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Master's Thesis in
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for sustainable development

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Optimizing Last Mile Delivery using Public Transport with Multi-Agent based Control

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ABSTRACT

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The majority of research work carried out in the field of Operations-Research uses methods and algorithms to optimize the pick-up and delivery problem. Most studies aim to solve the vehicle routing problem, to accommodate optimum delivery orders, vehicles etc. This paper focuses on green logistics approach, where existing Public Transport infrastructure capability of a city is used for the delivery of small and medium sized packaged goods thus, helping improve the situation of urban congestion and greenhouse gas emissions reduction. It carried out a study to investigate the feasibility of the proposed multi-agent based simulation model, for efficiency of cost, time and energy consumption. Multimodal Dijkstra Shortest Path algorithm and Nested Monte Carlo Search have been employed for a two-phase algorithmic approach used for generation of time based cost matrix. The quality of the tour is dependent on the efficiency of the search algorithm implemented for plan generation and route planning. The results reveal a definite advantage of using Public Transportation over existing delivery approaches in terms of energy efficiency.

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LIST OF SYMBOLS AND ABBREVIATIONS

ACL	Agent Communication Language
AI	Artificial Intelligence
DVRP	Dynamic Vehicle Routing Problem
GHG	Green House Gas
H2M	Human to Machine
IP	Interaction Protocol
IoT	Internet of Things
JADE	Java Agent Development Framework
MABS	Multi Agent Based systems
MAS	Multi Agent systems
MCTS	Monte Carlo Tree search
NMC	Nested Monte Carlo search
PlaSMA	Platform for Simulation of Multi-Agent system
TSP	Travelling Salesman problem
TSPTTW	Travelling Salesman problem with Time Windows
VRP	Vehicle routing problem

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1 INTRODUCTION

1.1Background

The human society is constantly evolving towards a progressive improvement for a better quality of life and in order to support the growing requirements generated within the past decade, there has been major transformations in the field of technology and industry. The emergence of new technologies such as the Internet of Things, wireless sensor networks, embedded systems, and cloud computing and mobile internet has brought about developments within the manufacturing and service sector which is often attributed to as the fourth industrial revolution or popularly called the Industry4.0. The European economy, for example adopted strategic initiatives as part of the German Initiative of "High-Tech Strategy 2020". Similar efforts and initiatives in research and development have also been made in other parts of the world, which has also witnessed a high degree of industrialization such as the United States, China, and Japan among other countries. The Industry 4.0 as discussed in[1] has been described as the development of cyber physical systems capable of integrating manufacturing, ware-houses, logistics, and social networking process's to create a value chain based process. It explores a wide area of research in human–machine (H2M) interface interactions, self-maintaining systems, safety, security, energy efficiency to name just a few.

However, the current trend of industrial production is not a sustainable one, with depletion of existing non-renewable resources and is the responsible for global pollution and environmental degradation. The promise of Industry 4.0 lies [1]in integrating the emerging technologies with business processes and services in order to offer solutions which are flexible, efficient and ecologically compatible with improved standards of quality in key areas of engineering, planning, manufacturing and logistics process.

Some of the enabling technologies such as big data, cloud computing, IoT (Internet of Things) as well as AI (Artificial Intelligence) and technologies related to MAS (multi-agent based) technologies are some of the factors which have facilitated the industrial revolution. One of the emerging economic sectors is the electronic-commerce (e-commerce) industry which is an example of horizontal integration of business within the industry process. The surge of online e-commerce is one of the examples where personalized needs of the customers have led to innovation and remodelling of the business process. Customers expect a high quality of goods, convenience of access to service, affordable prices and short delivery times. Industry 4.0 allows the individual customer-specific requirements to be integrated within the product life cycle process.

As the platform for services offered in the web-business widens, it has been observed there is a high demand for goods and services worth billions of dollar in the online market. The popularity of the online marketing has made Amazon, e-bay, Alibaba household names. The internet has therefore transformed into an online virtual marketplace, for channelling goods between the customer and firms. The paper [2] describes an e-commerce as :

> *From a communications perspective, electronic commerce is the delivery of information, products/services, or payments via telephone lines, computer networks, or any other means.*
>
> *From a business process perspective electronic commerce is the*

application of technology, towards the automation of business transactions and workflows.

From a service perspective, electronic commerce is a tool that addresses the desire of firms, consumers, and management to cut service costs while improving the quality of goods and increasing the speed of service delivery.

From an online perspective electronic commerce provides the capability of buying and selling products and information on the Internet and other online services. (p.13)

This thesis is mainly concerned with the *online perspective* of e-commerce. The following sections discuss about the importance of this industry in terms of revenue generated, and it also discusses some of the major growth factors behind this industry and identifies the gaps within the infrastructure which can impede this growing industry, with a focus on India.

In [3] "The Census Board of department of Commerce" of U.S. has announced the e-retails sales of United States for the fourth quarter of 2015, was 89.1 billion U.S. dollars, an increase of 2.1 percent from its third quarter earnings. Compared to 2014, the report [3] found the net revenue of estimated sales in 2015, was an increase by 14.7% from the fourth quarter of previous year.

Current e-commerce statistics suggests that nearly 40% of users worldwide have brought products or goods online at some point using desktop, mobile, tablet or other services, which puts the total number of online buyers at nearly a billion users. The popularity of digital devices, growth of internet are some of the closely related factors which has contributed to the popularity and growth of e-commerce sales worldwide.

Alternative digital payment options such as digital wallets and growth of online payment providers like PayPal have also contributed to an increase in the adoption rate and the rapid growth of online sales in past several years. The e-commerce growth trend is not restricted to the U.S market, but revenues from online purchases have increased generally worldwide. Similar trends of a growing online-retail market have been observed in the markets in Europe, Asia including developing nations of India and Africa. The revenue earned in Germany alone, by the e-commerce market is estimated to b 61,938.8 million U.S. dollars by 2016. It is also expected to steadily rise by another 7.41% by 2020 as estimated by report in [4]. In the Asian market, for example in China the total revenue in e-commerce is estimated at 300,468.3 million U.S. dollars in 2016, with a predicted revenue growth of nearly 19% in 2017, estimated by reports in[4]. In the Indian sub-continent, the impact of the growth of e-commerce industry has been phenomenal, and it is regarded as one of the fastest growing markets in the Indian economic sector. The e-commerce industry in India is estimated to be worth 17,547.2 million U.S dollars by 2016. At an annual growth rate of 16.98% it is estimated to have acquired a market share of 32,862.1 million U.S. dollar by 2020 [4].

1.2 Factors behind the rise of e-commerce industry

The paper [5] cites Murillo (2001) who discussed some of the parameters which affects the success of an e-commerce business or service, such as computers, internet, satellite technology, logistic assets and services. The author in [5] also emphasizes the positive relationship between the success of a firm and the efficiency of its distribution network. The study identified logistics process as one of the primary factors responsible for cost differentiation and revenue generation in this industry. Logistics is also regarded as a key corporate strategy behind competitive advantage in the market.

1.2.1 Increase of internet smart phone users

The Fig.1 (below) gives the reader an impression of the rise of the internet users through the past decade worldwide.

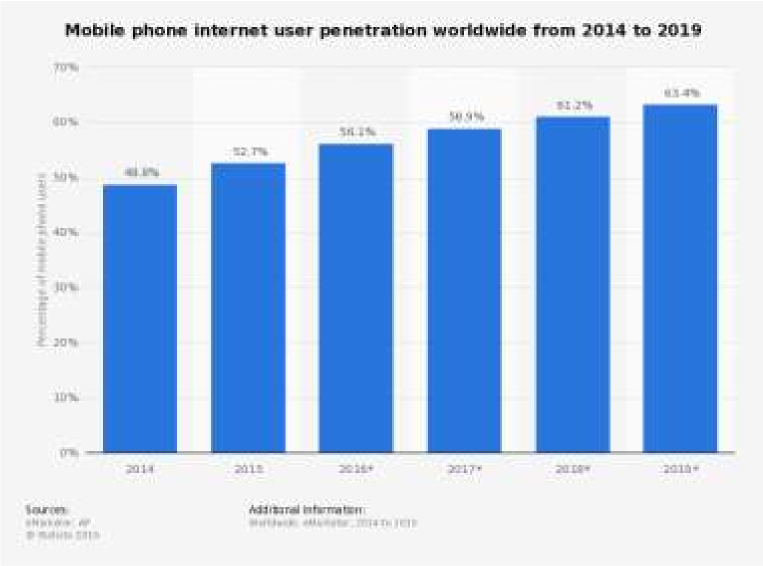

Figure 1: Internet users between 2014-2015[Source:[4], accessed 5th May 2016]

In India alone, the internet penetration is expected to increase to nearly 35.7% by 2020. Additionally, increase in the number of electronic devices such as tablets, smart-phones and other internet-enabled devices are observed in [6] as the other essential factors which have attributed to the growth of online users. The number of mobile phone users alone are expected to grow by 31.5% by 2019 from current trend as estimated by statistic in [4]. An estimated 50% of the orders generated, are through mobile apps and industries reportedly experience nearly 40-70% of their traffic from mobile phones alone.

1.2.2 Change in lifestyle and convenience

The lifestyle of the average Indian is adapting to the ease and convenience offered by the online e-commerce industry. The report by KPMG, [6] cites popularity of year round discounts and deals and the convenience of shopping at the comfort as some of the factors which has encouraged online buyers even further, especially among the younger generation. In addition, availability of international brands, which are not otherwise available in retail stores often are cited as other reasons which makes online shopping a lucrative option.

1.3 Role of logistic within e-commerce industry in India

The report by PwC[7], suggests that lack of availability of proper logistics infrastructure can act as one of the key deterrent for the growth of the e-commerce industry in most developing countries including India. The report claims the logistic models currently implemented in India, focus mostly on development of the Tier-1 cities which are inhabited by the affluent and middle class population compared to Tier-2 and Tier-3 cities. The report also observes that although most e-retailers are initially dependent on the third party logistics provider (3PL) for the fulfilment of their logistics needs recent observations suggests a drift in the trend, where organizations are focussed on developing their own supply chains networks to build a reliable delivery system to ship their goods in time. Indian retail companies nearly invest 30% of their income in logistics for supporting their business. However, this is an expensive investment given the logistic is quite a complicated process to manage. For example, Flipkart and Snapdealtwo of India’s major e-commerce business spends much of their money on logistics and are therefore unlikely to be profitable as business even in the next couple of years[8]. India does not have a single distributor of goods at a national level, like DHL in Germany, which makes the whole logistics process a lot more chaotic and complicated and left up to individual organizations.

1.3.1 Existing Indian logistics infrastructure

The report “Building India-Transforming the nation’s Logistics Infrastructure” [9] has pointed out some serious gaps in the infrastructure capability in India’s growing economy. The report found out that the current logistic infrastructure is not well equipped to support and maintain the expected growth rate economy. The report has estimated that current infrastructure capability can only meet only $1/3^{rd}$ of the demand requirements. It also observes that based on current trends, the investments needed in the logistics sector could be over 500 billion U.S. dollars by 2020. Despite this enormous investment, the report observes that growth in traffic will in fact worsen the service levels and deteriorate the transit time. It observed that current economic losses due to lack of proper logistics infrastructure are already at around 45 billion U.S. dollars, which could rise to140 billion U.S. dollars by 2020 in absence of proper action. The report advocates the need for development of an effective and smart logistic infrastructure system which could benefit India both economically and ecologically..

1.4 ICT solutions for greener economy

The definition of sustainability most widely cited was coined in the report, “Our Common Future” released by the Brundtland Commission[10] where sustainability is -

> *“development that meets the needs of the present without compromising the ability of the future generations to meet their needs.”*

The definition encompasses the three fundamental concepts core to sustainable development which is summed up in Fig. 2

1. economic growth.
2. social equity - for meeting the needs of the present generations and
3. Environmental protection - for the ability of the future generation to continue to meet their requirements.

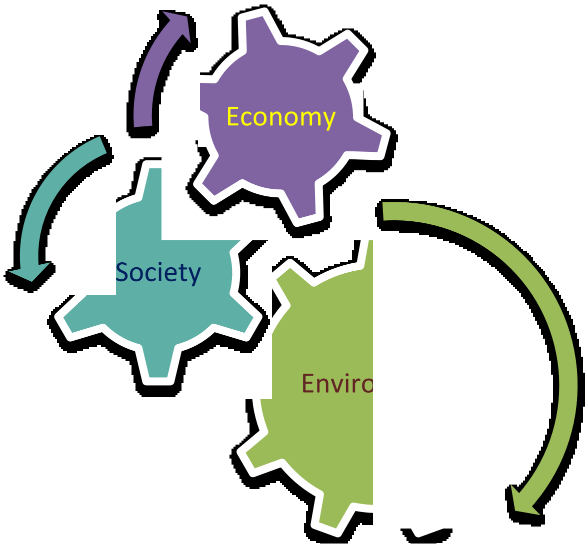

Figure 2 : Sustainability three pillars

The ecological challenges are rising with development, and increased fuel consumption attributed to the rising number of vehicles worldwide is one of the important reasons behind the ecological crisis faced globally. Goods transportation is growing rapidly worldwide because of globalization and economic growth. The "Smart 2020" report in[11] observes that the transportation sector alone accounts for nearly 14% of the global emissions. The report further observes that an optimization of the logistics sector using Information and communication technology (ICT), could result in reduction of transport emission by nearly 16%. Moreover, increasing fuel cost and rising taxes are other motivation behind the need to build more-efficient logistics systems. Conversely, [11] has estimated that ICT driven application in building logistic solutions could lead to global emissions reduction by 1.52 $GtCO_2$. Adoption of ICT enabled strategies for controlling emission is estimated to reducing emission by up-to 225 $MtCO_2$by 2020 which is 27% less than BAU(Business as usual). Adopting a ICT enabled smart logistic industry could alone help in saving 280 billion euro of which alone 29 billion euro could result from saving carbon costs alone.

1.5 Motivation

The potential of the e-commerce industry as a major revenue earner has been discussed in the previous section. The importance of development of an efficient logistics system for a competitive advantage in the market has also been presented. The potential of the sector in the Indian market has been also discussed and also the factors which limit the growth have been identified. Additionally the importance of developing a ecologically friendly transportation network has been deliberated.

The main motivation behind this research study is therefore, to investigate the possibility of the feasibility of use of the existing infrastructure in an energy efficient manner (achieved by the use of fewer vehicles for transportation), to support the potential of an emerging economy

1.6 Scope of the Thesis and Research Objective

This thesis proposes a model capable of optimization of the distribution phase of the supply chain management and investigates if improvement in efficiency of time, cost

and energy can be achieved which are at least comparable to existing solutions. In a real life-dynamic environment, there are several parameters which influence the decision making process involved in planning and distribution of goods in the supply chain management process. It is therefore a challenge to successfully co-ordinate, process and optimize the high amount of information obtained from the various participating components and synchronize their behaviour in a dynamic environment.
In order to a build system which is capable of making independent decisions, it is essential to consider the co-ordination among various system components, which in this problem case, involves collaboration between the various process involved in the logistics phase of the supply chain management system such as the courier service provider, transport service providers and end customers.

The thesis investigates the planning, control, monitoring of the integration of a public transport system with the delivery phase of the supply management process of the e-commerce industry.
It thesis aims to carry out research with the following objectives in mind:

1) To develop a simulation model for the delivery of small and medium packaged goods using the existing adopting an inter-modal transportation approach. The delivery phase includes a combination of existing transportation infrastructure facility of a city and ecologically friendly e-cargo bikes instead of using conventional dedicated pick-up and delivery vehicles used in most current scenarios.

2) To investigate the efficiency of the proposed model to study the parameters of service time, cost and energy consumption and compare its suitability to traditional approaches which uses dedicated delivery vehicles and to find out if the proposed solution is feasible in real-life applications.

The study has assumed the use of combination of public transport and e-cargo bikes by the Courier Service for delivery of goods. The paper [12] discusses the various benefits of using an alternative delivery option compared to conventional delivery modes such as cars and vans. The author describes the success of Micro-Carrier Urban Vehicle (MCUV) Fig.3, in pilot tests compared to conventional delivery for the following reasons-

a) Reduced inconvenience to pedestrians-due to less noise emissions, absence of exhausts gas pollution, and compact structures that leads to minimum spaces, which leads to minimum discomfort for pedestrians.
b) Possibility of driving and walking on sidewalks- Conventional vans are usually parked in bike lanes or second lane for delivery which apart from reducing traffic capacities add to increased emission because of the de-accelerated traffic flow.
c) Adherence to Euro 6 emission standards-The environmental benefits are obvious since door-to-door delivery is achieved with an electric vehicle.

