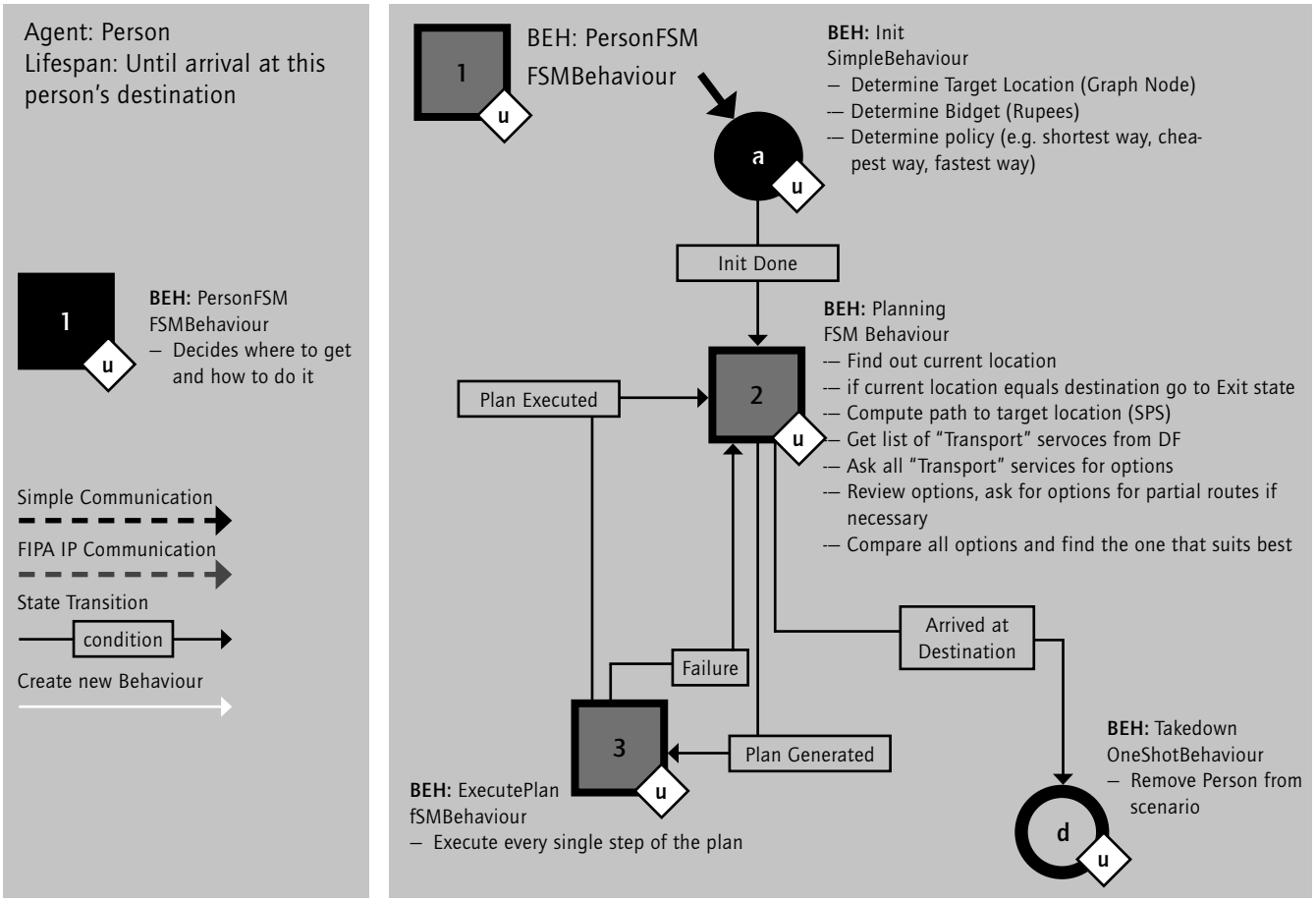
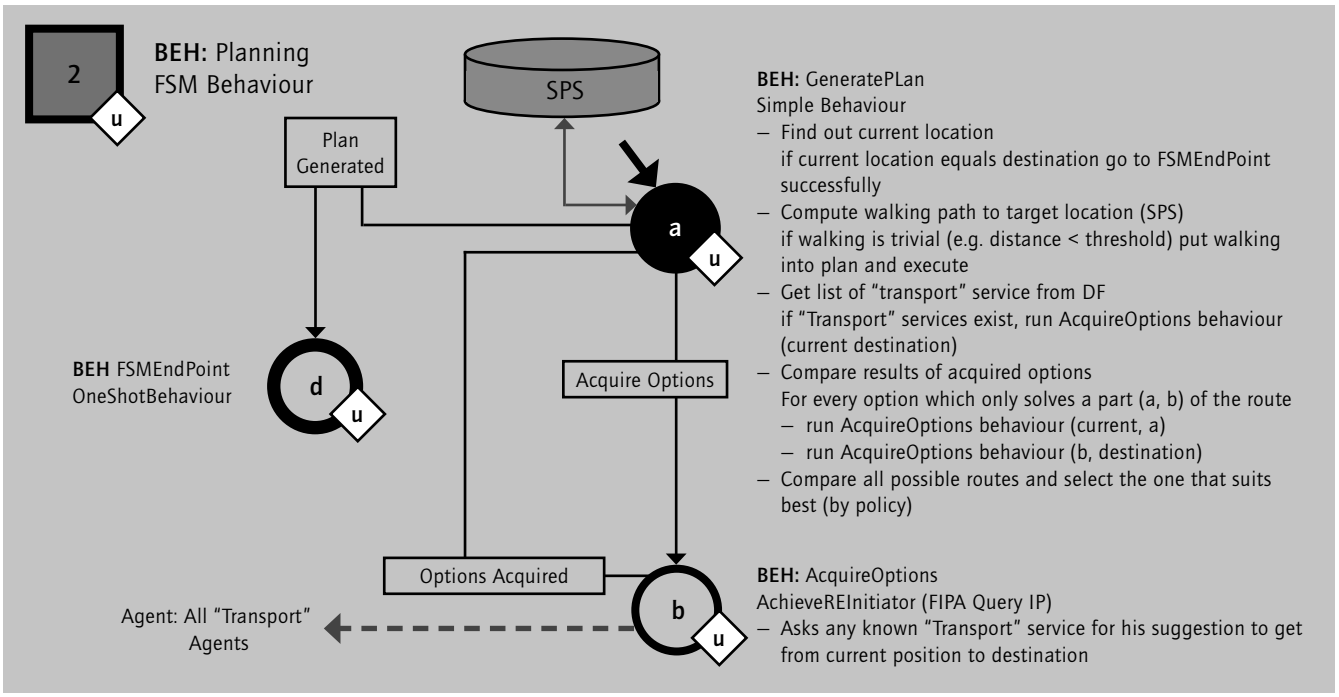
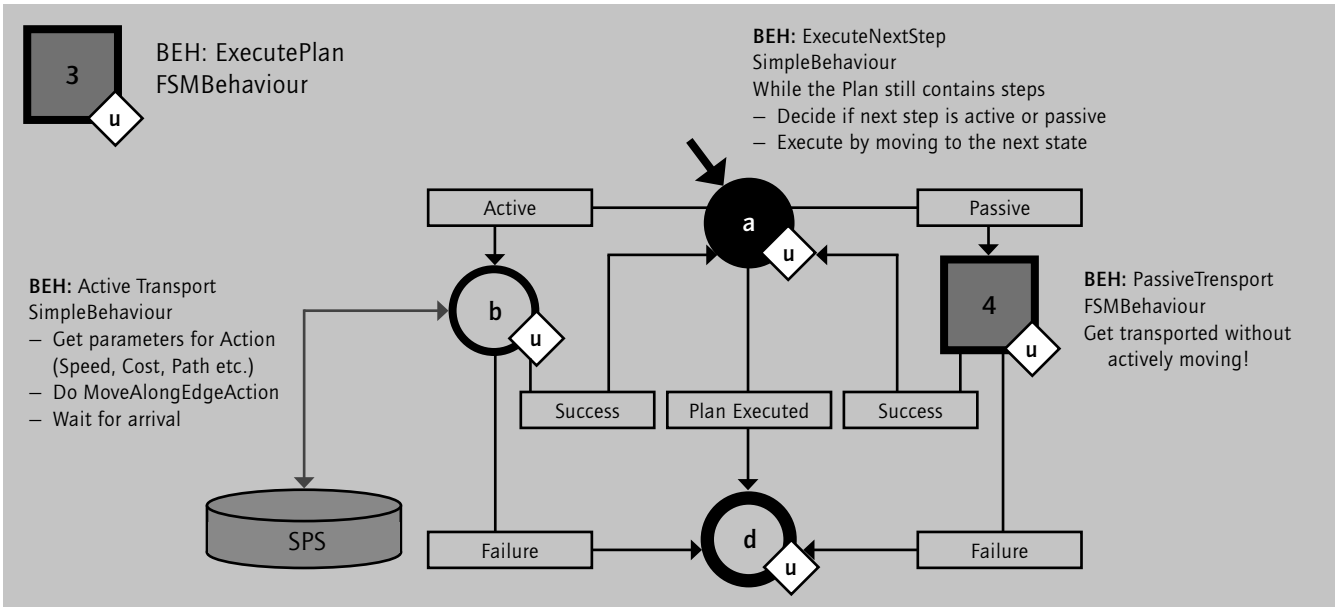
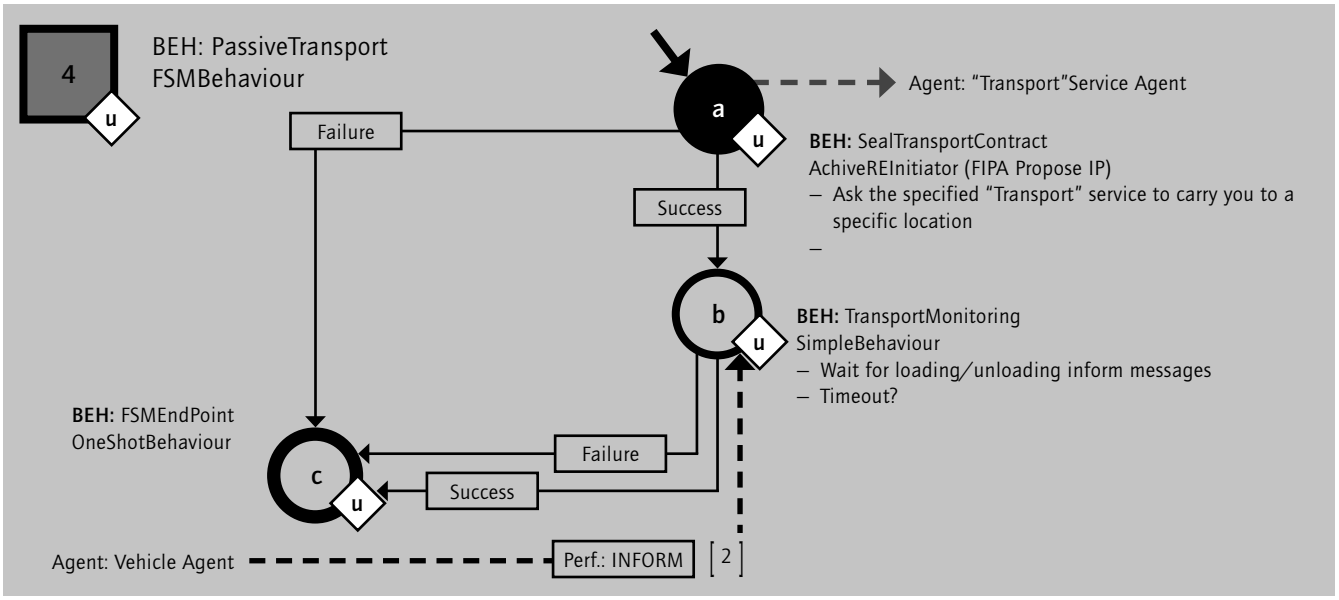



Figure 7: PlaSMA model of Person Agent.




2
u
BEH: Planning
FSM Behaviour
SPS
Plan
Generated
a
u
BEH: GeneratePLan
Simple Behaviour
– Find out current location
if current location equals destination go to FSMEndPoint successfully
– Compute walking path to target location (SPS)
if walking is trivial (e.g. distance < threshold) put walking into plan and execute
– Get list of "transport" service from DF
if "Transport" services exist, run AcquireOptions behaviour (current destination)
– Compare results of acquired options
For every option which only solves a part (a, b) of the route
– run AcquireOptions behaviour (current, a)
– run AcquireOptions behaviour (b, destination)
– Compare all possible routes and select the one that suits best (by policy)
BEH FSMEndPoint
OneShotBehaviour
d
u
Acquire Options
Options Acquired
b
u
BEH: AcquireOptions
AchieveREInitiator (FIPA Query IP)
– Asks any known "Transport" service for his suggestion to get from current position to destination
Agent: All "Transport"
Agents


3
u
BEH: ExecutePlan
FSMBehaviour
BEH: ExecuteNextStep
SimpleBehaviour
While the Plan still contains steps
– Decide if next step is active or passive
– Execute by moving to the next state
Active
a
u
Passive
BEH: Active Transport
SimpleBehaviour
– Get parameters for Action
(Speed, Cost, Path etc.)
– Do MoveAlongEdgeAction
– Wait for arrival
b
u
4
u
BEH: PassiveTrensport
FSMBehaviour
Get transported without actively moving!
Success
Plan Executed
Success
SPS
Failure
d
u
Failure


4
u
BEH: PassiveTransport
FSMBehaviour
a
u
Agent: "Transport"Service Agent
Failure
BEH: SealTransportContract
AchiveREInitiator (FIPA Propose IP)
– Ask the specified "Transport" service to carry you to a specific location
–
Success
b
u
BEH: TransportMonitoring
SimpleBehaviour
– Wait for loading/unloading inform messages
– Timeout?
BEH: FSMEndPoint
OneShotBehaviour
c
u
Failure
Success
Agent: Vehicle Agent
Perf.: INFORM
[2]

```
birthgiver:
actions Agent_BirthGiver.java  behaviours data

bus:
actions Agent_BusController.java  behaviours data routing util

person:
Agent_Person.java behaviours data util

scheduledtransportationcompany:
Agent_ScheduledTransportationCompany.java  behaviours data util
```

The Java agent implementation splits into different files.

```
birthgiver / Agent_BirthGiver.java bus / Agent_BusController.java person / Agent_Person.java
scheduledtransportationcompany / Agent_ScheduledTransportationCompany.java

birthgiver / actions:
Act_ProducePhysicalObject.java

birthgiver / behaviours:
Beh_GiveBirth.java

birthgiver / data:
BirthGiverAttribute.java

bus / actions:
Act_ChangeGraphPosition.java  Act_ChangeRelativeObjectPosition.java

bus / behaviours:
Beh_Init.java general

bus / data:
BusStops.java  ScheduledStop.java  Stop.java

bus / routing:
TSPSolver.java  TwoKOptInsertionHeuristic.java Util.java

bus / util:
ConfigKeys.java  DSKeyChain.java

person / behaviours:
Beh_FSMEndPoint.java  Beh_PersonFSM.java executeplan
Beh_Init.java Beh_Takedown.java planning

person / data:
TravelSegment.java

person / util:
DSKeyChain.java

scheduledtransportationcompany / behaviours:
Beh_CreateBus.java Beh_HandleTransportRequests.java
Beh_HandleBoardingQueries.java  Beh_Init.java
Beh_HandleInformationRequests.java

scheduledtransportationcompany / data:
BusRoutesManagement.java BusRouteTimeTable.java  PassengerInformation.java

scheduledtransportationcompany / util:
DSKeyChain.java
```

In the toolkit, we find the communication and some further utilities like the routing algorithms.

```
comm / acl:
BustrafficComm.java

util / actions:
Act_ConsumePhysicalObject.java

util / routingAlgorithms:
DijkstraShortestPathRadix.java  Node.java  Radix.java  RoutingTest.java
```

The Birth Giver is the simplest agent implementation, which is as follows.

```
::::::::::::::
Agent_BirthGiver.java
::::::::::::::
package org.tzi.plasma.agents.birthgiver;

import org.tzi.plasma.agents.birthgiver.behaviours.Beh_GiveBirth; import org.tzi.plasma.agents.birthgiver.data.BirthGiver-
Attribute; import org.tzi.plasma.control.AgentConfiguration;
import org.tzi.plasma.control.SimulationAgent;

@SuppressWarnings(«serial»)
@AgentConfiguration(BirthGiverAttribute.class)
public class Agent_BirthGiver extends SimulationAgent  {
    @Override
    protected void userSetup() {
    this.addUserBehaviour(new Beh_GiveBirth(this));
    }
}
```

```
::::::::::::::
behaviours/Beh_GiveBirth.java
::::::::::::::
package org.tzi.plasma.agents.birthgiver.behaviours;

import jade.core.behaviours.SimpleBehaviour;

import java.util.HashSet;
import java.util.Iterator;
import java.util.Random;
import java.util.Set;

import org.tzi.plasma.agents.birthgiver.actions.Act_ProducePhysicalObject;
import org.tzi.plasma.agents.birthgiver.data.BirthGiverAttribute;
import org.tzi.plasma.agents.person.Agent_Person;
import org.tzi.plasma.agents.person.Agent_Person.Policy;
import org.tzi.plasma.analysis.logging.LogLevel;
import org.tzi.plasma.control.SimSystem;
import org.tzi.plasma.control.SimulationAgent;
import org.tzi.plasma.control.UserBehaviour;
```

```
import org.tzi.plasma.worldmodel.PhysicalObject;
import org.tzi.plasma.worldmodel.graph.Node;
import org.tzi.plasma.worldmodel.graph.NodePosition;
import org.tzi.plasma.worldmodel.onto.OntologyService;
import org.tzi.util.BasicRI;

@SuppressWarnings("serial")
public class Beh_GiveBirth extends SimpleBehaviour implements UserBehaviour {
    private int personsPerInterval;
    private long interval;
    private BasicRI defaultPos;
    Node[] nodePool;
    private long nextSimTime;
    private Random random;
    private int personCounter;
    private final SimulationAgent controller;

    public Beh_GiveBirth(SimulationAgent controller) {
    this.controller = controller;
    Iterator<Node> iterator = this.controller.getWorld().getGraph().allNodes().iterator();
    this.nodePool = new Node[this.controller.getWorld().getGraph().nodeSize()];
    for(int i = 0; i < this.controller.getWorld().getGraph().nodeSize(); i++) {
          nodePool[i] = iterator.next();
    }
    this.random = new Random(SimSystem.getRandomSeed()
    + this.controller.getLocalName().hashCode());
    this.personCounter = 0;
    this.personsPerInterval = this.controller.getParameter(BirthGiverAttribute.persons_per_interval, Integer.class); this.
    interval = this.controller.getParameter(BirthGiverAttribute.birth_giving_interval, Long.class); this.controller.
    log("Birthgiver was created!", LogLevel.TRACE);
    }

    @Override
    public void startNewRound() {
    }

    private BasicRI getNextRandomNode() {
    Node n = nodePool[random.nextInt(this.nodePool.length)];
    while(!this.controller.getWorld().getGraph().edgesConnectedToNode(n).iterator().hasNext()) { this.controller.log(„Node
    „ + n.getId() + „ has no Edges attached!", LogLevel.WARNING); n = nodePool[random.nextInt(this.nodePool.length)];
    }
    return n.getId();
    }

    @Override
    public void action() {
    if(controller.getSimTime() >= this.nextSimTime){
          for(int i = 0; i < personsPerInterval; i++){
          BasicRI destinationID = getNextRandomNode();
          BasicRI startID;
          if(this.defaultPos!=null) {
              startID = defaultPos;
          } else {
              startID = getNextRandomNode();
          }
          int budget = this.controller.getParameter(BirthGiverAttribute.budget, Integer.class);
          Policy policy = this.controller.getParameter(BirthGiverAttribute.policy, Policy.class);
          BasicRI personPhysicalID = new BasicRI(OntologyService.SCENARIO_DEFAULT_URL,
              this.controller.getInstanceId().getLocalId() +
                "Person_" + personCounter);

          BasicRI personAgentID = new BasicRI(OntologyService.SCENARIO_DEFAULT_URL,
              this.controller.getInstanceId().getLocalId() +
```

```
                "PersonAgent_" + personCounter);
        PhysicalObject  person = new PhysicalObject(personPhysicalID, true);
        Object[] userArgs = new Object[]{
            personPhysicalID,
            destinationID,
            budget,
            policy
        }
        Set<BasicRI> assertedOntologyConcepts = new HashSet<BasicRI>();
        assertedOntologyConcepts.add(onto.concept.Trans.Person.id);
        // Produce physical representation of the person
        new Act_ProducePhysicalObject.Builder(person, new NodePosition(startID),
            assertedOntologyConcepts, personAgentID)
        .registerForAgent(this.controller).build();
        this.controller.createNewAgent(Agent_Person.class, personAgentID, userArgs);
        this.controller.log("Created Person #" + personCounter +
              " at " + startID.getLocalId() +
              " with destination " + destinationID.getLocalId() ,
              LogLevel.DEBUG);
        personCounter++;
        }
        this.nextSimTime = controller.getSimTime() + interval;
    }
    controller.finishedCycle(this, nextSimTime);
    }

    @Override
    public boolean done() {
    return false;
    }
}
::::::::::::::
```

```
data/BirthGiverAttribute.java
::::::::::::::
package org.tzi.plasma.agents.birthgiver.data;

import org.tzi.plasma.agents.person.Agent_Person.Policy;
import org.tzi.plasma.control.ConfigAttribute; import org.tzi.plasma.control.ConfigKeyInterface; import org.tzi.util.Time-
Toolkit;

public enum BirthGiverAttribute implements ConfigKeyInterface {
      persons_per_interval(ConfigAttribute.ofType(Integer.class).withValues(1)),
      birth_giving_interval(ConfigAttribute.ofType(Long.class).withValues(TimeToolkit.DAY)),
      budget(ConfigAttribute.ofType(Integer.class).withValues(100)),
      policy(ConfigAttribute.ofType(Policy.class).withValues(Policy.CHEAPEST_WAY))
;

    private ConfigAttribute data;

    private BirthGiverAttribute(ConfigAttribute data) {
    this.data = data;
    }

    @Override
    public ConfigAttribute data() {
    return data;
    }
}
```

# 5 FEASIBILITY ASSESSMENT

By writing a general and flexible multiagent system for people's travel in Bangalore, using different sorts of vehicles, urban mobility is possible.