Figure 3 : DHL operation of MicroCarrier research in Hannover within EU research project FIDEUS [Source: [12],page 137]

1.7 Contribution of Research Work

Although substantial work has been carried out in the field of operational research for optimization of the delivery phase, previous research has mostly focused on route optimization which relies on use of dedicated vehicles for goods delivery. The main contribution of this work lies therefore in eliminating the use of dedicated vehicles for goods delivery. The proposed model advocates the use of an intermodal transportation approach for goods delivery, which utilizes the existing public transport infrastructure for delivery rather than conventional delivery vehicles.

The elimination of conventional delivery vehicles means less number of vehicles, which can be argued to be an approach capable of improving energy and cost efficiency.

The complexity of the research lies in integrating the public transport infrastructure network of a city with the distribution phase of the supply chain process of an e-commerce industry. Several factors such as delivery time window, duration of total tour, time-schedules etc. of the public transport system needs to be taken into consideration for consideration of one of the most complex logistics process. In order to achieve the research goals, communication and negotiation mechanisms, decision-making algorithms and performance evaluations are all necessary which deals with the courier services of parcel delivery.
Three approaches, which are discussed in later sections, have been proposed for the study of the efficiency of the proposed planning algorithm implemented by the proposed system. The study evaluates the performances of three methods, which have been considered most critical for the evaluation of the thesis work-

1. duration of travel of tour
2. distance of tour covered by public transport system (passive distance) to distance covered using individual vehicle (active transport) and
3. Computation time of planning process.

All three approaches have considered the high amount information which need to be processed and updated continuously even after the plan generation and execution phase is rolled out. Additionally, constraints of the realistic modelling of the delivery system include consideration of the constraints of individual entities of the modelled entities.

1.8 Problem Description

This study has considered a delivery-planning problem shown in Fig 4 where a Courier Service has to deliver several medium to small sized packaged goods from a depot to several geographically dispersed customer locations within a city. The mode of delivery is a combination of public transport and e-cargo bikes, the reasons for which have already been presented in foregoing sections.

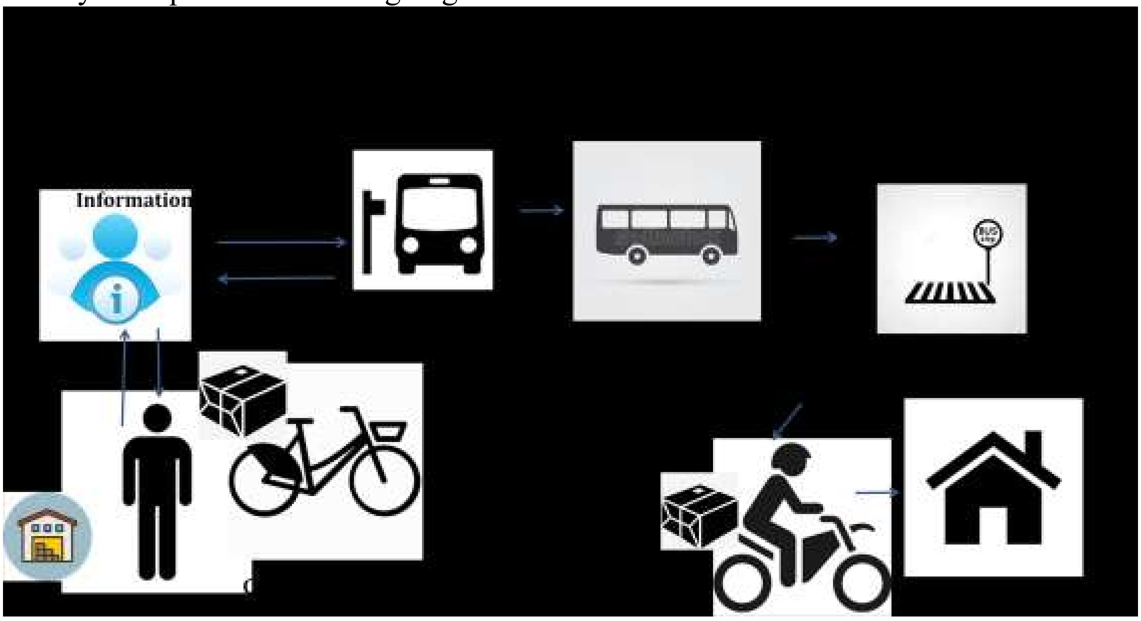

Figure 4 : Architecture of Proposed system

All deliveries are assumed to lie within a time-frame of 09:00 hours to 18:00 hours within a 24-hour day.
The Courier Service leaves the depot with the parcels to be delivered and information of the list of delivery locations.
It queries an Information System for a tour plan which invokes a planning algorithm to generate a tour plan based on public transport time schedule of the city, time of query, availability of transportation for the routes for the delivery locations etc.
Constraints such as bus and tram schedules, delivery time window and shortest path calculation to reach the maximum number of customers, are also taken into consideration in the planning algorithm.
The plan proposed is generally a tour which is a combination of distances travelled using public transport and e-cargo bikes. E-cargo bikes are considered since they are ecologically friendly and are small enough to be carried inside the public transport systems as well, for the part of the journey which proposes travel by public transport.
The Courier Service tries to closely execute the plan proposed by the Information System. The tour plan is considered successful if all locations are visited within the time window within the 24 hour day.
The Fig.5 (below) represents the high level flow of information within the broad components within the system, such as Courier Service, Information System, and the end Customer.

Figure 5 : Abstract Distribution Process Representation

The pickup and delivery problem is an important area of research field in combinatorial optimization and operations research. There has been extensive research already carried out in the field of Vehicle Routing Problem (VRP), Travelling Tourist Problem (TTP), Travelling Salesman Problem (TSP) and Travelling Salesman with Time Windows (TSPTW), which are the some of the most important background concepts that has helped to build this thesis work.

1.9 Outline of Thesis

The remaining thesis is structures as below. The Chapter 2 presents an in-depth discussion of related work and identifies the scope of the work in areas where it is most relevant. In Chapter 3, the research methodology appropriate for this work is presented and discussed. Chapter 4 presents the essential concepts related to multi-agent based systems, communication protocols and discusses an overview of architecture modelling using Finite State Machines. Chapter 5 discusses the implementation details and presents the results of the work. In Chapter 6 a summary of the thesis work is provide. Finally, in Chapter 7 a discussion of the work for its advantages and disadvantages is presented.

Summary

The chapter began with a discussion of the various technological inventions which has transformed business models worldwide. The e-commerce is one such result of shift in the business and technological paradigm. The chapter further discussed the various factors which impacted this industry and identified logistics as one of the key elements which have a direct correlation with the growth of the industry. It also weighed the need for development of smart logistics systems in order to mitigate adverse ecological and economical consequences. The main motivation behind the thesis was then presented which is, to propose a sustainable delivery model that uses existing infrastructure capabilities, to support a growing e-commerce sector in a developing nation such as India, which currently does not have the proper logistics capabilities to support the demands for this sector. The chapter has also addressed the main research objective for the thesis, and it has introduced some of the related problems studied in operations research which will be discussed in detail in the following chapter.

2 LITERATURE REVIEW

Overview

The previous chapter introduced the main idea of the thesis and also emphasized the importance of optimizing the delivery process of the distribution phase for both cost and ecological efficiency. In this chapter the objective of the thesis is summarized and the related body of work are discussed which has helped in shaping the thesis work by discussing all the relevant contents which helps to understand this work. It includes concepts both from the point of functional and technical relevance. The chapter be Relevant literature were selected and surveyed from a wide set of academic databases such as Springer, IEEE, Science Direct and Wiley etc. They were accessed from the University library Of Bremen , using keywords such as multi-agents, travelling salesman with time windows, tourist planning problem, vehicle-routing, optimization algorithm, green logistics, vehicle routing problem, sustainability in transportation etc. Finally, bibliographies and references of the reviewed papers related to TSP were also selected for research purposes. The objective of the thesis as presented in previous chapter is, to present and validate a model for the optimization of the delivery of small and packaged goods from the depot to several customer locations, given constraints of time and energy. The following sections discuss the literature which has helped to develop the model from the point of view of design of concept, modelling, formulation, and selection of methods and tools for verification and analysis purposes.

2.1 Supply Chain Management and Public transport system

Since the thesis deals with the distribution phase of the logistics process a brief overview of the Supply Chain might be useful to put the topic in its correct context. The Supply Chain Management process is generally viewed as the flow of goods from the production to the end users. Although, there is no widely accepted definition of Supply Chain Management (SCM), the author in [13] has classified SCM based on perspective. The author described that SCM can be defined either in operational terms, or as a management philosophy. The paper concludes SCM to be defined as:

> *as a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer*(p.4)

In [14]SCM has been classified as a complex system which is mainly composed of *Production Planning and Inventory Control process* and a *Distribution and Logistics Process*. The scope of the thesis is limited to delivery of the finished goods from the depot to the location of the customer, which lies within the broader scope of the *Distribution and Logistics Process*. In order to study the SCM processes closely the modelling and analysis of the various stages in SCM can be achieved by using deterministic analytical modelling, stochastic analytical modelling, economic modelling and simulation modelling which have been discussed in [14]. The choice of modelling implemented is dependent largely on the case under study and the parameters which are studied. Within the scope of this thesis, the public transport system plays an integral role in the delivery process within the scope of the distribution process, and therefore the complexity of the system is first studied in order to assess the appropriate modelling approach suitable for in this research. Public transport infrastructure systems such as bus, tram, metro and rail are the key designs for mobility. As discussed in[14] an urban public transport network is a complex system which is a result of interaction between a set of distributed and evolving entities such as the means of public transport, people and the network infrastructure. The complexity of the public transport system is further amplified by other dynamic parameters such as traffic jams, unexpected events such as accidents and changes in routes, weather etc. Since the purpose of the thesis is to utilize the public transport system for goods delivery, it is necessary to study the various parameters which are capable of influencing the system.

However, the size and complexity of the different influencing parameters, makes the realization of a theoretical model for the problem harder. Therefore, an approach which utilizes a simulation model for the implementation of the planning, control and analysis of the system would be more effective for the study of complex systems. Simulation modelling allows flexibility of observation, constraint verification and network evaluation which have been discussed in[16]. The first criteria "observation" is self-explanatory, since simulation provides the designer's, operators and other stakeholders of the inter-connected public transport infrastructure the visual impression of the different interacting parameters. The second criterion, allows checking for global and local constraints. It allows observation of the behaviour of several entities as they interact among themselves and with the system and thirdly, it allows scope for evaluations of the dynamic and static processes which are often difficult to realize otherwise. In absence of a simulation modelling system, the calculation becomes extremely complex and time-consuming for analysis of a complex system such as a Public Transport Network.

2.2 Simulation Software

There are multiple platforms and tools for simulation of MABS (Multi agent based simulation), e.g. Jadex (Pokahr and Braubach, 2013) based on the Belief Desire Intention (BDI) modelling which facilitate intelligent agent construction. Other professional tools, which support simulation and execution of large scale MASs, are JACK (Winikoff 2005) and EMERALD (Kravari et al. 2010). While these are general platforms and are not specialized for any domain, the PlaSMA Simulation Framework (PlaSMA) has especially been developed for, but not limited to, simulating dynamic scenarios in transport logistics. This study uses the PlaSMA system, which is an event-driven simulation platform based on multi-agents which was developed on the guidelines of the FIPA compliant JADE(Java Agent Development) Framework studied in[17]. It provides a distributed multi-agent based platform for the modelling, simulation, evaluation, and optimization of dynamic planning and control processes in logistics. It was developed by the Collaborative Research Centre 637 (Autonomous Cooperating Logistic Processes- SFB 637) by the Institute for Information and Communication Technologies (TZI) at the University of Bremen.

The authors in [17] has described the PlaSMA simulation environment as a composition of the following software components:

a) The simulation core (*PlaSMA core*) which controls the execution, and is described as an intermediate level built on the FIPA-compliant JADE.
b) A *database system* which is optional for the purpose of simulation but is used to store information related to performance indicators and other scenario specific data often used for purpose of analysis.
c) The *PlaSMA client* is useful for visualization, and the selection and control of the simulation configurations by the user.
d) The *agents* in PlaSMA represent various actors within the simulation scenario.

As described by the authors Warden et al., the PlaSMA system architecture is composed of the following components - a world model, physical objects, infrastructure and agents with their unique behaviours. The simulation system includes primary components necessary for simulation process control such as - interface for world model access, simulation agents, user interface, and simulation time management. The simulation control allows the initialization of the world model, access to the world model and performs agent life cycle management and time synchronization. PlaSMA also includes the capabilities allowed by the JADE framework such that distributed agent implementation is possible with only one top level controller and additional sub-controller for each of the distributed process or computers. The current implementation of the scenario does not support distributed simulation, although it is possible to extend it to include a distributed simulation environment in future.

Generally, a MABS system is capable of combining distributed discrete event or time-stepped simulation with decision making, encapsulated within the agents as separate logical processes. Moreover, within a MABS system, agents can interact with every other agent and they also have the freedom to join or leave the execution. That along with the flexibility offered also complicates the time management in a simulation. In a multi-agent simulation it is necessary to distinguish the concept of terms as *simulation time,* which is virtual time that represents the physical time in simulation, and *physical time*, which refers to time progression in the physical real world. Moreover, for an agent based simulation in a distributed environment with different host computing powers, results in problems mainly related to *causality,* which is the 'out of order' event processing. The problem of ensuring events are processed according to a time stamp order is described as the synchronization problem which is addressed by implementing either the *conservative* or *optimistic* approach for time synchronization.[18]

In PlaSMA, the causality problem is addressed using a coordinated conservative approach. In this approach, the top controller sends notification of progression of simulation time to sub ordinate sub-controller. The sub-controllers in turn identify the locally managed subset of simulation agents due in the next time stamp, and advances the local virtual time of these agents and sends wake up notifications to the same. The individual agents are responsible for execution of their respective behaviours. At the end of each action cycle, the agents send notification to the local controller for further requirements, in case it expects additional responses from another agent, or it could also explicitly specify a particular time event in future for next execution. The consolidated result of the activities propagates as a single activity to the controller to take decision on time progression and scheduling of the next simulation cycle. In PlaSMA implementation, a world model of the physical world based on OWL-DL ontology's is provided. Some of the main benefits of adopting an ontology based modelling approach are the standardization of the scenario development and design process. There are five core ontology modules relevant to a logistic scenario process. However, it is possible to extend or customize them for other scenarios. These are broadly divided as follows -

a. TLO –the *top-level domain ontology*, extended by all other ontology's. It defines the general specification for logistic based processes, general physical based objects, traffic infrastructures etc.
b. TRANS – this ontology is for multi-modal *transportation*, and includes various types of transportation, multimodal transport systems, means of transport, loading equipment, etc.

c. PROD – this ontology specifies resources related to *production* and orders with their respective properties and constraints.
d. COM – the *communication* ontology defines communication and computation related properties.
e. GOOD- the *good* ontology provides a schema for goods description.

The ontological representation of the modelling allows initializing a scenario in PlaSMA with an environment representing associations between objects and its agents. However, these ontological instances of the agents need to bind to an agent in PlaSMA using a Java implementation, which is necessary for the simulation to progress. Each simulation agent once instantiated, has access to the ontological specifications using world model queries. [17]

2.3 Modelling Public Transport Infrastructure using Graph Theory

In the above section a brief description of the benefits of adopting an ontology based simulation approach has been explained in terms of improvements in reusability, scalability, portability of the domain which is some of the primary motivations behind adopting PlaSMA for the purpose of simulation. The present section discusses the representation of the modelled system as a graph such that the real environment can be translated into the system model.

In urban modelling of transport network infrastructures and road network, graph theory has been used to varying degree of success. Graph theory has proved to be a useful and simplified scheme for modelling transportation networks. However, it needs to be pointed out that often some important aspects related to the network structure are lost such as the angular structure during modelling. More often, the modelling of the transportation network is an educated approximation and not the exact representation of the real world infrastructure model. In real life infrastructures, the links have properties such as capacity, type of use, construction cost, etc.