## 5.1 DATABASE INFRASTRUCTURE

The road infrastructure is working and includes the international airport where people arrive and leave Bangalore. It is completely mapped to Postgres/GIS and imported by PlaSMA. Importing the road infrastructure takes about 50s on a contemporary laptop and is subject to be improved.

The routing graph extracted from OpenStreetMap is in operational shape but not highly detailed. Given that OpenStreetMap is developed in a Web 2.0 community platform, the accuracy is expected to improve over time.

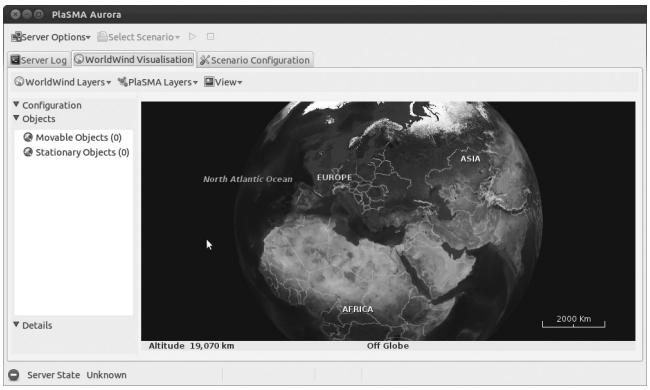
We encourage our partners to enhance the map so that we can use it by automatically extracting additional information. Thus far, we have not used any attached information beyond road type, but it would be interesting to process GPS linked information on bus stops or rental bike services.

## 5.2 COMPUTATIONAL REQUIREMENTS

The system for running the simulation has been tested in our group as working well on laptop infrastructures running Windows 7, Linux Ubuntu, and Apple iOS. The running time of the simulation is naturally subject to the CPU installed. We mainly experimented with Intel i5 and i7 processors. The core difference between the two processors was that the loading time for the infrastructure differed based on the number of parallel processes, with i7 taking about 30 seconds and i5 about 50 seconds.

After inserting the graph, 2-4 GB are required to visualize the setting and run a simulation. Efforts are currently being made to reduce these requirements. One reason is that the graph is represented both client and server side, and if both run on the same machine the memory requirements double. However, some aspects can be enhanced using PlaSMA's command line interface for running simulations.

Figure 8: Aurora GUI.




When the graph is shown on top of the WorldWind panel in the Aurora GUI (see Figure 8), zooming is very slow, so that the graph has to be included only on high zoom level, where its visualization is faster due to clipping. There is a commercial variant of PlaSMA that is faster, as it does not display the graph at all zoom levels.

More positively, on a faster laptop or desktop computer with 4-8 GB RAM the system is capable of handling the entire infrastructure of Bangalore and running ten days' worth of simulation without any problems.

Figure 9: Running simulation with buses and people.

Figure 10: Running simulation with buses and people on top of routing graph

Figure 11: Running simulation with buses, people, rickshaws and bikes on top of routing graph.

## 5.3 IMPLEMENTATION AND VISUALIZATION OF AGENTS

The implementation of agents for the initial study is fully operational. There are refinements that can be implemented on request. At the end of our initial implementation, we have human agents (Person), a generator agent that samples humans and rickshaws (BirthGiver), bus agents that follow time tables (Scheduled Vehicle), a BMTC Agent (Scheduled Vehicle Agency), as well as (e)bikes as a substitute for walking longer distances. Taxis (Autonomous Transportation Vehicle), if required, are yet to be implemented.

Figure 9 shows a snapshot of a simulation in progress. There are many different layers that can be added to the WorldWind view. We discovered that MS Virtual World Road Map looks attractive, but it seems to no longer be supported by Microsoft. In the future, we expect to add a layer for displaying annotated OpenStreetMap data, which would then match the routing graph the agents operate on. So far, the underlying road infrastructure can be added, and Figure 10 depicts the simulation (at a later point in simulation time) with highways.

In the restricted time frame (three months) we had for the study, we only managed to fully implement humans, birth givers, bus agencies and bus agents.

However, it was possible to clone the birth giver agent to produce auto-rickshaws instead of people (parameters for the birth giver can be used to change the ontological concept and thus the outlook and speed of the objects created).

Moreover, we were able to add some (e)bikes, so that people can decide how to get to the bus stop or home: if the distance is smaller enough (smaller than some predefined threshold) they walk, otherwise they ride a bike (see Figure 11). Some further aspects can be added by modifying the Scenario Configuration as indicated in Figure 12. It shows that the PostgreSQL database is local, so the graph is not transmitted via the internet (which yields a considerably slower initialization time). In Figure 13, we show how agents (in particular the Birth Giver agent) can be modified in the Aurora GUI. In changing the agent's parameters, different variants

Figure 12: Scenario configuration in PlaSMA.

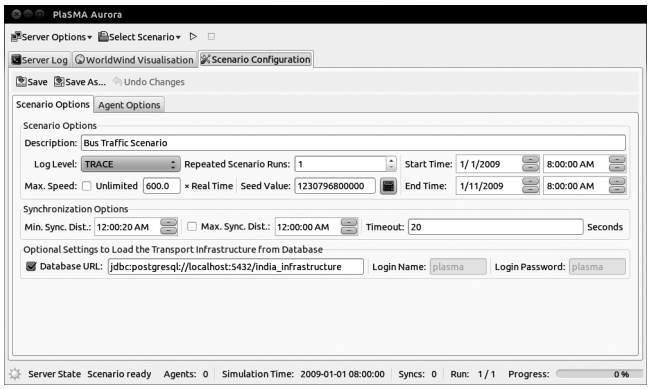
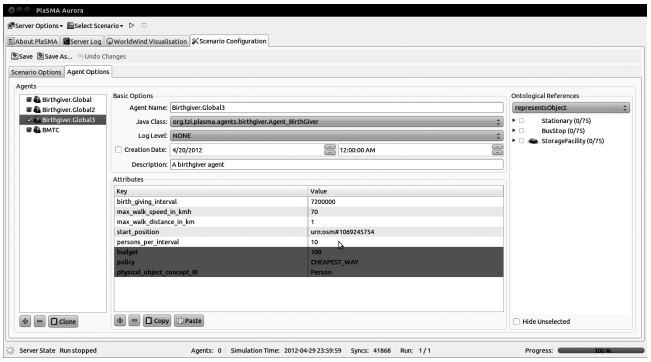



Figure 13: Agent configuration in PlaSMA.




of simulation scenarios can be selected and executed. Within the server log window, we can monitor the running simulation on different verbose levels. It is also possible to change the order of events to prefer either the newest or the oldest event first.

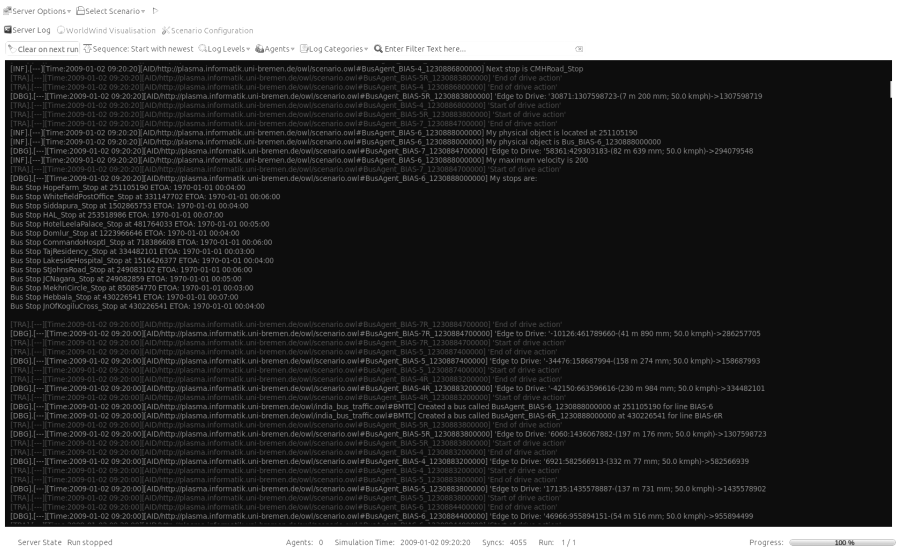
## 5.4 SIMULATION RESULTS

A simulation run does not produce results per se, and the data to be monitored has to be exported. One standard format is compatible with spread-sheet programs, but has the problem that each run results in a new file. To script runs and to display the averaged results of the measurements of interest, a database interface has been made to store simulation results.

```
DROP TABLE IF EXISTS tbl_experiments;

-- This table stores the different experiments for whom data is stored  in the
-- data base.
CREATE TABLE tbl_experiments( exp_ID serial PRIMARY  KEY, exp_scenario varchar(128) NOT NULL, exp_start_date timestamp
     NOT NULL, repeated_run smallint NOT NULL, CHECK (repeated_run > 0)
);

DROP TABLE IF EXISTS tbl_performance_indicators;

-- This table stores the different types of key performance indicators which are
-- used in experiments.
         CREATE TABLE tbl_performance_indicators(
    indicator_ID serial PRIMARY  KEY,
    exp_ID int NOT NULL REFERENCES tbl_experiments,
    name varchar(128) NOT NULL, datatype varchar(128) NOT NULL, unit varchar(64)
);

DROP TABLE IF EXISTS tbl_simulation_entities;

         CREATE TABLE tbl_simulation_entities(
    entity_ID  serial PRIMARY  KEY,
    entity_name varchar(256) NOT NULL UNIQUE
);

DROP TABLE IF EXISTS tbl_performance_measurements_long;

-- Table for long-typed key performance indicators
CREATE TABLE tbl_performance_measurements_long(
    measurement_ID serial PRIMARY  KEY,
    -- Specification of measurement
```

```
    indicator_ID int NOT NULL REFERENCES tbl_performance_indicators,
    measurement bigint NOT NULL,
    simtime bigint NOT NULL,
    -- Context
    measured_by int NOT NULL REFERENCES tbl_simulation_entities,
    measured_for int REFERENCES tbl_simulation_entities
);

DROP TABLE IF EXISTS tbl_performance_measurements_double;

-- Table for double-typed key performance indicators
CREATE TABLE tbl_performance_measurements_double(
    measurement_ID serial PRIMARY KEY,
    -- Specification of measurement
    indicator_ID int NOT NULL REFERENCES tbl_performance_indicators,
    measurement double precision NOT NULL,
    simtime bigint NOT NULL,
    -- Context
    measured_by int NOT NULL REFERENCES tbl_simulation_entities,
    measured_for int REFERENCES tbl_simulation_entities
);

DROP TABLE IF EXISTS tbl_performance_measurements_string;

-- Table for string-types key performance indicators
CREATE TABLE tbl_indicators_string(
    measurement_ID serial PRIMARY KEY,
    -- Specification of measurement
    indicator_ID int NOT NULL REFERENCES tbl_performance_indicators,
    measurement varchar(16384) NOT NULL,
    simtime bigint NOT NULL,
    -- Context
    measured_by int NOT NULL REFERENCES tbl_simulation_entities,
    measured_for int REFERENCES tbl_simulation_entities
);

DROP TABLE IF EXISTS tbl_performance_measurements_complex;

-- Table for key performance indicators with arbitrary serialized Java objects
-- as values
CREATE TABLE tbl_performace_measurements_complex(
    measurement_ID serial PRIMARY KEY,
    -- Specification of measurement
    indicator_ID int NOT NULL REFERENCES tbl_performance_indicators,
    measurement bytea NOT NULL,
    simtime bigint NOT NULL,
    -- Context
    measured_by int NOT NULL REFERENCES tbl_simulation_entities,
    measured_for int REFERENCES tbl_simulation_entities
);

DROP TABLE IF EXISTS tbl_indicators_ntuple;

          CREATE TABLE tbl_indicators_ntuple(
    measurement_ID serial PRIMARY KEY,
    -- Specification of measurement
    indicator_ID int REFERENCES tbl_indicators,
    measurement int[] NOT NULL,
    simtime bigint NOT NULL,
    -- Context
    measured_by int NOT NULL REFERENCES tbl_simulation_entities,
    measured_for int REFERENCES tbl_simulation_entities
);
```

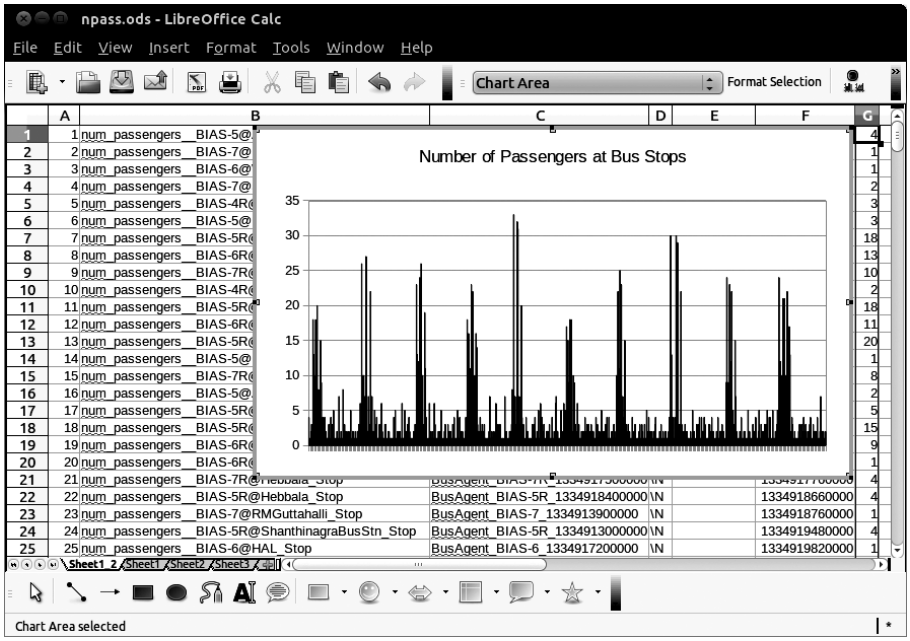
Figure 14: Running simulation with buses and people.




After a simulation terminates, all data is flushed to log files. If key measures are defined, they are logged. For example, in our sample scenario we are interested in the number of passengers at the bus stop. The corresponding log file appears as follows:

```
1|num_passengers_ BIAS-5@AshokaPillar_Stop|BusAgent_BIAS-5_1334905800000|\N||1334905940000|4
2|num_passengers_ BIAS-7@Koramangala_Stop|BusAgent_BIAS-7_1334906700000|\N||1334906840000|1
3|num_passengers_ BIAS-6@WhitefieldPostOffice_Stop|BusAgent_BIAS-6_1334906400000|\N
    ||1334907220000|1
4|num_passengers_ BIAS-7@StJohnsHospital_Stop|BusAgent_BIAS-7_1334906700000|\N||1334907420000|2
5|num_passengers_ BIAS-4R@Hebbala_Stop|BusAgent_BIAS-4R_1334908800000|\N||1334909060000|3
6|num_passengers_ BIAS-5@HighgroundsPS_Stop|BusAgent_BIAS-5_1334905800000|\N||1334909120000|3
7|num_passengers_ BIAS-5R@Hebbala_Stop|BusAgent_BIAS-5R_1334909400000|\N||1334909660000|18
8|num_passengers_ BIAS-6R@Hebbala_Stop|BusAgent_BIAS-6R_1334910000000|\N||1334910260000|13
9|num_passengers_ BIAS-7R@Hebbala_Stop|BusAgent_BIAS-7R_1334910300000|\N||1334910560000|10
10|num_passengers_ BIAS-4R@MekhriCircle_Stop|BusAgent_BIAS-4R_1334908800000|\N||1334911240000|2 [...]
746|num_passengers_ BIAS-7@RMGuttahalli_Stop|BusAgent_BIAS-7_1335725700000|\N||1335730579511|1
747|num_passengers_ BIAS-6R@Hebbala_Stop|BusAgent_BIAS-6R_1335730800000|\N||1335731079511|2
748|num_passengers_ BIAS-7R@Hebbala_Stop|BusAgent_BIAS-7R_1335731100000|\N||1335731379511|7
749|num_passengers_ BIAS-5@AshokaPillar_Stop|BusAgent_BIAS-5_1335733800000|\N||1335733959511|2
750|num_passengers_ BIAS-5R@Hebbala_Stop|BusAgent_BIAS-5R_1335733800000|\N||1335734079511|2
751|num_passengers_ BIAS-5R@HighgroundsPS_Stop|BusAgent_BIAS-5R_1335730200000|\N
    ||1335734359511|2
752|num_passengers_ BIAS-6R@Hebbala_Stop|BusAgent_BIAS-6R_1335738000000|\N||1335738279511|2
753|num_passengers_ BIAS-5R@MekhriCircle_Stop|BusAgent_BIAS-5R_1335737400000|\N||1335739859511|1
754|num_passengers_ BIAS-6@JCNagara_Stop|BusAgent_BIAS-6_1335734400000|\N||1335741399511|1
755|num_passengers_ BIAS-5R@HighgroundsPS_Stop|BusAgent_BIAS-5R_1335737400000|\N
    ||1335741559511|2
```

Figure 15: Running simulation with buses and people.




By accessing the data, inferences can be made and plots for the key measures can be generated. Figure 15 shows the operation in a spreadsheet program. As well as the number of passengers that board or disembark a bus, there are a host of other interesting key measures for the simulation like the time people spend getting home, the cost of the journey, or a combination of both.

Using the PostgreSQL database interface, plots can be generated fully automatically. Moreover, key measure data recorded in different simulations can easily be combined and analysed (e.g., averaged).

The execution of the full ten day scenario depends on the simulation speed and takes about 20 minutes with GUI visualization on a modern laptop. If the speed is set to a large value (or visualization is completely turned off), then we encounter problems. But it is not displaying the simulation which creates a computation bottleneck, but computing several shortest paths on the routing graph. Recall that shortest path queries are frequently posed by different agents such as people and vehicles; buses even compute shortest paths from every bus station to the next. Given the size of the infrastructure graph and the large amount of concurrent agents, it is no surprise that shortest path queries turn out to be the most time and memory consuming problems in this simulation scenario. Therefore, we implemented a radix-heap-based variant of the A* search algorithm to increase the overall simulation performance.

# 6 SHORTEST PATH SEARCH

In our initial experiments, we found that shortest path search was one of the core bottlenecks for the multiagent simulation in PlaSMA. The reason is that the exploration of larger graphs requires complex queries to be processed. We looked at the existing code for expanding a node:

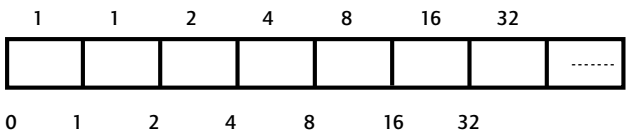
```
private void expandNode(final FrontEntry ne) {
    expandedNodes.add(ne.n);
    final Iterable<Edge> outEdges = graph.
    edgesConnectedToNode(ne.n);
    for (final Edge nextOutEdge : outEdges) {
          if (expandedNodes.contains(nextOutEdge.
          getTo()))
              || !isCompliantEdge(nextOutEdge)
              || (nextOutEdge.isOneway() &&  nextOutEdge.
              getTo().getId()
                .equals(ne.n.getId()))) {
                continue;
          }
          final Path p;
          if (ne.p == null) {
              p = new Path(nextOutEdge);
          } else {
              p = new Path(ne.p.pathEdges());
              p.add(nextOutEdge);
          }
          final FrontEntry newNe = new FrontEntry(p,
              pathCost(ne, nextOutEdge),
              heuristic(nextOutEdge.getTo()));
          nodeFront.add(newNe);
    }
    nodeFront.remove(ne);
}
```

We established different factors that hinder fast exploration:

1) The entire generating path to each node is stored and traversed while the shortest path is computed, even though a predecessor pointer would suffice.
2) There is no check whether the path that is inserted improves the current one. Hence, there are duplicates in the search frontier, even if only one is expanded.
3) The optimality relies on consistent heuristics, which is true for the straight-line (or air) distance, but not necessarily for the timed variants. Without reopening, A* resorts to a variant of Dijkstra's single-source shortest path search with $f(s) = h(s)$ and $w(u, v) = w(u, v)+h(u)-h(v)$.
4) Values for $f$, $g$ and $h$ are stored in the nodes, where the $f$-value alone would suffice.
5) Distances are of the long data type, which suggests the use of a radix heap.
6) Memory is allocated during the search. This can be avoided if the graph node offers priority queue functionality, i.e., has additional pointers for realizing all operations on the data structure.

## 6.1 RADIX HEAPS

Figure 16: Example of a radix heap. The bottom row of numbers denotes current values of the bounds $u$, while the top row denotes the sizes of the intervals defined by two successive u-values.