The simulation system's physical world as a directed graph consists of nodes and edges. Nodes represent road junctions, stops, dead-end, sources or sink whereas the edges represent the transport infrastructure such as roadways, rails etc. Nodes are locations represented in terms of geographical co-ordinates as *tlo: Vertex*. The edges have properties such a length with exactly one start and sink location represented as *tlo:Edge* [19]. In order to model public transportation network realistically it is necessary to ensure that traffic modelling represent both-ways traffic and therefore requires two edges.

The simulation model is independent of the environment where it is built therefore it is quite possible to exchange the infrastructure and the simulated Public Transport Network depending on the place of the simulation scenario. The PlaSMA system supports the import of OSM (Open Street Map) data, which contains information related to the public transport routes as well as other information related to position and names of the stops. Volunteers usually add this data to OSM manually. Therefore, it is not always most accurate and recent changes maybe not updated. OSM data however provides no information related to the timetable.

A Public Transport Company (PTC) provides the time-table schedules in a standardized format containing the geographical coordinates of stops. The data from the PTC is not sufficient to map the stop ID's with their related location in the world map, for the simulation model. The modelling technique used in the simulated environment has been

discussed in [20] where Greulich et al, uses the Needleman Wunsch algorithm for resolving naming conflicts between different stop locations and diverse travel directions at crossings in order to resolve the matching problem.
In a multi-modal transportation system scenario using public transportation time scheduling is of paramount importance. Timetables for public transport are extracted and geo-located in the maps. The association between the street map data and public transport combined with the timetable information includes the travel and waiting times resulting in a realistic travel simulation.

2.4 Routing in Public Transportation Network

In a transportation network routing is an area of research closely studied in urban network transportation and operations research field. Computing an optimal route in transportations for computing journey between a source and destination point is an application which utilizes algorithms in real-world scenarios. In the real-world scenarios there are several route optimization applications such as logistic planning, traffic simulations, travel planning. The optimization algorithms for tour planning are generally associated with a cost function. A cost function can have several interpretations, such as travel time, distance travelled, energy consumption, preferred travel route, no. of transfers, etc. In this thesis, the delivery of goods are dependent on multimodal transportation option which relies on time based schedule information of buses, trams, etc. and therefore the cost function is associated with time.

2.4.1 Routing Algorithms

In this section and following, the existing routing algorithms used in Operations Research field has been discussed, which provides a discussion of the body of work already carried out in this field. The effective and efficient management of goods is one of the essential motivational factors in both the public and private sector. Due to the complexity of the distribution networks, mathematical programming models and algorithms are a means of extensive use for economic and social reasons. The routing algorithms relevant to the problem are discussed below.
The vehicle routing problem is a very important field studied in operations research and combinatorial optimizations. The Travelling Salesman Problem (TSP) discussed in the previous chapter, is in fact a variant of vehicle routing problem (VRP) where only one capacity, namely one vehicle is concerned. Also the Tourist Planning Problem (TPP) is the other variant of the TSP problem which lays the background in this research.
The vehicle routing problem involves the design of a minimum cost route originated and terminated at the depot. Lin et al. [21] discuss the evolution of the vehicle routing problem and discusses several variants of VRP. It discussed the earlier problems of Capacitated VRP which was first addressed by Danztig and Ramser in1959 and then traces the gradual evolution towards more complex research problem. Applications of VRP are found in various fields such as waste management, postal delivery, pick up and drop of schoolchildren, banking services, food delivery services etc. The diverse nature of the application therefore finds different variants of the VRP problem briefly summarized in this section. Lin et al.[21]has discussed the important variants such as the time-dependent VRP(TDVRP), where the time of the day influence the solution, thus taking into real-life factors of urban congestion, rush hours and weather conditions into considerations while calculating inter-nodal distances. It also references the works of Cookie and Hasley in 1966 which was one of the earliest works extending the static inter-nodal time function to include a varying inter-nodal time. The extension of the

DVRP to time dependent VRP with time windows has also gained a lot of attention in operations research. The time dependent variant poses a constraint of time window of earliest and latest arrival time for the delivery of goods to a customer's location. The works of Speidel(1976) and Psaraftis (1980) considered the problem which integrated the dynamic information such as new incoming customer orders and other information related to the vehicle location for routing decision problem as early as the early 1980's. The other variant of VRP which deals with the pickup and delivery problem was discussed by Wilson and Weissberg in 1967. Pickup and delivery problems deal with backhauls which is an important area for reverse logistics study. Other related works are those of simultaneous pickup and delivery. The operational constraints of VRP were studied by Chen & Xu, 2006. In dynamic VRP with time windows (DVRPTW) were studied by Gendreau, Guertin, Potvin &Tailard, 1999 and Hong2012.

Generally, in literature, there are two time windows studied,

a *Hard Time Window*-The vehicle needs to service the customer within the specified time window and later arrival is not permitted.

b *Soft Time Window* - Soft time window permits violations of the service times but at the cost of some penalty.

There is extensive literature for VRP with time windows and recent studies have focussed beyond the minimization of transportation cost. Figliozzi (2009) studied the variation of time windows with customer demands and service-window time restrictions, which is an important decision maker for fleet sizing, facility location, network design etc. Among other constraints which had been studied are the ones related to priority delivery for customer, delivery of goods which needed special requirements for handling such as hazardous or perishable goods, soft and hard time windows. The areas of research in Vehicle routing problem are related to the fleet capacity, and often a combination of heterogeneous vehicle fleet capacity which differ in terms of speed, capacity are studied by logistic decision makers to find the optimum choice which is economically viable. The research of Baldacci, Battarra & Vigo, 2009; Liu, Hang &Ma, 2009 studied the fleet management and vehicle capacity problem in depth. Most studies in VRP assume a Hamiltonian cycle of route path where the delivery vehicles return to the origin or depot at the end of the journey. However, the study of Open VRP, first studied by Sariklis and Powell in 2000, assumed a Hamiltonian path instead of a cycle for tour problem, where the vehicle does not return to the depot after tour completion. This problem is more naturally encountered in real-world delivery of newspaper, mail delivery services and is also a common phenomenon in logistic based companies which utilize 3PL.

A major development in VRP research was the benchmarking tests of Solomon (1987) for evaluation and comparison of quality of solution and the computation time for the solutions. Several algorithms exist for finding optimal solutions to the problems related to VRP and its close variant the Travelling Salesman Problem (TSP).

The TSPTW is the focus for the concepts of this research and a closer look at a related problem the TPP will be discussed here which form the basis for the mathematical interpretation of this work. Both the problems are NP hard combinatorial optimization problems and therefore a solution, which is optimal or near optimal are obtained generally by an exact or approximate algorithm methods. The TSPTW is explained as below

2.4.2 Travelling Salesman problem with time windows

The Travelling Salesman Problem is an extensively studied research problem in operations research. TSP is defined as a problem which deals with finding an optimum solution for travel distance, when a salesman wants to visit each of a set of cities exactly once and return to the point of origin. The TSPTW is a variant of TSP with a service time window constraint.

TSPTW deals with the design of a minimum cost function for the path travelled by a vehicle /salesman that visits a set of nodes. Each node is visited exactly once and the service at a node must lie within the earliest and latest time. In case of arrival at node before start of service time, an additional wait time is added until the beginning of service time. TSPTW has important implications in various application problems related to scheduling, automated manufacturing, bank and postal service deliveries.[22].

Dumas et al [22] cite the research of Savelbergh (1985) which has shown that even a feasible solution to the TSPTW, is considered a NP complete problem.
Dumas et al.[22]studied the dynamic programming method for finding a feasible solution which increased the performance and minimizes the total cost for the TSPTW. In this study the objective function formalization for the TSPTW problem is very similar to the one described in the paper by Dumas et al. referred here. The problem described is related to the TSPTW which defines a network, as a state graph$G = (N, A)$ where $N = \{0,1, \dots n\}$ is the set of nodes that needs to be traversed and A is the feasible arcs between the nodes. In this problem the node 0 represents the depot and the n other nodes represent the customer locations which need to be visited. Consider a time window associated with each node $i \in N$,$[a_t, b_t]$and a service time s_t for each node. Every arc $k \in A$. The cost function in this study also includes the public transport time schedule apart from the time taken to travel between every node, therefore let the cost function be defined as $C = c_{ij}^{t}$, and time duration t_{ij} is the time taken to travel from node i to j. The cost function varies depending on the parameter constraints that are essential to the problem at hand. Let M be the time (or cost function) matrix dependent onc_{ij}. The cost function can be expressed as the minimum time required for travelling through each of the nodes. In several, applications, including this study c_{ij}^{t} one interprets as a cost or travel time distance matrix.
An arc $(i, j) \in A$ is only feasible if $a_i + s_i + t_{ij} \leq b_j$. Let$N'$bedefined as $N - \{n\}$. A path in the network G is therefore defined as a set of nodes $i_1, i_2, \dots, i_k$ such that every arc$(i_j, i_{j+1}) \in A$and the service time begin at node $i_j, j = 1, \dots k$, is within the time window of that node.
Consider the time of departure from node 1 is a_1 and the time at which service begins at node $i \in N$ bet_i. If a path goes from node i to node j, the service time for node j is given by,$t_{ij} = \max(t_t + s_t + t_{ij}, a_j)$ if$t_t + s_t + t_{ij} \leq b_j$, and else $t_j = \infty$,otherwise. The definition implies in case of an earlier arrival at a node, there is a waiting period before it can be serviced. For an optimal TSPTW solution, a least cost feasible function $F(S, i, t)$ such that every node in G is visited exactly once is found out. We look for the least cost of a path starting at node 1, which visits every node of$S \subseteq N'$ exactly once, ending at node $i \in S$, ready to service node i at time $t$or later. In this study the service time is t. Since the cost$F(S, i, t)$the time t and the public transport time Tone needs to address separately, it becomes a multi-dimensional problem. However firstly here the TSPTW has been described mathematically as the function $F(S, i, t)$computed by solving the recurrence equations:

$$F(S, i, t) = \min_{i,j \in A} \{F(S - \{j\}, i, t') + c_{ij} \mid t \geq t' + s_t + t_{ij}, a_j \leq t' \leq b_j\} \quad (1)$$

For all $S \subseteq N^{'}, j \in S$ and $a_j \leq t \leq b_j$.the recursion formula is initialized as

$$F(\{1, j\}, j, t) = c_{1j} \text{ if } (1, j) \in A \text{ and,(2)}$$

$$F(\{1, j\}, j, t) = \infty \text{ otherwise,}$$

where $a_j \leq t \leq b_j$ and $t = \max\{a_1 + s_1 + t_{ij}, a_j\}$. The optimal TSPTW solution one obtains by

$$\min_{(i,j)\in A} \min_{a_j \leq t \leq b_j} \{F(N, i, t) + c_{in} | t \geq b_n - t_{in} - s_i\} \qquad (3)$$

The equations$(1) - (3)$ define a shortest path algorithm on a graph whose nodes (S, i, t) and arcs represent the transition from one state to another. S is defined as the unordered set of visited nodes, $wherei$ is the last visited node and$i \in S$,and t is the time at which service begins at node i.

TSPTW, reduces to the TSP when the service time is between$0, \infty$. In the paper [23] explains given a travel time t_{ij}, between node i and j, the symmetric TSP holds the relation t_{ij}, =t_{ji} true, whereas for asymmetric TSP that is not the case.

2.4.3 Tour Planning Problem

A closely related variant of the TSP is discussed in this section which helps gain a deeper insight of the problem due to its relatedness with this research.

In [24]describes the TPP as a sightseeing problem to decide an optimal route which considers maximizing the total number of sights visited under time dependent parameters, such as time bound travelling times between sites. The paper [25] further defines the TPP as an itinerary planning problem which utilizes the public transport system for routing and scheduling. The paper [26] has considered the Genetic Algorithm for scheduling of the route planning problem of the travelling tourist.

The following section gives a brief discussion of the various algorithms which has been used in solving TSP, TSPTW and TPP. It will form the basis for choosing Nested Monte Carlo algorithm for the purpose of this research.

The relatedness of the TPP with the research study draws to the conclusion that the research is studied as a variant of the TPP problem. Since TPP is relatives less researched as yet, the following literature has reviewed some of the existing algorithms for finding optimal solution to its close variants, the VRP and TSP.

The paper of[21] classifies the search technique used by algorithms broadly as *exact* and *approximate* algorithm methods. While *exact* methods are useful when the search space is relatively small, *approximate* algorithm often yields satisfactory solutions to large-scale problems as well.

The optimality of a solution degrades once the solution space increases significantly and in the paper [27] suggested that current known *exact algorithm* techniques do not produce consistent optimal results with more than 50 customer. Heuristic based solutions range from *constructive heuristics* (Clarke and Wright, 1964), *two-phase heuristic* (Gillet and Miller, 1974) to *improvement methods* which act on single routes by the application of the Travelling Salesman problem (TSP) heuristic. As reported in [27] which references the work of Laporte and Sernet (2002), with classical heuristic and sweep algorithms (Gillett and Miller, 1974) the execution speed is high but solutions produced have large gaps with existing optimal solutions.

Over the last decade, solutions using *metaheuristics* have been out. It has been observed that *metaheuristics* methods are often more successful since it carries a more thorough search of its solution space, and are able to discard infeasible solutions. One can further classify metaheuristic into *local search* and *population search* methods.

The main local search methods for metaheuristics include Tabu-Search(TS),

Simulated Annealing(SA), Greedy Randomized Adaptive Search Procedure(GRASP), Variable Neighbourhood Search (VNS) and Large Neighbourhood Search (LNS). Some typical examples of population search methods include Genetic Algorithms (GA) and Ant Colony Optimization (ACO).
Some of *approximate* and *exact* algorithm search methods used in VRP and TSP as summarized here: The paper [28] studied the Tabu-search method for studying the Delivery and Pickup Vehicle Routing problem with Time windows and compares the quality of results using SA algorithm. The [29] used Genetic Algorithm methods for finding an optimal solution in the multi vehicle pickup and delivery problem. The paper by Laporte [30] summarizes some of the best known research in the TSP field. The Branch and Bound algorithms(BB) are the commonly used algorithms for solving problems related to TSP Some of the best known research using BB are the work of Arpanet and Toth (1980), Balas and Christofides(1981) and Miller and Pekny (1991). The work of Miller and Pekny (1991) was successful in producing optimal solutions for randomly generated asymmetric TSP's up to 3000 vertices.

Other algorithm such as ant colony optimization algorithm[31] has been used in TSP. Also [32] uses SA for finding optimal solutions of the TSP problem.
Other methods used use heuristics based algorithms such as The nearest neighbour algorithm (Rosenkrantz, Stearns and Lewis, 1977), and Insertion algorithm (Rosenkrantz, Stearns and Lewis, 1977;Stewart,1977;Norback and Love, 1977)as surveyed in the paper[30]. Some of the other algorithms, which Laporte, comments in his survey, are composite algorithms. Of the composite algorithm the following have been developed, GENIUS (devised by Gendreau, Hertz and Laporte in 1990) and CCAO (Golden and Stewart) 1985.
The Monte Carlo search based algorithms revolutionized the game of Go and AI approach since their advent in 2006 where traditional approaches were failing to outperform their human counterparts. Since then Monte Carlo Tree search (MCTS) based search [33]has been applied to several other games related where information was sparse. The Monte Carlo had also been applied to numerous combinatorial optimization problems including the TSP. Rimmel et al. used the Monte Carlo search solve the TSP with time windows to reach optimal solutions with 29 cities. The paper studied the problem of Physical Travelling Salesman Problem to find out the optimality of the solution using Monte Carlo search. The basic idea in Monte Carlo search relates to random pay out (described in the previous section) and therefore overcomes the need to have prior knowledge of the system. The application of the Monte Carlo algorithm extends to fields beyond the realm of classical Artificial Intelligence(AI), as mentioned in [34]successfully to dynamic, continuous and multi-agent environments as well. Research uses it in fields of vehicle routing, container packing, and robot motion planning. The utilization of the Monte Carlo Algorithm for the purpose of tour order planning in this research was motivated by the success of its performance in previous fields of research study.