A radix heap maintains a list of $[\log(C + 1)] + 1$ buckets of sizes 1, 1, 2, 4, 8, 16, etc. (see Figure 16). The main difference from layered buckets is the use of buckets of exponentially increasing sizes instead of a hierarchy. Therefore, only $O(\log C)$ buckets are needed.

For our implementation we maintain buckets $b[0..B]$ and bounds $u[0..B + 1]$ with $B = [\log(C + 1)] + 1$ and $u[B + 1] = \infty$. Furthermore, the bucket number $\varphi(k)$ denotes the index of the actual bucket for key $k$. The invariants of the algorithms are: *i)* all keys in $b[i]$ are in $[u[i], u[i + 1]]$, *ii)* $u[1] = u[0] + 1$, and *iii)* for all $i \sim \{1, \ldots, B - 1\}$ we have $0 \leq u[i + 1] - u[i] \leq 2^{i-1}$.

The operations are as follows. *Initialize* generates an empty radix heap according to the invariants *ii)* and *iii).* The pseudo code is shown in Algorithm 1.

Algorithm 1: Creating a radix heap.

**Procedure Initialize**
**Input:** Array $b[0..B]$ of lists and array $u[0..B]$ of bounds
**Side Efect:** Initialized radix heap with arrays $b$ and $u$

**for each** $i$ **in** $\{0, \ldots, B\}$ $b[i] \leftarrow \emptyset$ — **Initialize buckets**
$u[0] \leftarrow 0$; $u[1] \leftarrow 1$ — **Initialize bounds**
**for each** $i$ **in** $\{2, \ldots, B\}$ $u[i] \leftarrow u[i-1] + 2^{i-2}$ — **Initialize bounds**

To insert an element with key $k$ in a linear scan a bucket $i$ is searched, starting from the largest one ($i = B$). Then the new element with key $k$ is inserted into the bucket $b[i]$ with $i = \min\{j \mid k \leq u[j]\}$. The pseudo-code implementation is depicted in Algorithm 2.

Algorithm 2: Inserting an element into a radix heap.

**Procedure Insert**
**Input:** Radix heap with array $b[0..B + 1]$ of lists and array $u[0..B + 1]$, key $k$
**Side Effect:** Updated radix heap

$i \leftarrow B$ — **Initialize index**
**while** $(u[i] > k)$ $i \leftarrow i - 1$ — **Decrease index**
**Insert** $k$ in $b[i]$ — **Insert element in list**

For *DecreaseKey*, bucket $i$ for element with key $k$ is searched linearly. The difference is that the search starts from the actual bucket $i$ for key $k$ as stored in $\varphi(k)$. The implementation is shown in Algorithm 3.

For *DeleteMin*, we first search for the first non-empty bucket $i = \min\{j \mid b[j] = \emptyset\}$ and identify the element with minimum key $k$ therein. If the smallest bucket contains an element, it is returned. Otherwise $u[0]$ is set to k and the bucket bounds are adjusted according to the invariances, i.e. $u[1]$ is set to $k + 1$ and for $j > 2$ bound $u[j]$ is set to $\min\{u[j-2] + 2^{j-2}, u[i+1]\}$. Last but not least, the elements of $b[i]$ are distributed to buckets $b[0], b[1], \ldots, b[i-1]$ and the minimum element is extracted from the smallest non-empty bucket. The implementation is shown in Algorithm 4.

Algorithm 3: Decreasing the priority of an element in a radix heap.

**Procedure DecreaseKey**
**Input:** Radix heap with array $b[0..B + 1]$ of lists and array $u[0..B + 1]$
Index $i$ in which old key $k$ is stored, new key $kl$
**Side Effect:** Updated radix heap

**while** $(u[i] > kl)$ $i \leftarrow i - 1$ — **Decrease index**
**Insert** $kl$ in $b[i]$ — **Insert element in list**

Algorithm 4: Deleting the minimum in a radix heap.

**Procedure DeleteMin**
**Input:** Radix heap with array $b$**[0..B + 1] of lists and array u[0..B + 1]**
**Output: Minimum element**
**Side Effect: Updated radix heap**

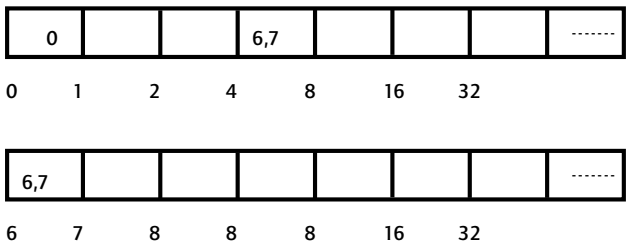
| | |
|---|---|
| $i \leftarrow 0$ | **Start with first bucket** |
| $r \leftarrow Select(b[i])$ | **Select (any) minimum key** |
| $b[i] \leftarrow b[i] \setminus \{r\}$ | **Eliminate minimum key** |
| **while** $(b[i] = \emptyset)$ $i \leftarrow i + 1$ | **Search for first non-empty bucked** |
| **if** $(i > 0)$ | **First bucket empty** |
| $k \leftarrow \min b[i]$ | **Select smallest key** |
| $u[0] \leftarrow k,\ u[1] \leftarrow k + 1$ | **Update bounds** |
| **for each** $j$ **in** $\{2, \ldots, i\}$ | **Loop on array indices** |
| $u[j] \leftarrow \min\{u[j-1] + 2^{j-2}, u[i+1]\}$ | **Update bounds** |
| $j \leftarrow 0$ | **Initialize index** |
| **for each** $k$ **in** $b[i]$ | **Keys to distribute** |
| **while** $(k > u[j+1])$ $j \leftarrow j + 1$ | **Increase index** |
| $b[j] \leftarrow b[j] \cup \{k\}$ | **Distribute** |
| **return** $r$ | **Output minimum element** |

As a short example for *DeleteMin*, consider the following configuration (written as $[u[i]] : b[i]$) of a radix heap $[0] : \{0\}$, $[1] : \emptyset$, $[2] : \emptyset$ $[4] : \{6, 7\}$, $[8] : \emptyset$, $[16] : \emptyset$ (see Figure 17). Extracting key 0 from bucket 1 yields $[6] : \{6, 7\}$, $[7] : \emptyset$, $[8] : \emptyset$, $[8] : \emptyset$, $[8] : \emptyset$, $[16] : \emptyset$. Now, keys 6 and 7 are distributed. If $b[i] = \emptyset$ then the interval size is at most $2^{i-1}$. In $b[i]$ we have $i - 1$ buckets available. Since all keys in $b[i]$ are in $[k, \min\{k + 2^{i-1} - 1, u[i+1] - 1\}]$, all elements fit into $b[0], \ldots, b[i-1]$.

The amortized analysis of the costs of maintaining a radix heap uses a potential function. We have that *Initialize* runs in $O(B)$, and *Insert* runs in $O(B)$. *DecreaseKey* has an amortized time complexity in $O(1)$, and *DeleteMin* runs in time $O(1)$ amortized. In total, we have a running time of $O(m \log C + l)$ for $m$ *Insert*, $l$ *DecreaseKey*, and $m$ *DeleteMin* operations.

Utilizing this representation, A* runs in worst-case time $O(e + n \log C)$ in a graph with $e$ edges and $n$ nodes. For modern computers, the value of $\log C$ for encompassing the entire integer range is small (32 or 64), so that A* on integers using a radix heap runs in linear time in practice.

Figure 17: Example for *DeleteMin* operation in a radix heap.



## 6.2 IMPLEMENTATION

To evaluate options for improvements, we wrote a shortest path search module with a radix-heap implementation for the priority queue.

```
I* An implementation of radix  heaps
Author:  Stefan  Edelkamp, 2012 *I

import java utiLVector ;
importjavalang Math;
importjavalang Number;

public dass Radix {

    public long S;
    public in t  B;
    public long n; II number of nodes

    Node buckets [];
    long u [];
    long b [];

    public Radi x() {
          S = L ong MAX_VALUE;
          B = (int ) (M ath ceii (M athlog(S)  I M ath  log(2)))  + 2;
          buckets = new Node [B];
          b = new long [B];
          u = new long [B];
          for (in t i  = 0; i   < B; i++) {
              buckets[i] =  null;
              b[i] = u[i] = 0;
          }
          b[0] = 1;
          b[B-1] = Lon g.MAX_VALU E;
          for (int  i  = 1;  i   < B-1;  i++)
              b[i] = 1L << (i-1) ;
          u[ B-1]  = Lon g MAX_VALUE;;
          n = 0;
    }

    public long size()  {
          return n;
    }

    public  bool ea n empty() {
          return (n == 0);
    }

    public  Node next( Nod e p) {
          if (p succ  !=  null )
              return  p succ;
          eise {
              int next  = p.buc ket  + 1;
              while ((next < B) && ( buckets[next] == null ))
                next ++;
              if (next == B)
              return null;
          else
              return buckets[next];
          }
    }
```

```
public void insert_node(Node p, int i) {
      p.succ = buckets[i];
      if (buckets[i] != null)
          buckets[i].pred = p;
      p.pred = null;
      p.bucket = i;
      buckets[i] = p;
}

public void extract_node(Node p) {
      if (p.pred != null) {
          Node q = p.pred;
          q.succ = p.succ;
      }
      else {
          buckets[p.bucket] = p.succ;
      }
      if (p.succ != null) {
          Node q = p.succ;
          q.pred = p.pred;
      }
}

public void adjust(long m, int t) {
      int i;
      u[0] = m;
      for (i = 1; i < t; i++) {
          u[i] = u[i-1] + b[i];
          if (u[i] > u[t])
          b reak;
      }
      for (; i < t; i++)
          u[i] = u[t];
}

public int find(Node p, int i) {
      if (p.element == u[0]) {
          return 0;
      }
      while (p.element <= u[--i]) ;
      return i+1;
}

public Node top() {
      return buckets[0];
}

public Node insert(Node p) {
      long k = p.element;
      if (n > 0) {
          int i = find(p,B-1);
          insert_node(p,i);
      }
      else {
          adjust(k,B-1);
          buckets[0] = p;
          p.bucket = 0;
      }
      n++;
      return p;
}

public void decrease(Node x, long k) {
      x.element = k;
      if (k <= u[x.bucket-1]) {
          extract_node(x);

          int i = find(x,x.bucket);
          insert_node(x,i);
      }
}

public Node extract() {
      for (int i = 0; i < B; i++) {
          Node p = buckets[i];
          if (p != null) {
            extract_node(p);
            n--;
            return p;
          }
      }
      return null;
}

public Node extract(Node x) {
      int i = x.bucket;
      extract_node(x);
      if ((n > 1) &&  (i == 0) &&(buckets[0] == null)) {
          int j = 1;
          while (buckets[j] == null)
            j++;
          Node p = buckets[j];
          Node d = p.succ;
          while (d != null) {
            if (d.element < p.element)
                      p = d;
            d = d.succ;
          }
          adjust(p.element,j);
          extract_node(p);
          insert_node(p,0);
          p = buckets[j];
          while (p != null) {
            Node q = p.succ;
            extract_node(p);
            int l = find(p,j);
            insert_node(p,l);
            p = q;
          }
      }
      n--;
      return x;
}
}
```