2.4.4 Nested Monte-Carlo Algorithm

The TSP is an important optimization problem used for benchmarking optimization algorithms. The TPP problem discussed was tackled by combining it with a Nested Monte Carlo (NMC) search algorithm. In this approach the function to be optimized is based not on the average but instead the best score in a predefined number of runs. In the absence of available heuristics to guide a search the NMCS algorithm is used as a tree-search algorithm. The tree space to be searched is large and has the leaves of the tree (final positions) are evaluated without any prior knowledge. It is useful in problems where decision making is important at all stages of the problem solving.

NMC uses several levels and at each level the result of the lower level is evaluated to ascertain the next move. The level 0 in a NMC is where random playouts take place until a final position is reached. At each step of the NMC the move with the highest score in lower levels are selected. At each step the algorithm tries out all possible moves and, and invokes a nested search at the lower level after each move, and memorizes the sequence of moves which has the best scores of the lower level searches. Precisely, a search of level n will perform $n-1$ NMC and the sequence with the best score is selected. Once an action is selected the problem repeats the process until a final position is reached.
As the samples are randomized it is not guaranteed that a nested search will always improve on previous searches or lower level searches. In order to retain the best score, the algorithm always memorizes the sequences. Iteration ends by advancing the current node one playout towards the present best solution. If no other moves improve upon the current best score, that move is played; else it is updated with the new sequence. The algorithm implemented in this study with policy adaption, where nesting levels $n \geq 2$ do a fixed number of iterations beginning with the current policy. It begins with the current policy as a starting point and updates when an improvement is found.[35][36][37]
The algorithm has been mathematically explained below-

```
nestedMoneteCarlo(level)
best playout←{}
best.score=MAX_VALUE
while not end of game do
if level is 0 then
          move← arg 〖 _max(play(position,m))〗
     else
move=arg max(nestedMonteCarlo (play (level-1) ) )
     if score of move>best.score
         best.score=score after move
         best.sequence=sequence after move
     else
       bestMove=move of the sequences so far
return score
```

2.4.5 Dijkstra's Algorithm-

In order to build an optimal route plan, the shortest distance between nodes or customer locations are first calculates using the Dijkstra's algorithm for time expanded network as described in [38] for the calculation of the earliest arrival matrix,

Dijkstra's algorithm is the most popular algorithm for shortest path calculation. This is the classical algorithm implemented for route planning, such that all nodes of a graph $G = (V, A)$ are visited in the order of increasing distances from the source where $, s \in V$. The algorithm maintains an array of distances $d[u] \geq d(s, u)$ for each node. During the initialization phase all distances are set to∞. In a iteration the node with the minimum value say, u is visited. Once the node has been visited its outgoing edges $(u, v) \in E$ are relaxed i.e. to say $d[v]$ is set to the $\min(d[v], d(s,u) + w(u,v))$. If the path, which goes via u, yields a better result in traversing the distance between s to v, it is added to a priority queue order, or if v had been previously added its priority is decreased. The order of visited nodes is the Dijkstra's rank $rk_s(u)$. The algorithm terminates if all nodes have been visited or alternatively if the target node has been reached.[39];[40]

The computation of the tour for the delivery problem under study uses a two-phase mechanism for computation of the tour order. In the first phase, the cost function is assumed to be a parameter of time, and time distance matrix is built, $[M] = [a_{ij}]$. Each element within the matrix a_{ij}, is the arc for the earliest arrival time connecting two locations i and j.

Summary

The foregoing discussion has presented a comprehensive discussion over the key research areas in Operations Research and their evolution from the VRP to the more recent TPP problem. The evolution of the various variants of the VRP, TSP and TSPTW problem was presented to give a context to the reader of the widely studied areas and form the basis where the current study is similar to existing problems and also in scope where it differs. The delivery problem studied in this research falls very closely within the scope of TPP and is similar to the TSPTW because of its limitation to the time window for delivery. Other findings from the research study helped to find out that although significant study had gone in improving existing algorithm very little research has focussed on implementation of delivery solution with a focus on energy efficiency. In short Green Logistics is an area which has been relatively very less studied. The paper [21] asserts the importance of integrating operations research study with a focus on ecological efficiency in order to extend the scope of research in Green Logistics. Current research has not so far focussed on providing ecologically efficient solutions for meeting the rising demands of delivery of goods. Having identified the gap in research in this domain, the current research stands as a piece of missing link between operations research optimization study and integrating it with sustainability. Therefore, in this research the aim is to study the gap in this research field that is yet to explore the potential of the utilization of existing urban transportation system for finding optimal solutions for delivery problem.

3 RESEARCH DESIGN METHODS

Overview

The previous chapter discussed the related work in the field of operations research and identified the current gap in body of knowledge. Therefore it established the groundwork for the benefit of this study. The current chapter focus on the methodology adopted in the research study.

3.1 Methodology adopted in research

A *quantitative scientific modelling* approach consisting of a four phase's research process was employed to investigate the research question for the thesis.

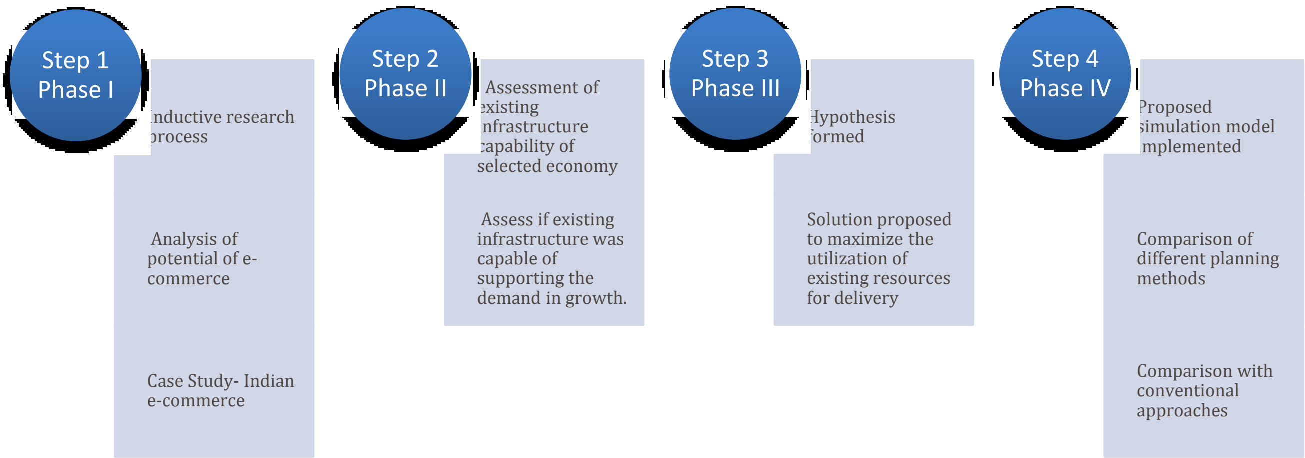

Figure 6 : Steps of Methodology Implemented

The Fig. 6 illustrates the four essential phases adopted within the research, which is explained below.

Phase I- In the *Phase I* of study an inductive process of research was implemented where a detailed investigation of the potential of the e-commerce industry as a major source of revenue earner was concluded. This study involved desk analysis of several research papers, online surveys, scientific and business journals, newspaper articles. In this phase, the assessment of e-commerce on the global economy was looked at carefully for estimating its impact on different world economies. The study identified developing economies as ideal markets which has the potential for e-commerce business growth in the future. It also further analyzed essential factors which contribute towards the development of this sector.

Phase II- The results of *Phase I* study helped in identifying the Indian e-commerce sector as potential economy as a case study for further research.

In this II phase of research, careful analysis helped to understand if the existing infrastructure and resources of the economy were capable of supporting the predicted growth rate in this sector. After careful reasoning some serious gaps in infrastructure capability was identified, for example lack of extensive transport network connecting different parts of the country, lack of a uniform address system for identification of addresses which led to several failed delivery attempts, an overburdened traffic network system already strained with a burgeoning population.

Phase III – The results of the previous phases were combined which led to the identification of the current un-prepared state of logistics infrastructure, which was found to be inadequate to support the expected growth of the e-commerce sector. The III phase, therefore explored solutions which would encourage maximum utilization of existing infrastructure and minimize the use of additional vehicles for transportation of small and medium sized packages goods, with an objective to minimize the number of vehicles used in order to avoid adding additional strain on the existing transport network. The solution hypothesis aims to minimize the cost, traffic jams, reduce emission rates. The proposed solution was implemented as a working simulation model in the PlaSMA simulation model framework using a Multi-agent based system approach.

Three different implementation approaches were employed, which checked for the efficiency of solution in terms of duration of tour travel, and effective distance travelled under different circumstances using controlled and random experiment methods.

a) *Case I* - studied the behaviour of the system when the tour was travelled on a bike/vehicle without use of any public transport system
b) *Case II* - studied the solution where a tour plan was generated taking an average approximation of time-table schedule of the public transport system.
c) *Case III* - studied the behaviour of the solution where a tour plan was generated using a higher sampling of time table schedules of the public transport system.

Phase IV – In this final phase the results of the different methods were implemented in *Phase III* using controlled and random experimentation were analyzed. An inductive reasoning maps the results with real-life situation and suggestion for more close improvement of the model-to-model in real-life situations. Simulations of real-life situations such as traffic jams were not part of this research. Although it was possible to simulate the failure probability of transport routes but for this research the feature was mostly kept disabled. The experiment and implementation section gives further details.

Summary

This chapter presented the methodology adopted in the research work and outlined the development of the work carried out in different phases. It established the relationship between the different phases and explained how the result of one phase was utilized for hypothesis formation for the next stage and ultimately led to the development and eventual analysis of the system proposed.

The following chapter will discuss on the core concept of multi-agent based approach adopted in system modelling, and discuss its importance to this particular study.

4 THE MULTI-AGENT APPROACH

Overview

In the foregoing chapter the methodology adopted has been presented. The multi-agent based approach employed for the planning, control and optimization process in transport logistics and which allows the handling of complex dynamic environment conditions has been discussed in this current chapter. This section also includes a detailed discussion of the tour-planning algorithm which the agents employ during the decision-making process. The section 4.1 provides an overview of the multi-agent approach. Section 4.2 presents the agent based communication process followed by a realization of the modelling architecture which is presented in 4.3. The following section 4.4 presents an in-depth discussion of the pre-processing algorithm. Finally section 4.4 presents the Interaction protocol.

4.1 Multi-Agent based system approach

The available techniques used for system modelling are broadly classified into three categories - System Dynamics, Discrete Event Modelling and Agent based modelling. The choice of modelling technique is influenced by the problem studied. The Agent based modelling technique is useful when only information regarding the individual entities of the system is available, but the global behaviour of the system when different entities interact with each other cannot be determined.

The Multi-agent based system is a growing area of research, and although there is no universal consensus over the definition of an agent within the scientific community, some properties which define an agent are widely accepted and are based on research by Wooldridge in [41] which defines an agent as :

> *agents as computer systems capable of autonomous actions in some environment in order to meet their design objectives*.

Wooldridge, further describes an agent based on three important characteristics–

a) *reactivity* - intelligent agents are able to perceive their environment and react accordingly to changes in the environment.

b) *pro-activeness* – agents are able to take the initiative to perform an action for the realization of a goal and finally

c) *social ability*- which means that agents are capable of interacting or communicating with other agents or humans in order to achieve their desired goal.

Compared to a universal definition of an agent, the simulation scenario and application needs of a particular case study define an agent more specifically.

In, [38] ; [42] ; [43] the authors have studied the urban environment modelling of public transport system where the model included bus operation, traveller behaviour and road traffic based on multi-agent simulation techniques. The studies have revealed that an agent based modelling technique allows to model autonomous, dynamic and interacting entities and are therefore a useful modelling technique for the study of Intelligent Transport System. The use of agent-based modelling techniques has the benefit of encapsulation, which allows the modelling of a single entity which includes a set of linked activities, a phenomenon popular in object oriented programming.

In this thesis, the simulation modelling encompasses several individual entities which participate within complex system model. The high-level architecture of the system has

been discussed in Chapter1. The public transport system includes the bus tram network and the public transport time schedule. The other entities involved include the Courier Service which is responsible for goods delivery, the system environment and the delivery location which all form part of the system. Other factors considered during the planning process are the waiting times of Courier service at bus stops for public transport and service time windows at customer locations.
Therefore, a multi-agent based approach is adopted to ensure that the level of concurrency of information while decision making increases such that all available information with various agents are utilized during the planning process.

Applying the multi-agent approach for the simulation of a scenario has other be benefits, such as availability of existing tools for such as Madkit, Netlogo, SWARM etc for development. In contrast, equation-based modelling approaches do not extend the same level of task decomposition and flexibility of modelling of individual behaviours of the different components.
Another advantage of agent based simulation is the ability to achieve, fine grained control of the scenario, at a micro-level, that allows the dynamic environment to be included within the solution space therefore achieving better accuracy of the model.

4.2 Agent based communication

The Agent Communication Language (ACL) represents messages exchanged between agents which is defined by a set of attribute specification of FIPA.
An agent that wishes to communicate needs to create a ACL message and fill its attribute with appropriate values. There are sets of existing specifications and methods defined by FIPA for sending a message, receiving a message or setting attributes. Attributes are named according to parameters defined in FIPA Agent communication specifications. The ACL message class refers to a set of constants that are used to refer to FIPA performatives i.e. REQUEST, INFORM, etc. When an ACL message is created one of these performatives is passed to the ACL message to select the correct message performative. In order to create a valid application specific reply to an ACL message it is necessary to set the appropriate values for the attribute in-reply-to, using the same conversation-id etc.
The JADE model allows an agent to perform several tasks in parallel which means several simultaneous conversations can be carried out. However, since the queue of the incoming messages is shared by all the behaviours of the agents, an access mode which allows message pattern matching technique was implemented. The Message Template class was implemented to build patterns to match ACL messages, which ensures that the queue of the message class is accessed by referencing to correct message meant for the particular behaviour and not accessed in a FIFO manner.

4.2.1 Interaction Protocol

The agent communication process used in this research study implements the Interaction Protocol mechanism for negotiation process between agents which is described in this section. The FIPA ***Contract Net Protocol*** **(CNP)** is an approach to implement the co-operation and co-ordination mechanism implemented in multi-agent system simulations which is illustrated in Fig. 7. The CNP protocol recognized the role of an ***Initiator*** (exactly one) and a Participant (at-least one) and wishes to optimize the task of a function further. The initiator is responsible for the initiation and negotiation, collection and evaluation and matching the proposals submitted by the participants and informing them about decisions. In any given task, more than one Participant can respond with a proposal and the rest may refuse. Further negotiations then continue with the participants which had previously sent a proposal.[44]

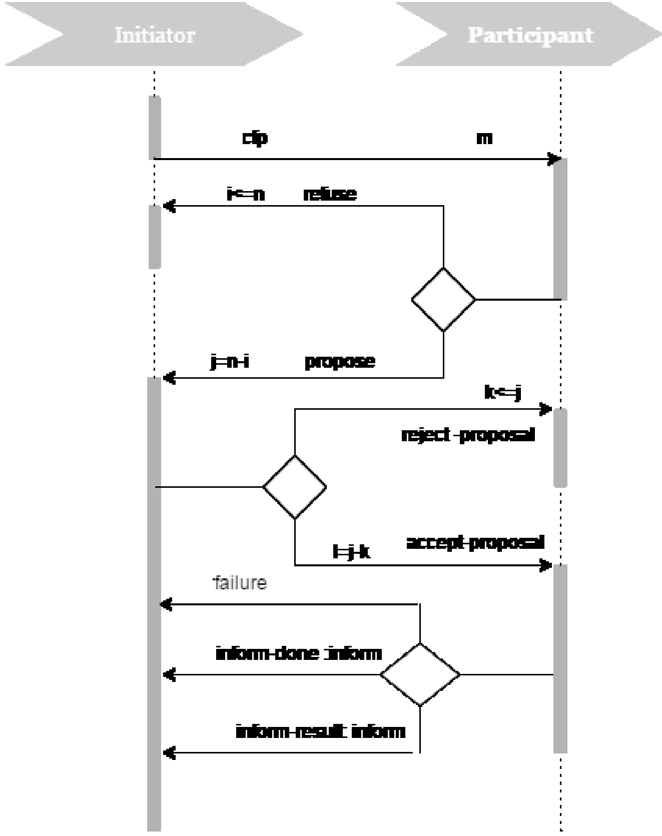

Figure 7: FIPA Contract Net Protocol, Source: FIPA Contract Net Interaction Protocol (IP) Specification (http://www.fipa.org/specs/fipa00029/SC00029H.html, accessed 5th May 2016)

<u>Explanation of the Protocol</u>

a) The *Initiator* seeks *m* proposals by issuing a cfp (Call for Proposal) which includes specifications of the task and any conditions that the *Initiator* might have placed upon the task to be executed. *Participants*, which received the proposals, are viewed as potential architects of the task and they generate *n* responses. Of the number of responses received j is the number of proposals sent back to the Initiator. The *Participants* proposal includes the pre-conditions for performing the task such as time to perform task, cost etc.
b) Apart from proposals the *Initiator* might also receive *i=n-j* refuse to propose messages. After a specific deadline for proposal has passed, the Initiator evaluates the proposals made by the agents, and sends out *l* accept messages to propose or *k=j-l* reject proposal messages.
c) The *Participants* have to commit and adhere to the terms of proposal once the *Initiator* has accepted it. The *Participant* is required to send out a message to inform the Initiator about the status of the task. It sends out an *inform-done* message or *inform-result* once the task is completed. If it fails to complete the task, it sends out a *failure* message.
d) The cfp also includes a timer, which counts the deadline by which the Initiator expects a response. Proposals received beyond the deadline are automatically

rejected.

e) All interactions for the Interaction protocol are determined by a conversation-id, which is a non-null global identifier assigned by the Initiator. All agents need to include the conversation-id in all communication for a specific interaction. The conversation - id is essential for example to identify the individual conversation.
f) In a 1: N conversation the Initiator has the liberty to choose if the interaction protocol or sub-protocols use the same conversation-id or if they should have individual ids. It is also possible to include a reply-by parameter in the conversation flow, to indicate the time-out period for the receipt of the subsequent message in the conversation flow.

Protocol behaviour in case of exceptions

a) At any point in the IP the receiver of a message can inform the sender that it was unable to understand the communication. This is accomplished by issuing a not-understood message. The communication of a not-understood message can terminate the entire IP which also means commitments made during the negotiation process are void.
b) Additionally, at any point in the IP process the Initiator could chose to issue a Cancel-Metal Protocol. The conversation-id of the cancel message carries the same conversation-id as that of the interaction which the Initiator wishes to terminate. The Participant informs the Initiator, using either the inform-done or issues a failure message if cancellation process failed.

The agent software-implementation uses the FIPA compliant Java Agent development framework as the underlying platform for management of agents illustrated in Fig.8. The core concepts of the JADE framework have been discussed briefly below -

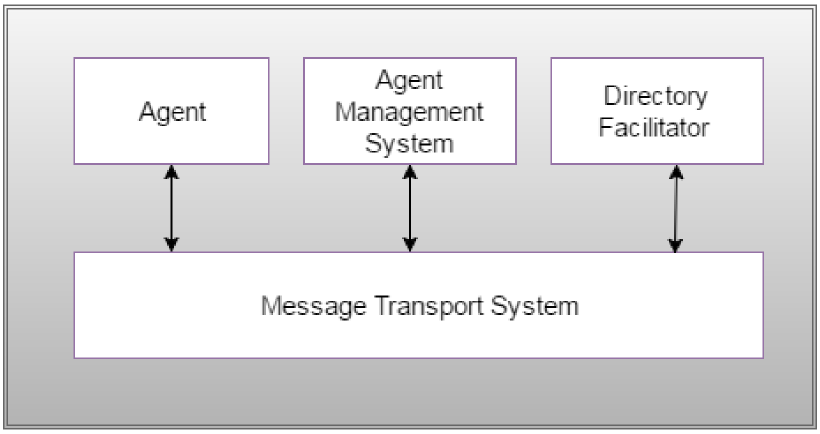

Figure 8: FIPA Agent Platform [Source [44]**]**

Agent Management System (AMS) is the agent that executes the supervisory control over access to and use of the Agent Platform. There can be only one AMS within a platform. It has functions such as providing life-cycle management service, maintaining a directory of agent –identifiers (AID) and state of agent. Every agent needs to register with the AMS in order to get a valid AID

Directory Facilitator (DF) is the agent that provides information related to the services offered by other agents.

Message Transport System (MCC) also referred to as Agent Communication Channel

(ACC) is the software component responsible for all message communication within and between platforms.
JADE confirms with this reference architecture. When the JADE platform is launched the AMS and the DF gets created immediately. The ACC is also activated in order to allow the message-based communication.
Normally only one Java application and therefore a single Java Virtual Machine(JVM) is active in each host, which is the container of the agents that provide the run-time environment for agent execution, and also allows several agents to exist in the same host simultaneously. The main container is where the DF and AMS exits while other containers connect to this main –container in order to provide the run-time environment for the JADE agents. The DF and AMS agents communicate via the *FIPA-SL0* content language, *fipa-agent management* ontology, and the *fipa-request* interaction protocol.

The agent management framework is responsible for the message transport and has a directory facilitator or DF that provides information related to the services offered by the agents. In addition, JADE includes agent behaviours, which are extended to implement finite-state-machine (FSM behaviours), cyclic behaviours, one-time behaviours, parallel behaviours.
Each agent executes as an independent thread in the Operating System, therefore several agents can run as parallel process at the same time. The multi-agent based system further extends as an implementation within PlaSMA for the evaluation and simulation of logistic processes. PlaSMA primarily considers two notions of time: a) physical time refers to the real-world physical system, and b) simulation time is the conceptualization of physical time within the simulation environment. While in the real-world, time is for synchronization of the physical world, simulation time is necessary in order to avoid agents receiving messages in future.

4.3 Agent architecture modelling

An integral component of developing multi-agent systems (MAS) based application is the set of models, technologies and tools that efficiently support specification and development of agent behaviours, message exchange and standardized protocols some of which has been discussed in the preceding sections.
Modelling Logistics process using agent technology is a common practice as discussed in section 4.1. Agents can assume several roles and their behaviour is determined based on their participation in negotiation and communication processes. However, emergent agent behaviour, which is described as the behaviour of an agent during runtime process are not considered during the design phase and can affect the overall system performance. Therefore, it is necessary to ensure that participating agents will not behave in an unexpected or unintended manner which is why modelling frameworks which encompass the various patterns of agent interaction are the basic modelling constructs for design and behavioural modelling of agents.
Behavioural modelling illustrates the behaviour of the individual agent, and the system as a whole. This process of building the behavioural model of agents from their specifications is called behavioural synthesis. One such commonly used modelling approach to transform scenarios to behavioural modelling is the Finite State Machine (*FSM*), as discussed in [45] which has been adopted in this research work.

One state machine is for each agent in the synthesis phase. Each state machine for the agent includes all the interactions of the particular agent, messages that it receives or sends and its transitions. The behaviour of a multi agent system (MAS) can be thought of as the combination of the parallel execution of all the state machines of the individual agents. In order to realize flexibility and control when programming an agent, an architecture based on state machine based programming of behaviour is adopted. The state based programming model realizes that any effective system must respond to dynamic conditions and variations within its environment, which aligns to the notion that requires software agents to react to their society. When a message arrives in the queue of an agent, a pool of interested behaviours awake and processes the incoming message with the first available behaviour. A combination of string matching technique on the attributes of the incoming message is used (explained in section 4.2) to determine if the message is intended for a particular behaviour. JADE provides several types of behaviours' depending on the scenario, for e.g. the OneShotBehaviour executes its action( ) method exactly once and terminates thereafter, or the SimpleBehaviour which is reused several times or the CyclicBehavior which executes a behaviour continuously.

The JADE framework provided a state machine class for complex behaviour handling called the "*FSMBehavior*" which maintains the relationship (transitions) between various agent states and selects the next behaviour to be executed based on the result of the current behaviour. Instead of executing registered child behaviours' in a fixed sequence, the FSMBehaviour allows to combine child behaviours' to a Finite State Machine. Each situation might be changed depending on a finite number of actions, which leads to transition from one state to another. Transitions might depend on conditions as actions might depend on situation requirements. In any case, transitions are always deterministic.

Once a state is registered, a string name is associated to its behaviour object for identification. Once all states have been named, the transitions between them are defined. Every transition is represented as an integer value. Whenever a behaviour terminates, a result value will be returned when its onEnd( ) method is called, whose result value is used as a transition condition to determine which behaviour ought to be scheduled next. Along with all other states transition function, the start and finish states are explicitly registered calling the registerFirstState() and registerLastState() methods. In the case, no transitions were associated; a default transition is taken if it was specified. Transitions, are used to serve as links to states, and are not used for encapsulation of agent behaviour.

In this section, implementation of the FSM modelling of the logistic process of SCM, as a functional representation using multi-agents has been discussed. The logistic process in a supply chain is a collection of interactions between various entities such as warehouse, distribution centres, distribution network, and the customers. The various entities in this process interact with each other and with the environment such as the transport network utilized for the delivery of goods to the customers. Therefore, the logistic process of a SCM was transformed into a MAS system, in which the functional agents interact and co-operate with each other to implement the system with a high degree of parallelization.

The various agents which participate in the system model are classified as follows-

Delivery agents- represent the Courier Service which is responsible for delivering the small-medium sized packages to customer locations. The representation of delivery agent also encapsulates the of section of journey travelled using e-bikes for package delivery which is described in Fig 9.

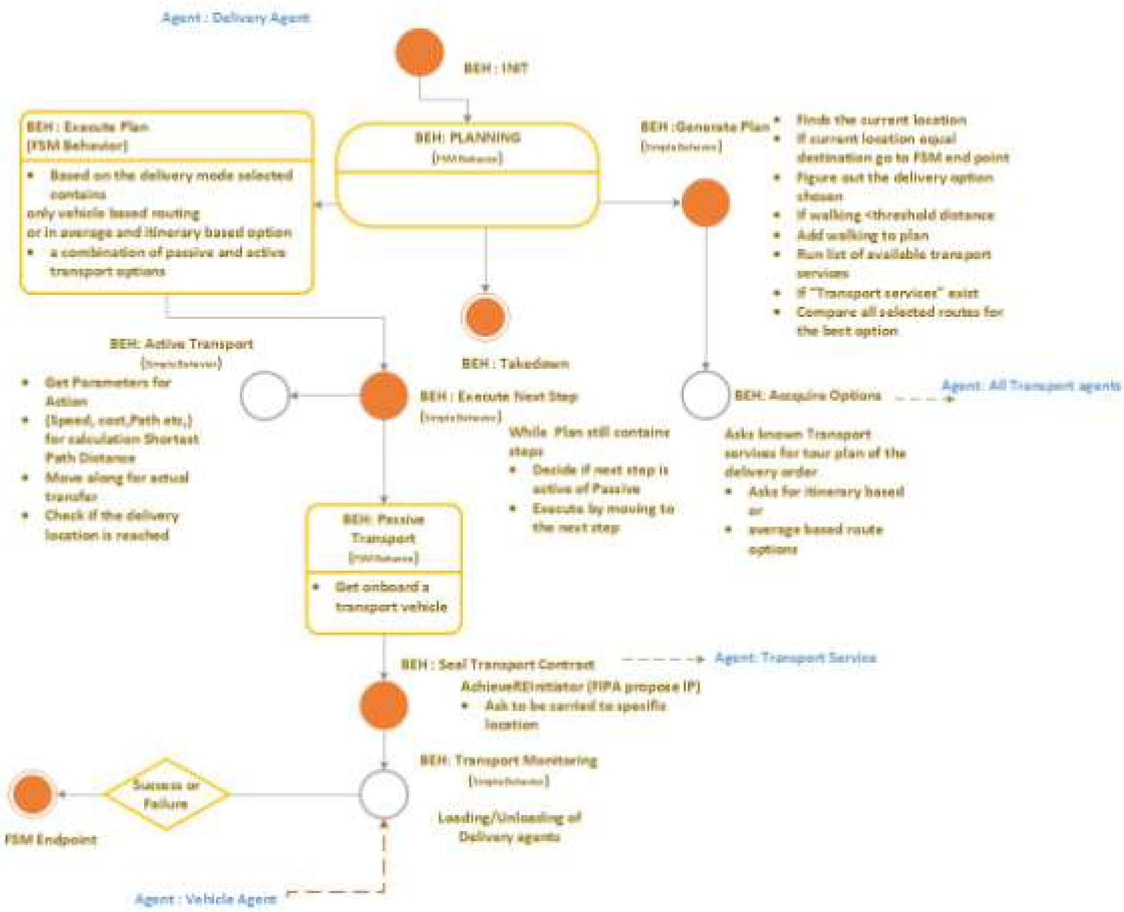

Figure 9: FSM modeling of Delivery agent

Bus agent/tram agent–represents the urban transportation system consisting of bus and tram transportation which carries the delivery agent between locations based on the plan generated.

Schedule transport agent – It represents the central Public Information system which manages the whole system. It handles planning query from the delivery agent and generates a tour plan based on public transport system schedule information and time of day selected for travel. The tour plan generated by the Schedule transport agent implements the Monte Carlo algorithm for generation of an optimized tour order for the delivery agent. It is also responsible for handling queries regarding passenger loading and unloading by Bus/ Tram agents. The planning and routing algorithm is implemented by the schedule transport agent, in order to avoid communication over-head which would otherwise occur if the delivery agent was allowed to implement the routing and scheduling functions. It serves as the information system which is queried for information related to a delivery route. The modelling of the system has been adapted from the [38] and in the current research the schedule transport agent has been adapted in order to include a Delivery Planning behaviour, which responds to queries for route planning for visiting multiple customer locations for delivery of goods. The planning algorithm has been adapted to include an optimal tour order generation using the Monte Carlo Search algorithm using policy adaptation. Moreover, the delivery agent has been adapted from the person agent, in [38] but with different behaviours, and has a journey plan which involves visiting multiple locations instead of one. The FSM modelling for bus/tram agent and schedule transport agent is given in below Fig. 10.

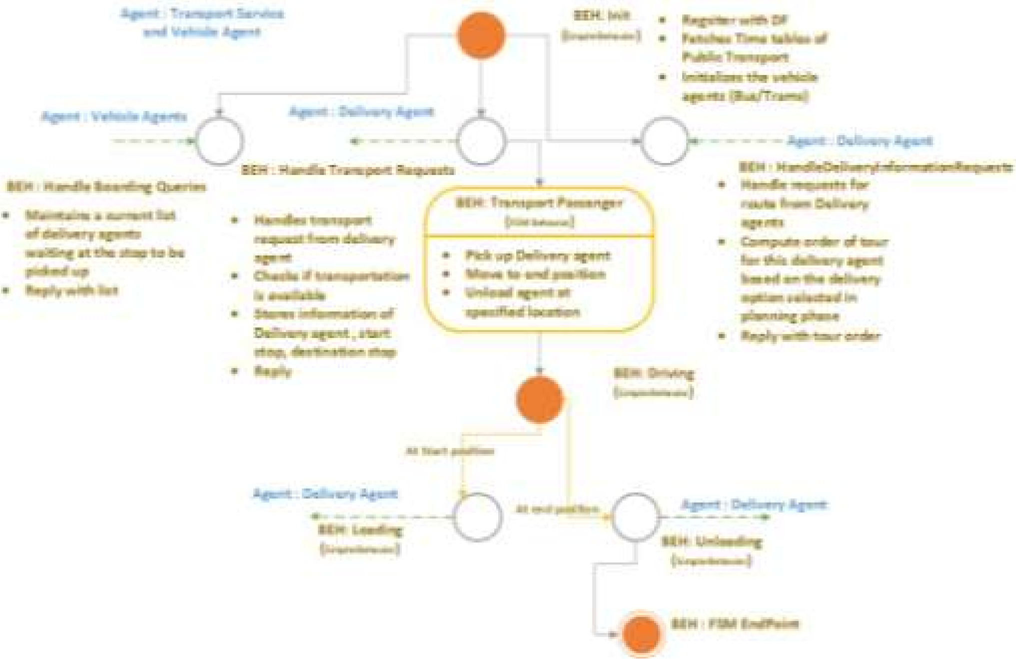

Figure 10: FSM modelling of Schedule agent and Vehicle agent

Explanation of the architecture-

The delivery agent receives a list of destinations it needs to visit as part of the tour and it sends a request to the schedule transport agent (information system) for a tour plan with the list of destinations it has to visit. Within the decision-making process of the applied route-planning algorithm, the schedule transport agent considers factors such as the time for request of plan, time table schedule of public transport network and consults the based on the time of day. Also, based on the kind of plan requested the tour plan might be different. It generates a tour for the delivery agent which is a journey plan that is a combination of distance travelled using e-bikes (active distance) and public transport (passive distance).The schedule transport agent is responsible for co-ordination between the public-transport systems and the delivery agents, which need transport to be transported by the public transport system. The transport agents request boarding/unloading route based negotiations to the schedule transport agents, which negotiate the pick up or drop of the delivery agents at destinations based on the route plan. The benefit of FSM modelling of the agents ensures the system design is stable and unexpected run-time behaviour of agents is eliminated. Also since agents are implemented to simulate the scenario the scenario can be most closely replicated to a real life situation, since agents have the capability to react to system changes dynamically and update their actions based on the interaction. The behaviour modelling of the agents allows maintaining the dynamic nature of agents ensuring their capability to react to changes within the environment while also ensuring that system does not break during runtime.