Random Graph creation and Dijkstra's single-source shortest paths search is realized in the following class. It assumes a combined node representation, with a state label (unlabelled, labelled or scanned), a linked list of edges, the element for storing the distances, the radix bucket a node is stored in, as well as two pointers (pred, succ) for linking the elements in the radix heap. An edge is a pair made up of a successor node ID and the respective weight/cost/distance value.

```
import java.util.Vector;
import java.util.Random;
import java.util.LinkedList;

public class Graph {

    public Vector<Node> nodes;

    public Graph(int n, int e) {
          nodes = new Vector<Node>(n);
          nodes.setSize(n);
          for (int i = 0; i < n; i++)
              nodes.set(i, new Node());
          Random r = new Random();
          for (int i = 0; i < e; i++) {
              int from = r.nextInt(n);
              int to = r.nextInt(n);
              long weight = (long) r.nextInt(n-1)+1;
              Pair p = new Pair(to,weight);
              nodes.get(to).edges.add(new Pair(from,weight));
              nodes.get(from).edges.add(new Pair(to,weight));
          }
    }

    public Node randomNode() {
          Random r = new Random();
          return nodes.get(r.nextInt(nodes.size()));
    }

    public void Dijkstra(Node s) {
          int n = nodes.size();
          int v = 0;
          for (int i=0;i<n;i++) {
              nodes.get(i).state = Node.Label.unlabelled;
          }
          System.out.println("Nodes initialized");
          s.element = 0;
          s.state = Node.Label.labelled;
          Radix heap = new Radix();
          heap.insert(s);
          System.out.println("Heap initialized");
          while (heap.size() != 0) {
              v++;
              Node t = heap.top();
              t.state = Node.Label.scanned;
              long d = t.element;
              for (Pair e : t.edges) {
                Node u = nodes.get(e.succid);
                long c = d + e.weight;
                if (u.state == Node.Label.scanned) {
                          ;
              }
```

```
                else if (u.state == Node.Label.unlabelled) {
                        u.element = c;
                        heap.insert(u);
                        u.state = Node.Label.labelled;
              }
                else if (u.element > c) {
                        heap.decrease(u, c);
                }
              }
              heap.extract(t);
            }
            System.out.println("Expanded nodes " + v);
      }
  }
```

## 6.3 EXPERIMENTS

For measuring the time complexity of the new implementation, we conducted some initial experiments on a laptop computer. Start and terminal nodes were randomly chosen.
We obtained the following results.

**Generate Random Graph with** 100000 **nodes and** 1000000 **edges**
**Time was** 2427**ms. Now Starting Dijkstra**
**Nodes initialized**
**Heap initialized**
**Expanded nodes** 100000
**Time was** 707**ms. SSSP done**

**Generate Random Graph with** 200000 **nodes and** 2000000 **edges**
**Time was** 4443**ms. Now Starting Dijkstra**
**Nodes initialized**
**Heap initialized**
**Expanded nodes** 200000
**Time was** 1668**ms. SSSP done**

We see that generating the graph was more complex than searching it. Moreover, 1s of run-time might be affordable.

Larger graphs (e.g. with 1,000,000 nodes and 10,000,000 edges) require larger Java heap space (this can be set by invoking java -Xms1024m -Xmx1024m).

**Generate Random Graph with** 100000 **nodes and** 1000000 **edges**
**Time was** 30574**ms. Now Starting Dijkstra**
**Time was** 45**ms. Nodes initialized**
**Time was** 0**ms. Nodes initialized**
**Expanded nodes** 100000
**Time was** 34631**ms. SSSP done**

We see that now the run-time for searching all shortest path dominates. Moreover, 30s of search time might be too much, and we should consider improvements. When terminating at goal states, the number of expanded nodes and the running time shrinks considerably, indicating that for (start, goal) queries the effect will be less harmful.

**Generate Random Graph with** 100000 **nodes and** 1000000 **edges**
**Time was** 29905**ms. Now Starting Dijkstra**
**Time was** 45**ms. Nodes initialized**
**Time was** 1**ms. Nodes initialized**
**Shortest path cost** 681233
**Expanded nodes** 364190
**Time was** 11988**ms. SSSP done**

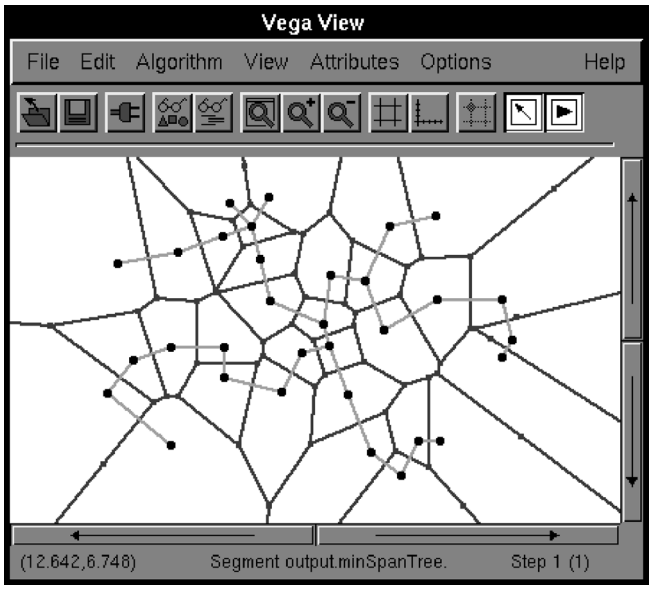
As a result, the refined shortest path search is sufficiently fast on large graphs. If better performance is needed, A* with a Euclidean Distance heuristic, and/or Bidirectional Shortest Path Search can be executed. Moreover, there are many speed-up techniques that preprocess the graph for a much better search time.

We have integrated the standalone into PlaSMA's core, and initial experiments show that we indeed get an increased speed to the existing path finding procedure. On a graph with 48 nodes the path is found in 18ms instead of 63ms. More experiments, especially on larger graphs, are needed to validate the findings.

# 7 NEAREST NEIGHBOUR SEARCH

If query points do not fall within a map, we often have the problem of finding the closest node to the query that is on the map. One option is to use *kd*-trees, but the complexity of finding the nearest neighbour is difficult to control. Another option is to collect close points within some surrounding (circle) by issuing queries to the GIS database and then select the shortest one. However, setting the parameter of the size of the circle around the query is difficult, since it might be that no node is present, or too many nodes are contained within the circle, and a different threshold has to be chosen. Clearly, the most elegant way to solve the nearest neighbour problem is the Delaunay triangulation. Its dual, the Voronoi diagram, partitions the graph embedding into parts of nearest neighbours, where each cell contains one graph node. It is shown in Figure 18.

Figure 18: Example of a Voronoi diagram. Delaunay triangulation is its geometric dual, parts are shown.




More formally, given a set $S = \{(x_1, y_1), \ldots, (xn, yn)\}$ of n points in two-dimensional Euclidean space, for a nearest neighbour search, we want to build a linear space data structure that can answer nearest neighbour queries: Given a point $q = (x, y)$, return the point $p \in S$ that minimizes the Euclidean distance $||p - q||_2$.

## 7.1 DELAUNAY TRIANGULATION

A *Simple and Fast Nearest Neighbour Search* algorithm based on (Full) Delaunay (Hierarchies) has been proposed by Marcel Birn, Manuel Holtgrewe, Peter Sanders, and Johannes Singler. Their algorithm preserves all Delaunay edges in the construction process and outputs a nearest neighbour and the expected number of nodes traversed, bounded by ln $n$ + 1.

We, however, implemented the Bowyer–Watson algorithm as a method for computing the Delaunay triangulation. This approach is an incremental algorithm. It works by adding points, one at a time, to a valid Delaunay triangulation of a subset of the desired points. After every insertion, any triangles whose circumcircles contain the new point are deleted, leaving a star-shaped polygonal hole which is then re-triangulated using the new point.

## 7.2 IMPLEMENTATION

The implementation consists of points, triangles, a graph of triangles, and a triangulation.

```
public class Pnt {

    private double[] coordinates;
    public Pnt (double... coords) {
          coordinates = new double[coords.length];
          System.arraycopy(coords, 0, coordinates, 0, coords.length);
    }

    public String toString () {
          if (coordinates.length == 0) return "Pnt()";
          String result = "Pnt(" + coordinates[0];
          for (int i = 1; i < coordinates.length; i++)
```

```
            result = result + ","  + coordinates[i];
        result = result + ")";
        return result;
    }

    public boolean equals (Object other) {
        if (!(other instanceof Pnt)) return false;
        Pnt p = (Pnt) other;
        if (this.coordinates.length != p.coordinates.length) return false;
        for (int i = 0; i < this.coordinates.length; i++)
            if (this.coordinates[i] != p.coordinates[i]) return false;
        return true;
    }

    public int hashCode () {
        int hash = 0;
        for (double c: this.coordinates) {
            long bits = Double.doubleToLongBits(c);
            hash = (31*hash) ^ (int)(bits ^ (bits >> 32));
        }
        return hash;
    }

    public double coord (int i) {
        return this.coordinates[i];
    }

    public int dimension () {
        return coordinates.length;
    }

    public int dimCheck (Pnt p) {
        int len = this.coordinates.length;
        if (len != p.coordinates.length)
            throw new IllegalArgumentException("Dimension mismatch");
        return len;
    }

    public Pnt extend (double... coords) {
        double[] result = new double[coordinates.length + coords.length];
        System.arraycopy(coordinates, 0, result, 0, coordinates.length);
        System.arraycopy(coords, 0, result, coordinates.length, coords.length);
        return new Pnt(result);
    }

    public double dot (Pnt p) {
    int len = dimCheck(p);
    double sum = 0;
        for (int i = 0; i < len; i++)
            sum += this.coordinates[i] * p.coordinates[i];
        return sum;
    }

    public double magnitude  () {
        return Math.sqrt(this.dot(this));
    }

    public Pnt subtract (Pnt p) {
        int len = dimCheck(p);
```

```
        double[] coords = new double[len];
        for (int i = 0; i < len; i++)
            coords[i] = this.coordinates[i] - p.coordinates[i];
        return new Pnt(coords);
    }

    public Pnt add (Pnt p) {
        int len = dimCheck(p);
        double[] coords = new double[len];
        for (int i = 0; i < len; i++)
            coords[i] = this.coordinates[i] + p.coordinates[i];
        return new Pnt(coords);
    }

    public double angle (Pnt p) {
            return Math.acos(this.dot(p) / (this.magnitude() * p.magnitude()));
    }

    public Pnt bisector (Pnt point) {
        dimCheck(point);
        Pnt diff = this.subtract(point);
        Pnt sum = this.add(point);
        double dot = diff.dot(sum);
        return diff.extend(-dot / 2);
    }

    public static String toString (Pnt[] matrix) {
        StringBuilder buf = new StringBuilder("{");
        for (Pnt row: matrix) buf.append(" " + row);
        buf.append(" }");
        return buf.toString();
    }

    public static double determinant  (Pnt[] matrix) {
        if (matrix.length != matrix[0].dimension())
            throw new IllegalArgumentException("Matrix is not square");
        boolean[] columns = new boolean[matrix.length];
        for (int i = 0; i < matrix.length; i++) columns[i] = true;
        try {return determinant(matrix, 0, columns);}
        catch (ArrayIndexOutOfBoundsException e) {
            throw new IllegalArgumentException("Matrix is wrong  shape");
        }
    }

    private static double determinant(Pnt[] matrix, int row, boolean[] columns){
        if (row == matrix.length) return 1;
        double sum = 0;
        int sign = 1;
        for (int col = 0; col < columns.length; col++) {
            if (!columns[col]) continue;
            columns[col] = false;
            sum += sign * matrix[row].coordinates[col] *
              determinant(matrix, row+1, columns);
            columns[col] = true;
            sign = -sign;
        }
        return sum;
    }
```

```
public static Pnt cross (Pnt[] matrix) {
      int len = matrix.length + 1;
      if (len != matrix[0].dimension())
          throw new IllegalArgumentException("Dimension mismatch");
      boolean[] columns = new boolean[len];
      for (int i = 0; i < len; i++) columns[i] = true;
      double[] result = new double[len];
      int sign = 1;
      try {
          for (int i = 0; i < len; i++) {
              columns[i] = false;
          result[i] = sign * determinant(matrix, 0, columns);
              columns[i] = true;
              sign = -sign;
          }
      } catch (ArrayIndexOutOfBoundsException e) {
          throw new IllegalArgumentException("Matrix is wrong  shape");
      }
      return new Pnt(result);
}

public static double content (Pnt[] simplex)
      { Pnt[] matrix = new Pnt[simplex.length];
      for (int i = 0; i < matrix.length; i++)
          matrix[i] = simplex[i].extend(1);
      int fact = 1;
          for (int i = 1; i < matrix.length; i++) fact = fact*i;
      return determinant(matrix) / fact;
}

public int[] relation (Pnt[] simplex) {
      int dim = simplex.length - 1;
      if (this.dimension() != dim)
          throw new IllegalArgumentException("Dimension mismatch");

      Pnt[] matrix = new Pnt[dim+1];
      double[] coords = new double[dim+2];
      for (int j = 0; j < coords.length; j++) coords[j] = 1;
      matrix[0] = new Pnt(coords);
      for (int i = 0; i < dim; i++) {
          coords[0] = this.coordinates[i];
          for (int j = 0; j < simplex.length; j++)
              coords[j+1] = simplex[j].coordinates[i];
          matrix[i+1] = new Pnt(coords);
      }

      Pnt vector = cross(matrix);
      double content = vector.coordinates[0];
      int[] result = new int[dim+1];
      for (int i = 0; i < result.length; i++) {
          double value = vector.coordinates[i+1];
          if (Math.abs(value) <= 1.0e-6 * Math.abs(content)) result[i] = 0;
          else if (value < 0) result[i] = -1;
          else result[i]  = 1;
      }
      if (content < 0) {
          for (int i = 0; i < result.length; i++)
              result[i] = -result[i];
      }
```

```
        if (content == 0) {
            for (int i = 0; i < result.length; i++)
                result[i] = Math.abs(result[i]);
        }
        return result;
    }

    public Pnt isOutside (Pnt[] simplex) {
        int[] result = this.relation(simplex);
        for (int i = 0; i < result.length; i++) {
            if (result[i] > 0) return simplex[i];
        }
        return null;
    }
    public Pnt isOn (Pnt[] simplex) {
        int[] result = this.relation(simplex);
        Pnt witness = null;
        for (int i = 0; i < result.length; i++) {
            if (result[i] == 0) witness = simplex[i];
            else if (result[i] > 0) return null;
        }
        return witness;
    }

    public boolean isInside (Pnt[] simplex) {
        int[] result = this.relation(simplex);
        for (int r: result) if (r >= 0) return false;
        return true;
    }
    public int vsCircumcircle (Pnt[] simplex) {
        Pnt[] matrix = new Pnt[simplex.length + 1];
        for (int i = 0; i < simplex.length; i++)
            matrix[i] = simplex[i].extend(1, simplex[i].dot(simplex[i]));
        matrix[simplex.length] = this.extend(1, this.dot(this));
        double d = determinant(matrix);
        int result = (d < 0)? -1 : ((d > 0)? +1  : 0);
        if (content(simplex) < 0) result = - result;
        return result;
    }

    public static Pnt circumcenter (Pnt[] simplex) {
        int dim = simplex[0].dimension();
        if (simplex.length - 1 != dim)
            throw new IllegalArgumentException("Dimension mismatch");
        Pnt[] matrix = new Pnt[dim];
        for (int i = 0; i < dim; i++)
            matrix[i] = simplex[i].bisector(simplex[i+1]);
        Pnt hCenter = cross(matrix);
        double last = hCenter.coordinates[dim];
        double[] result = new double[dim];
        for (int i = 0; i < dim; i++) result[i] = hCenter.coordinates[i] / last;
        return new Pnt(result);
    }
}
```

```
import java.util.Collections;
import java.util.HashMap;
import java.util.Map;
import java.util.Set;

public class Graph<N> {

    private Map<N, Set<N>> theNeighbors =
          new HashMap<N, Set<N>>();
    private Set<N> theNodeSet =
          Collections.unmodifiableSet(theNeighbors.keySet());

    public void add (N node) {
          if (theNeighbors.containsKey(node)) return;
          theNeighbors.put(node, new ArraySet<N>());
    }

    public void add (N nodeA, N nodeB) throws NullPointerException {
          theNeighbors.get(nodeA).add(nodeB);
          theNeighbors.get(nodeB).add(nodeA);
    }

    public void remove (N node) {
          if (!theNeighbors.containsKey(node)) return;
          for (N neighbor: theNeighbors.get(node))
              theNeighbors.get(neighbor).remove(node);
          theNeighbors.get(node).clear();
          theNeighbors.remove(node);
    }
    public void remove (N nodeA, N nodeB) throws NullPointerException  {
          theNeighbors.get(nodeA).remove(nodeB);
          theNeighbors.get(nodeB).remove(nodeA);
    }

    public Set<N> neighbors (N node) throws NullPointerException  {
          return Collections.unmodifiableSet(theNeighbors.get(node));
    }

    public Set<N> nodeSet () {
          return theNodeSet;
    }

}
```

```
import java.util.Arrays;
import java.util.Collection;
import java.util.Iterator;
import java.util.NoSuchElementException;

public class Triangle extends ArraySet<Pnt> {

    private int idNumber;
    private Pnt circumcenter = null;
    private static int idGenerator = 0;
    public static boolean moreInfo = false;

    public Triangle (Pnt... vertices) {
```

```
        this(Arrays.asList(vertices));
    }

    public Triangle (Collection<? extends Pnt> collection) {
        super(collection);
        idNumber = idGenerator++;
        if (this.size() != 3)
            throw new IllegalArgumentException("Triangle must have 3 vertices");
    }

    public String toString () {
        if (!moreInfo) return "Triangle" + idNumber;
        return "Triangle" + idNumber + super.toString();
    }

    public Pnt getVertexButNot (Pnt... badVertices) {
        Collection<Pnt> bad = Arrays.asList(badVertices);
        for (Pnt v: this) if (!bad.contains(v)) return v;
        throw new NoSuchElementException("No vertex found");
    }

    public boolean isNeighbor (Triangle triangle) {
        int count = 0;
        for (Pnt vertex: this)
            if (!triangle.contains(vertex)) count++;
        return count == 1;
    }

    public ArraySet<Pnt> facetOpposite (Pnt vertex) {
        ArraySet<Pnt> facet = new ArraySet<Pnt>(this);
        if (!facet.remove(vertex))
            throw new IllegalArgumentException("Vertex not in triangle");
        return facet;
    }

    public Pnt getCircumcenter () {
        if (circumcenter == null)
            circumcenter = Pnt.circumcenter(this.toArray(new Pnt[0]));
        return circumcenter;
    }

    public boolean add (Pnt vertex) {
        throw new UnsupportedOperationException();
    }

    public Iterator<Pnt> iterator () {
        return new Iterator<Pnt>() {
            private Iterator<Pnt> it = Triangle.super.iterator();
            public boolean hasNext() {return it.hasNext();}
            public Pnt next() {return it.next();}
            public void remove() {throw new UnsupportedOperationException();}
        };
    }

    public int hashCode () {
        return (int)(idNumber^(idNumber>>>32));
    }

    public boolean equals (Object o) {
      return (this == o);
    }

}
```

```
// Delaunay Triangulation with incremental site insertion.
// Author: Stefan Edelkamp, 2012

import java.util.AbstractSet;
import java.util.ArrayList;
import java.util.HashSet;
import java.util.Iterator;
import java.util.LinkedList;
import java.util.List;
import java.util.Queue;
import java.util.Set;

public class Triangulation extends AbstractSet<Triangle> {

    private Triangle mostRecent = null;
    private Graph<Triangle> triGraph;

    public Triangulation (Triangle triangle) {
          triGraph = new Graph<Triangle>();
          triGraph.add(triangle);
          mostRecent = triangle;
    }

    public Iterator<Triangle> iterator () {
          return triGraph.nodeSet().iterator();
    }

    public int size () {
          return triGraph.nodeSet().size();
    }

    public String toString () {
          return “Triangulation with “ + size() + “ triangles”;
    }

    public boolean contains (Object triangle) {
          return triGraph.nodeSet().contains(triangle);
    }

    public Triangle neighborOpposite (Pnt site, Triangle triangle) {
          if (!triangle.contains(site))
              throw new IllegalArgumentException(“Bad vertex; not in triangle”);
          for (Triangle neighbor: triGraph.neighbors(triangle)) {
              if (!neighbor.contains(site)) return neighbor;
          }
          return null;
    }

    public Set<Triangle> neighbors(Triangle triangle) {
      return triGraph.neighbors(triangle);
    }

    public List<Triangle> surroundingTriangles (Pnt site, Triangle triangle) {
          if (!triangle.contains(site))
              throw new IllegalArgumentException(“Site not in triangle”);
          List<Triangle> list = new ArrayList<Triangle>();
          Triangle start = triangle;
          Pnt guide = triangle.getVertexButNot(site);
```

```
        while (true) {
            list.add(triangle);
            Triangle previous = triangle;
            triangle = this.neighborOpposite(guide, triangle);
            guide = previous.getVertexButNot(site, guide);
            if (triangle == start) break;
        }
        return list;
    }

    public Triangle locate (Pnt point) {
        Triangle triangle = mostRecent;
        if (!this.contains(triangle)) triangle = null;

        Set<Triangle> visited = new HashSet<Triangle>();
        while (triangle != null) {
            visited.add(triangle);
            Pnt corner = point.isOutside(triangle.toArray(new Pnt[0]));
            if (corner == null) return triangle;
            triangle = this.neighborOpposite(corner, triangle);
        }
        System.out.println("Warning: Checking all triangles for " + point);
        for (Triangle tri: this) {
            if (point.isOutside(tri.toArray(new Pnt[0]))  == null) return tri;
        }
        System.out.println("Warning: No triangle holds " + point);
        return null;
    }

    public void delaunayPlace  (Pnt site) {
        Triangle triangle = locate(site);
        if (triangle == null)
            throw new IllegalArgumentException("No containing triangle");
        if (triangle.contains(site)) return;

        Set<Triangle> cavity = getCavity(site, triangle);
        mostRecent = update(site, cavity);
    }

    private Set<Triangle> getCavity (Pnt site, Triangle triangle) {
        Set<Triangle> encroached = new HashSet<Triangle>();
        Queue<Triangle> toBeChecked = new LinkedList<Triangle>();
        Set<Triangle> marked = new HashSet<Triangle>(); toBeChecked.add(triangle);
        marked.add(triangle);
        while (!toBeChecked.isEmpty()) {
            triangle = toBeChecked.remove();
            if (site.vsCircumcircle(triangle.toArray(new Pnt[0]))  == 1)
                continue;
            encroached.add(triangle);
            for (Triangle neighbor: triGraph.neighbors(triangle)){
                if (marked.contains(neighbor)) continue;
                marked.add(neighbor);
                toBeChecked.add(neighbor);
            }
        }
        return encroached;
    }
```

```
    private Triangle update (Pnt site, Set<Triangle> cavity) {
          Set<Set<Pnt>> boundary = new HashSet<Set<Pnt>>();
          Set<Triangle> theTriangles = new HashSet<Triangle>();
          for (Triangle triangle: cavity) {
              theTriangles.addAll(neighbors(triangle));
              for (Pnt vertex: triangle) {
                  Set<Pnt> facet = triangle.facetOpposite(vertex);
                  if (boundary.contains(facet)) boundary.remove(facet);
                  else boundary.add(facet);
              }
          }
          theTriangles.removeAll(cavity);

          for (Triangle triangle: cavity) triGraph.remove(triangle);

          Set<Triangle> newTriangles = new HashSet<Triangle>();
          for (Set<Pnt> vertices: boundary) {
              vertices.add(site);
              Triangle tri = new Triangle(vertices);
              triGraph.add(tri);
              newTriangles.add(tri);
          }

          theTriangles.addAll(newTriangles);
          for (Triangle triangle: newTriangles)
              for (Triangle other: theTriangles)
                  if (triangle.isNeighbor(other))
                         triGraph.add(triangle, other);
          return newTriangles.iterator().next();
    }
}
```