4.4 Pre-processing algorithm

One applies a static pre-processing algorithm to reduce the run-time of the scenario, which could run into several milliseconds. During the planning-phase the delivery agent begins a negotiation process to check if there are available public transport options, which could carry them. In order to reduce computational overhead all before all requests for tour delivery, the beginning of the application process based on the time table graph for the public transport system schedule a lookup table is generated for all the bus routes, which visit a particular stop and a graph is created from the time –table to avoid a computationally intensive process.

In order to satisfy the transport requests the *schedule transport agents* implement the public information system with routes that have earliest arrival time (EAP). Routes, which need fewer transfers, are preferred over ones which involve more transfer if the arrival times are the same in both. [20]. The graph types have been selected based on the results and conclusions of paper [20]. The *schedule transport agent* builds a time-expanded graph for solving the EAP. Now since the solution needs to build a tour based on public transportation, it is necessary to overlay the map of the route based on the timetable of the public transport system.

Therefore, once the delivery agent sends a query for tour the schedule transport agent first calculates a shortest – path distance matrix using a Dijkstra's algorithm based on EAP. The shortest path algorithm implements a clustering mechanism to select in the simulation world the stops closest to the start or destination points in order to identify the relevant stops for calculation of EAP. Once the algorithm identifies the stops it selects the most suitable route between pairs of stops which has the earliest arrival time. It helps to build a square matrix of time as a function of least distance travelled. The resultant matrix is then passed on to the Monte Carlo solver for tour order computation.
Three different approaches were utilized for comparison of the efficiency of the proposed solution for the effective distance travelled in passive mode (distance travelled using public transport) and active mode (distance travelled using an e-bike).
The cost function is a parameter that is a function of time. For routing a network of directed graphs, $G = (V, E)$ n nodes and m edges have been considered, where every edge that connects the nodes are expressed as, (u, v) and is defined by a non-negative edge weight,$w(u, v)$. A query for the shortest path between the source $s \in V$ and the target $t \in V$, queries for the minimum weight $d(s, t)$ between s, t.
The matrix which is built after calling the Shortest Path Solver algorithm in [38] helps the earliest arrival time matrix, $C = (c_{ij}^{t})$. The cost matrix is passed to the Monte Carlo solver for tour computation.

Case I –Vehicle Routing Approach
The first approach is assumed to only utilize a van/delivery truck for goods delivery and is similar to existing delivery approaches utilized commonly. It is used as the baseline method used for the comparison of the proposed solution to existing methods of delivery. In this approach the Information system or schedule transport agent relies only the list delivery locations to be visited to generate a tour plan. Since the public transport system is not involved, the time-schedule information of the public transport system do not play any role in the plan generation and therefore it is reduced to a route planning problem. The journey planned is solely a function of earliest arrival and the timetable schedule does not affect the tour planning process. The planning algorithm is described in the following figure. The delivery agent checks for available transports options (Fig.11, Line 1). When the DF returns no available services, it sends the resultant Distance Matrix which is basically a shortest path of distance between the first and final locations in the list. The TSPTW which basically is an implementation of the Monte Carlo algorithm uses the function of distance, in order to calculate a tour order. The Monte Carlo algorithm is basically a tree search algorithm which evaluates the

performance of its lower levels in order to determine the best possible sequence. It has several levels of searches depending on the level specified. At the lowest level a random playout takes place and based on the performance of the level the successor for the sequence are selected. For all purposes the service time window is kept between 09 am and 18:00 hours for purpose of simulation. The makespan value which is a function of time is calculated depending on the maximum of the values of arrival at current node, or the beginning of service time window at the current node. The makespan is iteratively incremented till a order is generated. The tour with the best score is returned, which is now used by the planning algorithm of the Information system to re-order the locations based on the result.

```
if (availableTransportServices == null || availableTransportServices.isEmpty()) {
destinationList.addFirst(startPosition);
resultantDistanceMatrix = new double[destinationList.size()][destinationList.size()];
LinkedList<BasicRI> destinationListToTavelByBike = destinationList;
for (BasicRI start : destinationListToTavelByBike) {
for (BasicRI endDestination : destinationListToTavelByBike) {
Path pathToCalculate = this.routingWrapper.getShortestPath(start, endDestination);
resultantDistanceMatrix[k][i] = pathToCalculate.getLength().inKilometres();
i++;
}
i = 0;  k++;
}
for (int counter = 0; counter < destinationList.size(); counter++) {
String temp = "";
for (int j = 0; j < destinationList.size(); j++) {
temp = temp + resultantDistanceMatrix[counter][j] + " ";
}temp = "";
}org.tzi.plasma.toolkit.util.routingAlgorithms.Tour deliveryTour;
TSPTW tour = new TSPTW(resultantDistanceMatrix);
deliveryTour = tour.search(2);
int positionOfNodeInTravel[] = new int[deliveryTour.tour.length];
for (int order = 0; order < deliveryTour.tour.length; order++) {
positionOfNodeInTravel[order] = deliveryTour.tour[order];}
LinkedList<BasicRI> sortedDestinationListOfTravel = new LinkedList<BasicRI>();
for (int travelOrder = 0; travelOrder < positionOfNodeInTravel.length; travelOrder++)
sortedDestinationListOfTravel
.add(destinationList.get(positionOfNodeInTravel[travelOrder]));}
Path travelPath =
this.routingWrapper.getShortestPath(currentPosition,sortedDestinationListOfTravel.getFirst());
for (int pathOrder = 1; pathOrder < sortedDestinationListOfTravel.size() - 1; pathOrder++) {
Path tmp = this.routingWrapper.getShortestPath(sortedDestinationListOfTravel.get(pathOrder -
1),sortedDestinationListOfTravel.get(pathOrder));travelPath.concat(tmp);
                              }
float distanceToTravel = (float) travelPath.getLength().inKilometres();
this.res = Beh_GeneratePlan.result.PLAN_GENERATED;
```

Figure 11: Case I algorithm implementation

Case II - Average Route planning algorithm-

The other approach of the Planning algorithm utilizes the varying Public transport system time schedule of the day for purpose of tour generation. The additional time factor of Public transport schedule increases the complexity of implementation of both these approaches manifold. In this approach, "average route planning", the method relies on the query time of the delivery agent for a tour order plan, which generates an average distance matrix that utilizes information of the public transport schedule 4 hours before and after the query time (line 8-10) in Fig 12. The distance matrix generated finds the shortest path between the starting point and every other points based on the transport schedule information found within this time interval.

```
    if (!destinationStopArea.equals(destinationStopAreaOuter)) {
        for (StopArea sourcePositionStop : nearestSourceAreaStops) {
        for (StopArea destinationPositionStop : nearestDestinationAreaStops) {
        currentArrivalTime = this.graph.getShortestPathFromTo(sourcePositionStop,
        destinationPositionStop, travelStartTime, include, exclude).getArrivalTime();
        if (currentArrivalTime < minArrivalTime || minArrivalTime == 0L) {
        minArrivalTime = currentArrivalTime;
        travelStartTime = travelStartTime - TimeToolkit.HOUR * 4;
        int counter = 1;
        while (travelStartTime <= startTimeOfJourney + TimeToolkit.HOUR * 4) {
        averageDistance += (this.graph.getShortestPathFromTo(sourcePositionStop,
        destinationPositionStop, travelStartTime, include, exclude)
        .getLength());
        travelStartTime += TimeToolkit.MIN * 30;
        counter++;
        }
```

Figure 12: Algorithm for average based method

The constructed time matrix is then passed on to the Monte Carlo Solver for tour order. In this case however the matrix is a function of time and not distance unlike the previous approach. Once the tour is generated, the delivery agent uses the information to re-order the order of the locations to visit. The delivery agent tries to follow the plan generated, which is a combination of journey travelled using e-bike (active distance) and public transport (passive distance). The generated plan may vary from the executed plan, due to reasons such as unexpected delay of transports; speed of travel of delivery agent, the scenario closely reflects the challenges faced in a real-life scenario.

Case III - Itinerary based planning algorithm

The third and final method for planning, implemented in this research also utilizes the public transport schedule information for plan generation However instead of utilizing a 4 hour gap before and after the time of query, a 24 hour day is divided into 48 distance matrices divided by 30 min interval (Line 1, fig 11). Therefore, once a planning query arrives with a list of destinations to travel, 48 shortest path distance matrices for the list of delivery locations, which is then passed on to the Monte Carlo Solver. The Monte Carlo Solver is also adapted from the previous approaches, where now the makespan is updated to include the travel start-time (Line 20, fig 13), and the calculation of distance travelled is a function of the time of day. Depending on the time taken to travel from previous to current node, the corresponding distance matrix is referenced in the Solver to evaluate the cost function. The itinerary based method is computationally more intensive. In this algorithm the left [ ] and right [ ] implements the service time window for delivery given Fig 14.

Once the tour order is generated the next steps implemented by the delivery agent to re-order the tour is fairly similar to Case II.

```
while (timeSlot <= 48) {
int k = 0;
for (BasicRI destinationStopAreaOuter : destinationPositions) {
nearestSourceAreaStops = this.nearestStopAreaToPosition(destinationStopAreaOuter, walkingThreshold);
int i = 0;
for (BasicRI destinationStopArea : destinationPositions) {
nearestDestinationAreaStops = this.nearestStopAreaToPosition(destinationStopArea,walkingThreshold);
if (!destinationStopArea.equals(destinationStopAreaOuter)) {
for (StopArea sourcePositionStop : nearestSourceAreaStops) {
for (StopArea destinationPositionStop : nearestDestinationAreaStops) {
  currentArrivalTime = this.graph.getShortestPathFromTo(sourcePositionStop,
destinationPositionStop, travelStartTime, include, exclude).getArrivalTime();
if (currentArrivalTime < minArrivalTime || minArrivalTime == 0L) {minArrivalTime = currentArrivalTime;
distanceForShortestPath =(this.graph.getShortestPathFromTo(sourcePositionStop,
destinationPositionStop, travelStartTime, include, exclude).getArrivalTime());
minDistance = distanceForShortestPath;
timeTablePath = this.graph.getShortestPathFromTo(sourcePositionStop,
destinationPositionStop, travelStartTime, include, exclude);
}
 } }
```

Figure 13: Itinerary based method

```
public SolverTSPTW(HashMap<Integer, double[][]> distanceMatrixFullDay, double travelStartTime) {
distanceMatrixFullDay.put(0, distanceMatrixFullDay.get(1));
this.distanceMatrixFullDay = distanceMatrixFullDay;
this.travelStartTime = travelStartTime;
Arrays.fill(left, 32400000.0);
Arrays.fill(right, 64800000.0);
random = new Random(System.currentTimeMillis());
tour[0] = 0;

public double evaluate() {
double makespan = 0.0;
double cost = 0.0;
int prev = 0; // starts at the depot
int violations = 0;
int hashKey = 0;
double[][] dist = null;
for (int i = 1; i < N; i++) {
int node = tour[i];
if (i == 1)
makespan = travelStartTime;
hashKey = getHashKey(makespan);
dist = distanceMatrixFullDay.get(hashKey);
cost += dist[prev][node];

public int legalMoves() {
int prev = 0; // starts at the depot
int opindex = 0;
double makespan = 0.0;
double cost = 0.0;
int hashKey = 0;
double[][] dist = null;
for (int i = 1; i < tourSize; i++) {
int node = tour[i];
if (i == 1)
makespan = travelStartTime;
hashKey = getHashKey(makespan);
dist = distanceMatrixFullDay.get(hashKey);
```

Figure 14: Adaptation of Monte Carlo Algorithm

Summary

Chapter 4 discussed essential design concepts of the research. Firstly multi-agent based system which are capable of handling complex dynamic scenarios are discussed with references to previous research, which is essential to appreciate why a multi-agent based approach for utilized in the current work to handle the dynamic interactions between various entities within the system. Additionally the behaviour modelling of the agents using FSM techniques was discussed, which is essential to avoid any unpredictable behaviour during run time process. Finally an in-depth discussion of the three methods or approach for implementation of the planning algorithm was presented. The first approach used a conventional delivery approach and served as the baseline method for comparison of the efficiency of proposed solution to existing methods. The second and third approach differed mostly in their concept of utilizing a more fine grained or average approach towards utilization of the public transport schedule for tour computation. The difference in the approaches and details of Monte Carlo solver was also discussed in this section. The following chapter would deal with implementation of the research work, and discuss more about the experiments conducted and present an analysis of the results obtained.

5 IMPLEMENTATION RESULTS AND ANALYSIS

Overview

The previous chapter presented a detailed discussion of the multi-agent systems used for the system modelling. Moreover discussion regarding the design of the various agents using a behavioural modelling process was presented. The usefulness of employing a modelling process for design was argued as well. Finally the pre-processing algorithm was explained which is used to compute the tour order for the delivery process. This chapter has the following sections: Section 5.1 lists the necessary system requirements, environments used in and external resources used for development, and the folder structure. Section 5.2 discusses about the experimental setup and simulation. Section 5.3 discusses and analysis the results of the experiments.

5.1 System Requirements, environments

In order to build a fine - grained simulation model, which behaves like real-world conditions, the road, tram infrastructure modelled for the simulation which includes the city of Bremen has been chosen. In order to evaluate logistics process reliably and perform analysis of the scenario described in previous section the PlaSMA simulation framework was used. PlaSMA has been discussed in detail in previous chapters, therefore in this section other related aspects of implementation has been discussed.

PlaSMA compatible scenarios follows a specific folder structure for their development where every PlaSMA scenario contains an owl ontology files that contains the information related to the simulation scenario, for example the Public Transport network and the geo-locations of the city. It also contains the trans: owl and tlo: owl files which have been discussed in section 2. These owl files contain the higher-level description of the various components associated with the building up the PlaSMA environment which interact with the environment.
Apart from the ontology files, every PlaSMA scenario also contains a config folder that contains scenario specific run-time configuration parameters. A timetable folder contains the timetable schedule which contains the Bremer Straßenbahn AG (BSAG) bus and tram schedules of year 2013 and is the vital piece of information which is utilized by the Planning algorithm for route planning.

The folder contains the full time-table schedules and a reduced-time time schedule which contains the relevant information for only a partial region of the city illustrated in Fig.15.
For the purpose of scenario deployment with Maven a scenario specific jar is created the description for which is found in a scenario specific pom.xml associated with every scenario. The folder structure for this scenario study, “bremen_busdelivery” is below-

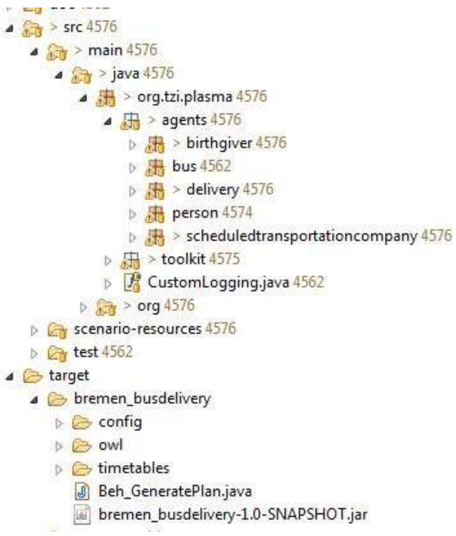

Figure 15: PlaSMA scenario development folder structure

The system specific requirements are-

a) Platform for development used –Eclipse IDE
b) PlaSMA system.
c) Development Environment (JDK) - Java version 1.6
d) Database -PostgreSQL 9.1

5.2 Experimental Setup and Simulation

The infrastructure model was reduced to include a set of connected edges, and nodes which were unreachable were removed in order to build a more efficient infrastructure for the purpose of simulation. The infrastructure map includes all relevant highways, motorways and tramways, bus and tram stops found in the Open Street Map (OSM) of Bremen. The various stops and junctions were modelled as nodes, while the roads and tramways were modelled as the edges which connect the nodes. The reduction in the number of nodes leads to improvement in memory requirements apart from building a better efficient model. The infrastructure map included 26126 vertices and 59957 edges which are used for the purpose of the simulations. The OSM importer tool allows the OSM data to be imported into PlaSMA in Fig. 16

A typical simulation scenario is depicted in Fig.17

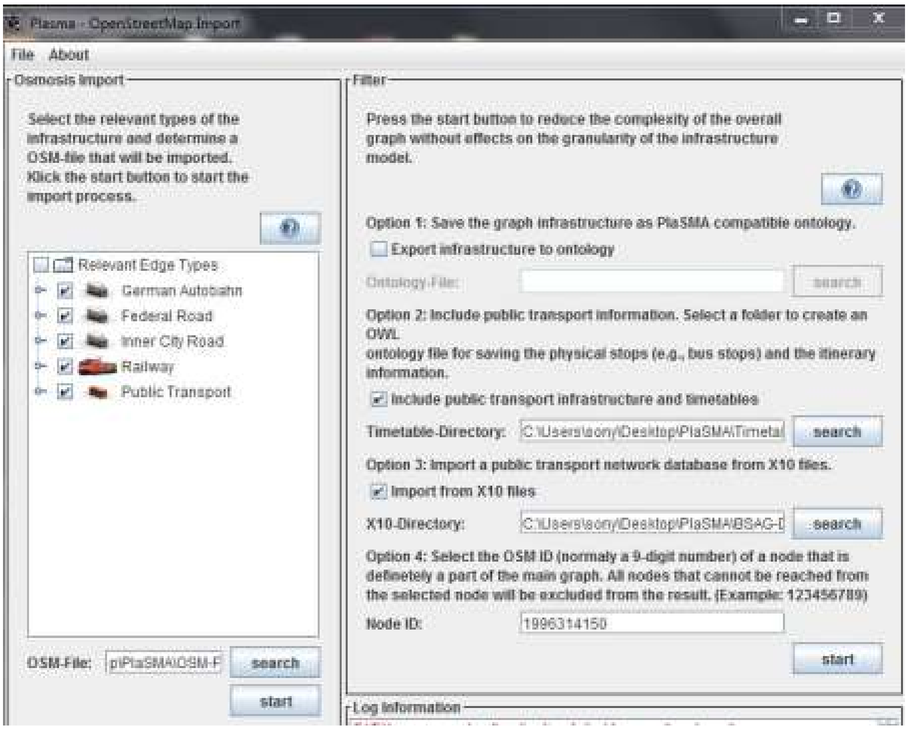

Figure 16: GUI for Tool to import OSM data that allows import of real life data

Figure 17: Simulated scenario of several bus/tram networks for package delivery to several locations

The simulation scenarios are divided based on the three methods or approaches used for analysis. The three methods vehicle-routing, average route plan and itinerary based approach, used in the planning algorithm for tour order generation have already been discussed in the previous chapter. The three approaches are used for finding out the most efficient method for goods delivery in terms of distance, time.

The simulated scenario represents a 24-hour period of a Monday morning for orders delivered by a courier service within the time window between 9:00 hours to 18:00 hours. Once a plan is generated the route is travelled using a combination of e-cargo bikes and public transport. The distance travelled using e-cargo bikes are referred in this thesis as active distance, and distance travelled using public transport is referred to as passive transport.

5.3 Results of Experiment

This research focussed on using simulated data for generation of delivery locations within the city. Live-data usually follows a pattern which means it would be difficult to predict the efficiency of the algorithm under varied conditions. On the other hand generation of locations using a multi-seeded random function ensures there is no bias or pattern during the selection of locations, which usually ensures the performance of the planning algorithm, can be tested more efficiently without any presumptions. It needs to be explained here, that this research is a prototype idea which has the scope to be extended to real-life situations based on the result outcome.

The simulations within PlaSMA follow a discrete pattern, which means for a particular experiment results do not vary depending on the simulation run. Therefore after initial verification with a set of experiments on the consistency of output of result irrespective of simulation runs, each experiment used a single simulation result.
The results are analysed for the parameters such tour duration, active and passive distances travelled and plan computation time. The three methods are compared for the efficiency of the tour generated. Only a tour where all the locations are visited were considered a valid tour and used for comparisons.
The experiments were divided based on following scenarios

a) Delivery locations were picked by author based on knowledge of the city
b) Delivery locations were generated using a random function.
c) Delivery Locations were generated randomly within a fixed radius from the start location.

In the set of experiments used, a combination of full graph of the public transport infrastructure and a reduced version public transport graph was used in order to compare the quality and of plan proposed.
All experiments were performed in a 64-bit OS, Windows Server with Intel(R) Xeon(R) CPU with processor speed of 3.30 GHz and 128 GB RAM.

Experiment set -I
Delivery location controlled - Delivery locations were selected by the author based on knowledge of city

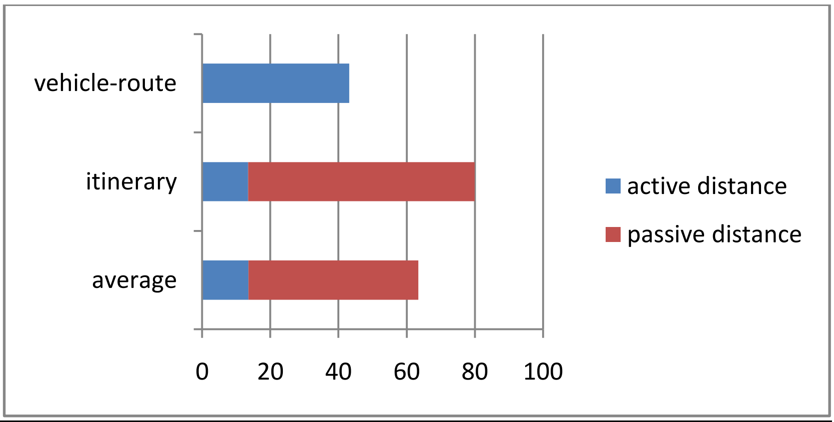

Figure 18: Results of experiment where nine locations for delivery are chosen in a controlled environment, and graph is reduced (distances are in km)

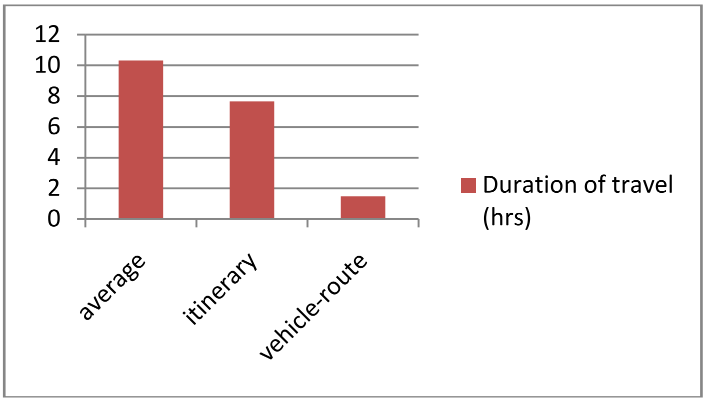

Figure 19: Comparison of travel duration for visiting nine delivery locations using reduced Public-Transport network (controlled location selection)

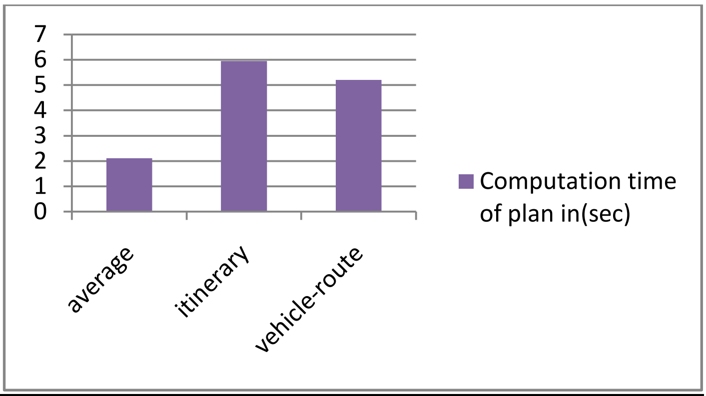

Figure 20: Plan computation time (in sec) for reduced graph of Public Transport network for nine deliveries

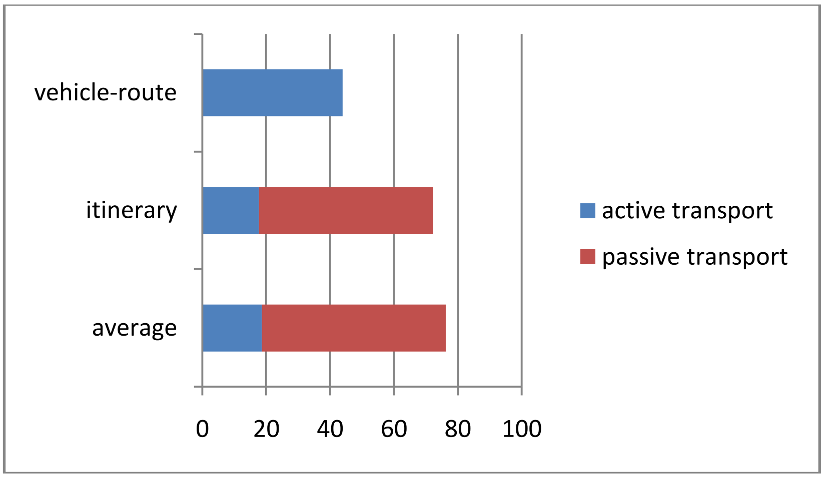

Figure 21: Results of experiment where nine locations for delivery are chosen in a controlled environment, and full graph is used, values are in (km)

In Fig. 18 and Fig. 21, represents the total distances travelled by the delivery agent when 9 different locations have been considered. It describes the total journey as a combination of active transport and passive transport modes for all the three approaches studied. In Fig. 18, a reduced version of the public transport network graph containing partial regions of the city has been considered whereas for Fig. 21 the public transport network for the entire city was available; hence the full time schedule for all available transportation networks was available for the calculation of the tour plan.

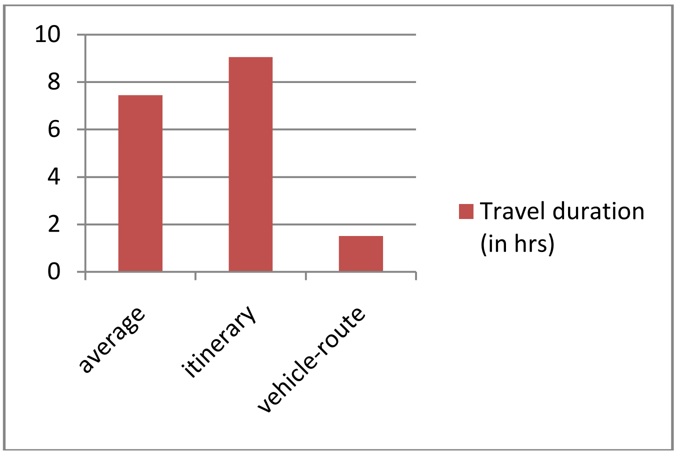

Figure 22: Travel duration for delivery to nine locations using full -public transport graph

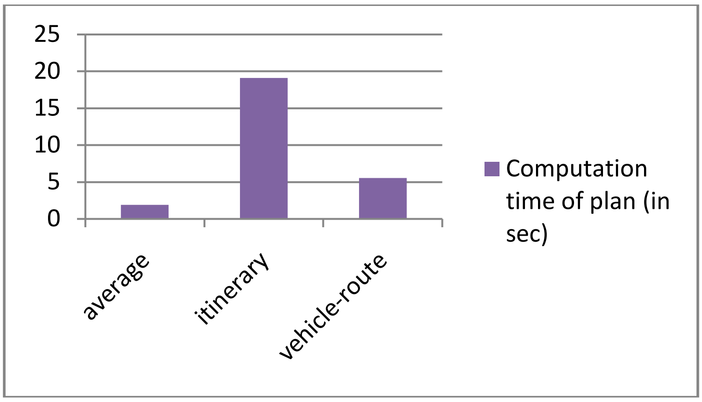

Figure 23: Computation time of plan for full graph and nine locations

Case II and Case III using the average plan approach and itinerary planning approach differ in the total effective distance travelled in the two scenarios when only partial time-schedule is available in Fig 18 compared to Fig. 21 when full time-schedule was available for planning of algorithm. However, very little change in distance travelled is observed when vehicle-routing approach has been used, which is expected, since vehicle-routing does not depend on the public transportation network(PTN) time-schedule for tour planning and the therefore the variation is only a function of the difference of quality of plan generated in the two sets of experiments.

The results of the experiments also show a significant reduction in the active distances travelled, when using inter-modal transportation (Case II, Case II), compared to the distance travelled in vehicle routing approach, (Case I). It was also found out that the tour generated by the Information system service was similar to a tour which would be taken by traveller with a good knowledge of the city and its public transport routes. This validates the assumption that the plan generated was a feasible one. Fig 19 and Fig. 22 represent the total duration of time taken to complete the entire tour in all three cases. The time duration was least in Case I and higher for the other two cases. Moreover the time duration is found to be higher in the later case when full time schedule was available compared to first experiment when only direct connected routes was available for computation. This shows that the planning algorithm generated a plan independently and it is possible a plan generated might have lower efficiency compared to other ones, for example when only direct routes where allowed to remain in the first case in figure 19. The figure 20 and figure 23 represents the computational times of the different approaches, and as expected the case II and case III is more computationally intensive compared to case I which process less information compared to other two. Of the two cases, Case III is more intensive since it needs to generate several distance matrices (48) in the 24 hour period before passing to the Solver, which also needs to scan several more matrices for generating the tour, compared to Case II which only takes an average of time schedule values with-in a 4 hour gap before and after the time of query.

Experiment Set II -
Delivery locations generated using Random function

In the next set of experiments, the delivery locations were generated using a random function as explained before. Few of the experiments resulted in incomplete tour, and successful delivery to only a limited number of locations could be achieved. During the evaluation phase, when only the partial PTN (reduced-graph) was available the number of locations reached were fewer compared to the experiment when full public transport graph was available. Although, in both cases the tour was not completed, the results are still better when full PTN time-table schedule was available. In random location generator, locations picked were often a random combination of distant and nearby-by location from the start point. Therefore, depending on the tour order computed by the Planning algorithm (Solver), it is possible that in absence of a well-connected PTN, the tour might not be completed within the available simulation time. Moreover, for the purpose of simulation, for case II and Case III during the active mode of the journey the velocity of travel of e-bike had been kept at 5km/hr. This means the journey time would be much higher, if distant locations were picked up by the random generator. However, for Case I when vehicles with a velocity of 30 km/h were used in **vehicle routing approach**, the tour completed every time. The result is expected since Case I do not involve waiting times for public transport and also the speed is uniformly higher for the entire duration of tour.

Experiment Set III -
Random location generated within 6 km radius from depot

In the next set of experiments locations were generated within a 6 km radius from the start position or depot. In these set of experiments, results improved, and tours could be completed successfully when the numbers of locations were limited to 10. Fig. 24 and Fig.25, represents the distance travelled as a combination of active and passive modes and the total travel duration for the entire tour respectively, when the entire PTN time-schedule was available for calculation of tour plan. Compared to distance travelled in previous set of Experiment II, the distance travelled is lesser in Fig.24, which is expected, since the distances were selected within a radius of 6 km in Fig 24 and are therefore more closely distributed even with the random function. The duration of time to complete the tour is also less (Fig. 25) compared to the previous set of experiments. The computation time of plan is given in Fig. 26. For the experiment set where 15 delivery locations were generated the results were found to be relatively less predictable and all the locations could not be reached within the simulation time although the radius was limited to 5 km. When 15 delivery locations were simulated only few tours, Case I and Case II could be completed (Fig. 27). The tour was incomplete for the itinerary based approach.