Generally, the algorithm operates in any number of dimensions, but we are only concerned with two. It is not the fastest method (the search for a triangle containing the query location traverses all triangles in the triangulation, instead of a greedy hill-climber), but has a concise implementation and is incremental.

## 7.3 EXPERIMENTS

Our result for a random graph with random coordinates in [0, 1] × [0, 1] are as follows:

```
Generate Random Graph with 1000 nodes and 100000 edges
Time was 52 ms. Now Starting Triangulation
Initial Delaunay triangulation created: Triangulation with 1 triangles
After adding 1000 points
Time was 713ms. Triangulation done
```

```
Generate Random Graph with 2000 nodes and 100000 edges
Time was 50 ms. Now Starting Triangulation
Initial Delaunay triangulation created: Triangulation with 1 triangles
After adding 2000 points
Time was 3236ms. Triangulation done
```

```
Generate Random Graph with 3000 nodes and 100000 edges
Time was 75 ms. Now Starting Triangulation
Initial Delaunay triangulation created: Triangulation with 1 triangles
After adding 3000 points
Time was 7996ms. Triangulation done
```

```
Generate Random Graph with 4000 nodes and 100000 edges
Time was 50 ms. Now Starting Triangulation
Initial Delaunay triangulation created: Triangulation with 1 triangles
After adding 4000 points
Time was 15276ms.  Triangulation done
```

```
Generate Random Graph with 5000 nodes and 100000 edges
Time was 62 ms. Now Starting Triangulation
Initial Delaunay triangulation created: Triangulation with 1 triangles
After adding 5000 points
Time was 24861ms.  Triangulation done
```

As this implementation is too slow and we expect query people to be located on the map, we have not integrated the above source code into PlaSMA. If needed, we recommend the implementation by Birn et al.

# 8 CONCLUSION AND OUTLOOK

We conducted an initial study of solving last-mile connectivity problems in Bangalore and illustrated that the multiagent simulation framework PlaSMA is capable of performing such complex simulations of urban mobility. Simulation parameters can be modified without recompiling the agent implementation. The agent model is fully operational and covers many aspects of urban mobility such as active walking behaviours and passive bus driving. Bus lines and individual buses are initialized according to a compact timetable that can be provided in a simple text file. Some behaviours, e.g., for modelling humans in the system, are rather complex as they require the realization of interleaved route planning and plan execution.

In retrospect, the design process of agents in form finite state machines resulted in a comprehensible and flexible model that was ultimately codeable. Seeing the successful simulation was a relief after the considerable programming efforts expended to that point.

## 8.1 RESULTS

We loaded the Bangalore road infrastructure from *OpenStreetMap* into the PlaSMA tool and started operating several artificial buses and people on it to demonstrate feasibility of the chosen approach. In cooperation with Prof. Sitharam (CiSTUP), we aimed to produce a small-sized scenario, modelling people and their travel to the airport and back.

The dynamics of the scenario make a strong mathematical treatment for off-line computing the optimal schedules for each individual person according to the infrastructure almost impossible. Due to the complexity of the task, fine-tuning key measures within a simulation is state-of-the-art and the method of choice. This does not mean that computational questions are negligible. Even within a simulation several subproblems like shortest path or nearest neighbour search have to be solved repeatedly.

We are confident that the model we have designed is generic. It is limited to neither transport agencies in Bangalore (since the infrastructure can be changed) nor to particular transport agencies. Different sorts of transport agencies and vehicles can be added to the scenario without much burden on the multiagent scenario designer.

We think that our model shows a strong connection between the transportation of humans in the system and the transportation of intelligent containers or goods in a logistics domain, so many aspects can be reused.

Interleaved planning and plan execution is one of the major strengths of the approach taken in PlaSMA. We are happy that the scenario encompasses these strengths in the model of the dynamic invocation of travel requests. It is even possible to imagine integrating a transport agency's existing web interface into the simulation for generating plans. From an AI perspective, conventional planners may be used to compute short multi-modal routes.

The core issue is and remains scalability. We showed how to significantly improve graph search by using refined data structures, but we only looked at a very limited scenario of transporting people from the airport to the city (or vice versa). Even in this scenario we made some simplifying assumptions about the types and number of vehicles operating, some prompted by the limited time window for executing this study (three month) and others by the time and space limitations of the PlaSMA tool.

Bangalore is a mega-city of about 10 million inhabitants and vehicles (two-wheelers, three-wheelers, four-wheelers) in the same order of magnitude. With that many agents, the underlying simulation system will likely encounter performance problems, so that alternatives must be investigated.

For the map infrastructure, there is an interface available on
http://www.openstreetmap.de/karte.html (search for 'bengaluru')

We cannot judge how accurate, detailed, and up-to-date the maps are and definitely need assistance from the Indian side. We noticed that public transport in Bangalore provided in OpenStreetMap is sparse and seems not to be modelled well. We definitely need substantially more travel data from companies like BMTS on bus fleet schedules, either in the form of timetables or GPS traces.

We emphasize that even with existing map data, modelling a larger scenario in PlaSMA involves human expertise and is a time consuming prospect. We are optimistic about extrapolating data generated by the system that eases understanding, but it will not necessarily be conclusive in giving final recommendations on how the last mile should be planned. We need iterations and interactions with other experts, especially from the traffic information side.

Figure 19: Incremental map generation based on GPS trajectories.

## 8.2 FUTURE WORK

In the future, the use of (smart) mobile devices to access routing and map information via a unified platform for the users is planned. Nowadays, GPS receivers are quite cheap, and many people use them for route planning in their cars. On the other hand, updated maps for the route planning systems are relatively expensive, if they are available at all. It is necessary to collect the data that people have recorded with their GPS-receivers and combine it into a freely available road map. Besides being cheap and always current, this map would also contain actual driving time information: Route planning on such a map would not have to use approximations based on road type to calculate the fasted route.

The idea behind the MapGeneration Project at
mapgeneration.berlios.de
is to collect GPS data from all over the world and incrementally create a digital road map (see Figure 19), that is freely available for everybody.
For aggregating GPS data to maps and overlays in existing maps like in OpenStreetMap, Google, or Yahoo, we refer to our interface at
http://ssd.informatik.uni-bremen.de/mapgen/?zoom=12&lat=6721345.27296&lon=833841.83935&layers=0B000T

There is another interesting project on integrating routing queries into the database server at
http://www.pgrouting.org

The stated advantages of the database routing approach are:

- Data and attributes can be modified by many clients, like Quantum GIS and uDig through JDBC, ODBC, or directly using Pl/pgSQL. The clients can either be PCs or mobile devices.
- Data changes can be reflected instantaneously through the routing engine. There is no need for precalculation.
- The cost parameter can be dynamically calculated through SQL, and its value can come from multiple fields or tables.

Core Features are: Shortest Path Dijkstra routing algorithm without heuristics, Shortest Path A* routing for large datasets, Shortest Path Shooting-Star routing with turn restrictions Traveling Salesperson Problem, and Driving Distance calculation.

As the key variable is time, we have to evaluate if the approach is practical. To do so, we will integrate heuristics and bidirectional search options into our refined routing module.

For more useful simulation results, joint efforts with different partners are required, e.g., different sorts of agents and mobility aspects must be designed on top of the road infrastructure. For electric vehicles like pedelecs, we need information from BOSCH GmbH, for public transportation BMTC Ltd. should be consulted.

For ride-sharing we expect important input from nextbike GmbH. Expertise has to be exchanged with e.g. with TRC Transportation Research and Consulting GmbH (Ltd.) and the Institute of Transport Logistics (ITL) in the Department of Mechanical Engineering at Dortmund University of Technology, which is associated with the Fraunhofer-Institute for Material Flow and Logistics (IML).

Even though there is a rich corpus of video data on traffic crossing at CiSTUP, it will be hard to extract detailed data on road lanes, traffic lights, as well as further traffic jam and time slot information. Processing this kind of information exceeds the scope of the study and may be addressed in subsequent projects with expertise in image processing.

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