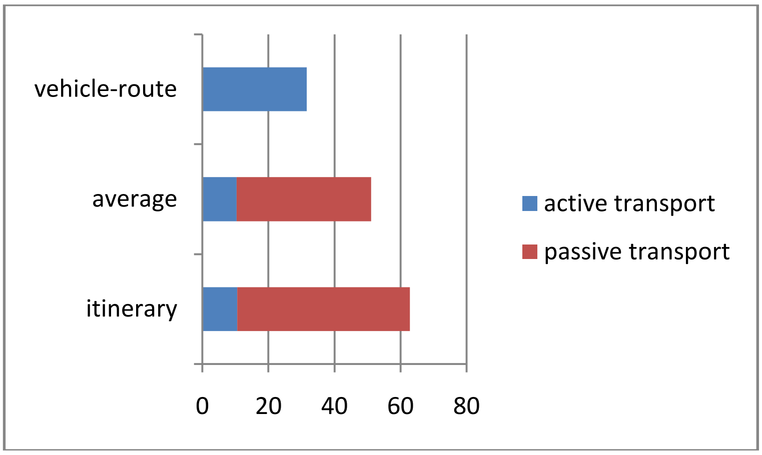

Figure 24: Distances travelled by active and passive routes for when 10 locations for delivery picked randomly within a radius of 6 km from the depot (distances are in km)

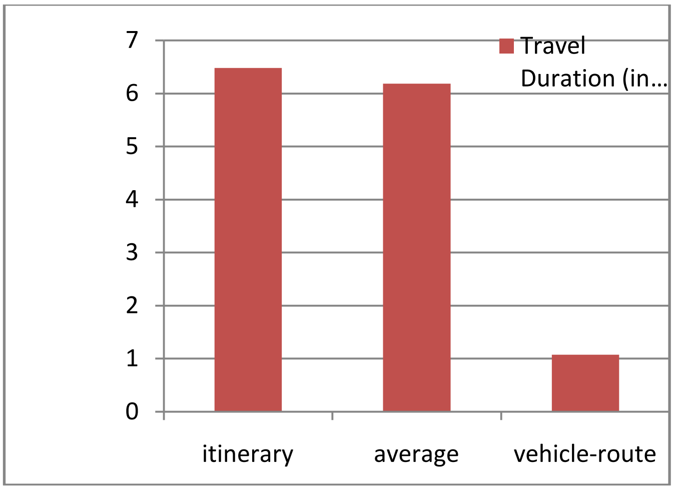

Figure 25: Travel duration for when the 10 locations for delivery picked randomly within a radius of 6 km from the depot

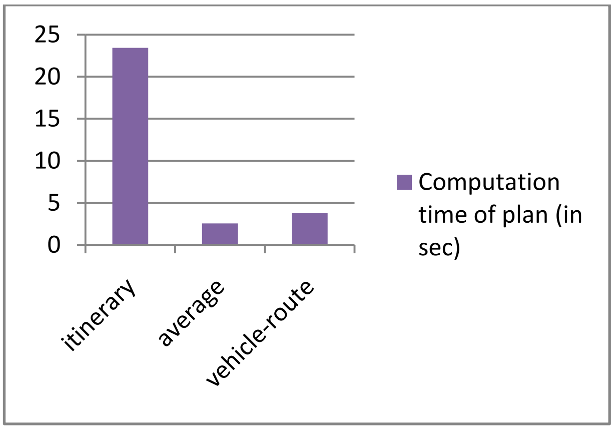

Figure 26: Computation time of plan (in sec) for 10 random locations selected within a 6 km radius

The below figure Fig.27 and Fig.28, gives a comparison of the distance travelled and duration of tour for average plan and the vehicle route when 15 delivery locations were selected. When the random location function generator selected 19 delivery locations within a 6 km radius of the depot the results the tour plan remained incomplete for the methods utilizing inter-modal delivery approach.

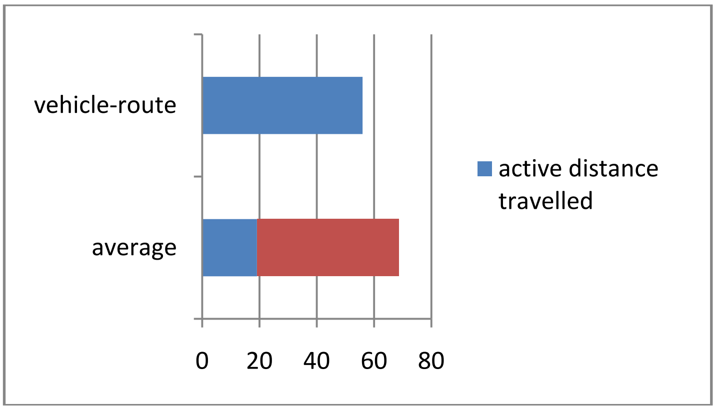

Figure 27: Active and Passive distance travelled for 15 locations within a 5 km radius from depot

The below Fig. 28 represents the time duration of travel in the average route plan and vehicle-route based approach and Fig. 29 gives the total computation time of plan.

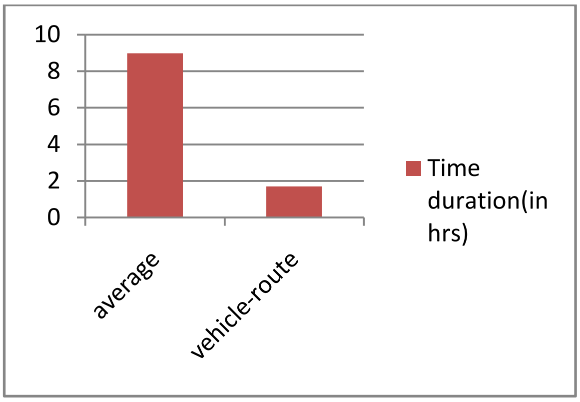

Figure 28: Time duration of delivery to 15 random locations within a radius of 5 km from depot

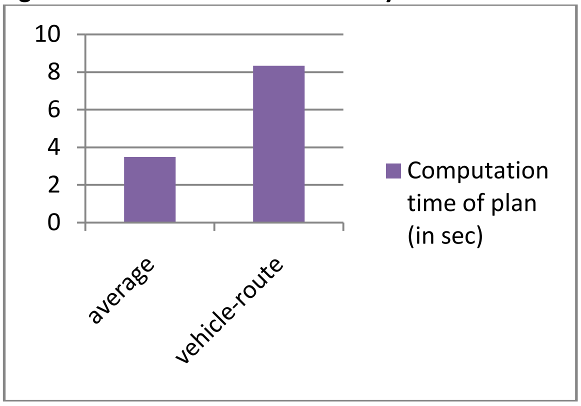

Figure 29: Computation time of plan (in sec) for 15 random locations picked within a 5 km radius from depot

<u>Experiment Set IV</u> - Random locations selected within 5 km radius from depot when speed of e-bike is 13 km/hr

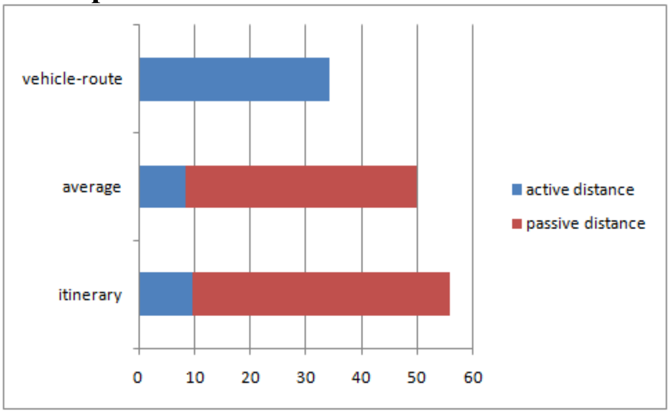

Figure 30: Active and Passive distance for 10 locations picked within 5 km radius

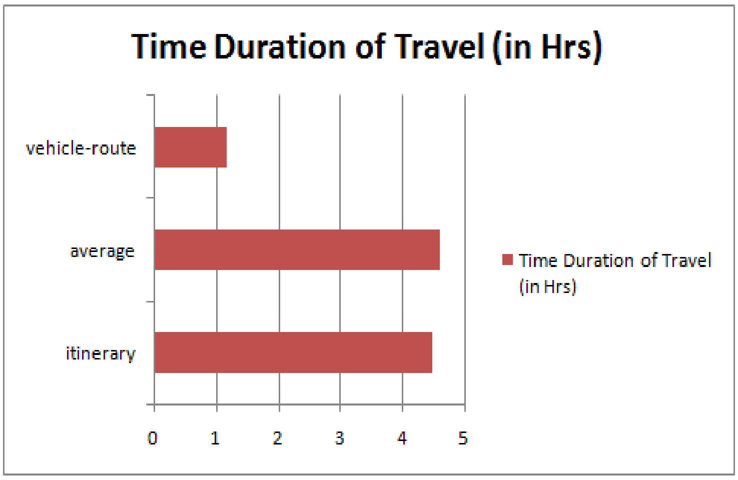

Figure 31: Travel duration for 10 locations

Until now all experiments considered the speed of travel during active transport mode for Case II and Case III to be limited to 5km/hr. When the speed of the e-bike was increased to 13 km/hr during the active mode of journey for these two cases the results improved significantly In the final set of experiments illustrated Fig 30, Fig 31 represents the distance travelled and time duration of tour when 10 delivery locations were selected within a 5km radius, and e-bike speed of 13km/hr during active mode transportation. The results of the experiment improved significantly. It was found that the duration of tour improved for the Case II and Case III approaches. The ratio of difference of duration of time of tour completion between vehicle-routing approach and inter-modal approaches dropped to 1/4th from 1/6th compared to the previous experiments.

Summary

Experiments have demonstrated the positive correlation between the number of locations travelled and the travel duration. When random locations are picked for delivery for the entire city, the chances of a successful tour using inter-modal transport are found to be reduced compared to a delivery which is limited within a certain radius boundary from the depot. The importance of delivery location assignment can be understood as well from the results and would be of interest of the research community, which studies the allocation of delivery locations to achieve optimal solutions.

The other parameter studied in the experiments is the computation time, which is found to be the lowest for plan generated using average route method and highest for the itinerary based approach. The higher computation time of itinerary based tour planning method is attributed to the high number of matrices, which need to be scanned in order to generate a plan, which makes it more computationally intensive. Between the two approaches studied in inter-modal transportation, the average route approach yielded better results in terms of shorter duration of tour travel and distances travelled. When more number of locations was picked, in the third set of experiments with 15 locations picked randomly within 5km radius to depot, the itinerary based tour plan failed to generate a successful tour plan, while the average tour-plan was still successful in tour completion. Therefore, the average-approach can also be assumed to be more predictable. Therefore, observations lead to the assumption that the average plan based approach, which calculates the tour based on information of the average time-table schedule of public transport yields a better quality of plan, compared to itinerary based approach which relies on immediate time schedule information for tour computation. The second approach can affect the overall tour if any section of the plan is unable to be executed due to unforeseen conditions.

In the final set of experiments when the speed of the e-bike in the active distance mode part of the journey was increased the total duration of travel was reduced for the inter-modal-transportation approaches. The time duration shared a 1:4 relationship to the vehicle-route approach which was an improvement from previous observations. In every set of experiments it was found the active distance travelled was always higher for vehicle routing approach which did not utilize the public transport in any part of its journey for delivery. So in terms of effective distance travelled, the suggested system model is definitely a better one, however in terms of duration of travel maybe the vehicle routing approach is better in most cases.

The following chapter discusses the conclusion drawn from the research.

6 SUMMARY

This section discusses the performance of the proposed approaches for study of the delivery optimization. The results in the previous section lead to the assumption that in terms of duration of travel the vehicle-route approach was most successful of the three approaches studied. Although the completion rate of tour is highest in the first approach due to its independence from the time-based schedule of public transport system, the efficiency of the results might be exaggerated due to bottlenecks arising out of environmental limitations which have not been considered in these experiments. Several assumptions were made for the sake of simplicity. The simulation does not consider several real-life situations such as traffic congestion, forbidden parking lanes for big vehicles, no-parking zones for trucks and wagons which could add significantly to the total duration of travel time and total distance travelled in the first method.
Other factors such as urban congestion and varying speed of velocity of vehicles in most road networks are the other parameters which can affect the journey time for delivery. Either of these parameters has not been taken into account in the simulations. . Therefore, considering real-life situations like traffic regulations, accelerations varying speed, the actual duration of travel time in Case I approach could be significantly higher, compared to the results obtained in the foregoing experiment, and hence the travel duration might fall within reasonable comparison with the other studied cases using intermodal transportation.

Moreover, for the sake of simulation study, the velocity of the e-cargo bike used in the intermodal transportation studies was assumed to be 5 km/h in first three sets of experiments. In real life cases, the speeds of bicycle are expected to be around 15 km/h, which would lead to a decrease in the travel duration. This assumption was confirmed in the Experiment set IV where the e-bike speed was assumed to be to 13 km/hr. The duration of travel in this Experiment was significantly reduced for the methods utilizing inter-modal transportation approaches. Additionally, it is concluded that although the travel duration is lesser for the vehicle routing approach the active distance travelled is much higher, which means that although the plan might be faster, it might not be an energy efficient one.
Additionally, in all the experiments studied, the intermodal transportation options have been only limited to surface delivery. In cities which support underground travel, the metro could also be included in the planning process which could lead to a significant improvement in duration of tour travel
Other factors such as increased public transport connectivity within the city and frequent travelling options would also help improve the duration of time spent in waiting for transports and allow more options for transfer. In real life dynamic environments, dynamic information of time-schedule could be used to update the tour during execution time, which could lead to more efficient solutions. The study found out that the use of intermodal transportation helps to reduce the effective surface distance travelled by vehicles on roads, which might be an effective method utilized for the reduction pollution and also help in improving the situation of urban congestions[21]. Since transportation is an integral part of delivery processes, the result of the study demonstrates the possibility of using public transport for goods delivery and encourages future research scope in green logistics.

7 DISCUSSION AND CONCLUSIONS

A growing e-commerce industry has led to the need for development of a sustainable distribution chain for supporting a burgeoning economic sector. The challenges are heightened in developing economies which although have very high potential for the market but lack the resources or infrastructure necessary to support it. This research was an initiative to explore the possibility of optimization of the distribution phase for the delivery of small and medium sized packaged goods using the existing public transport infrastructure of a city to develop a model which is both energy-efficient and economical.

The study sought to answer the research question of feasibility of use of a delivery model that utilized an inter-modal transportation approach using a combination of existing public transport infrastructure and e-cargo bikes compared to existing delivery methods which relied on conventional wagons or delivery vans. To validate the proposed approach, a model was developed using a multi-agent approach which is used in the simulation model to ascertain the various parameters, such as the duration of time, distance travelled which were the primary interest areas in the study. The Nested Monte Carlo algorithm was used as a planning algorithm which is used in the calculation of tour order. The integrated shortest path route calculation uses the information of the public transport time table schedule to generate a plan which is used to calculate the tour to minimize the cost functions of time and distance in the tour planning. The empirical findings are subject to several assumptions made during the implementation phase of the scenario which has already been discussed in detail in the previous chapter. The essential outcomes suggests that although tour plans that utilized vehicle routing were generally reliable in terms of rate of tour completion and duration of tour they were less efficient in terms of effective distance travelled. On the other hand the proposed solutions which used a combination of multi-modal transportation utilizing public transportation system was found to travel less effective distance although it was less efficient in terms of rate of completion. The duration of tour completion was nevertheless more energy efficient.

As final comment it needs to be stressed the concept of using inter-modal delivery was found to be of significant importance which has been used in some previous research for optimizing the transportation of passengers, but multi-modal delivery approach has never been used before. The concept studied here also has the potential to benefit both economically and contribute towards building environment friendly choices for business. A fair assumption would be therefore that there is ample scope of study of sustainability in operations research Some companies such as Amazon are implementing pilot tests with underground metros in New York to explore new methods of delivery, which further validates the importance and scope of future research in intermodal transportation for delivery [47].

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