

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

Rajeshwari Chatterjee, Christoph Greulich¹, Stefan Edelkamp¹

Center for Computing and Communication Technologies, University of Bremen, Germany

Abstract — The majority of research work carried out in the field of Operations Research have relied on optimization algorithms to improve 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 developing a system model, which uses existing Public Transport facility of a city for the transportation of small and medium sized packaged goods, to avoid further aggravating the situation of urban congestion and also help reduce green house gas emissions. The research carried out investigates the feasibility of the proposed multi-agent based simulation model, for efficiency of cost, time and energy consumption. The Dijkstra Shortest Path algorithm and Nested Monte Carlo Search have been implemented to build a time based cost matrix which is used to generate a tour plan for intermodal delivery of goods. 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.

I. INTRODUCTION

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, cloud computing and mobile Internet has brought about developments within the manufacturing and service sector which is often referred to the Industry 4.0. However, the current trend of industrial production is not a sustainable solution with depletion of existing non-renewable resources which leads to pollution and environmental degradation. The potential of Industry 4.0 lies in the capability to integrate the emerging technologies with business processes and services in order to offer efficient solutions which are flexible, efficient and ecologically compatible [1]. One of the emerging economic sectors is the e-commerce industry. The Industry 4.0 allows the individual customer-specific requirements to be included in the product life cycle process. The Census Board of department of Commerce of U.S. has determined the e-retails sales from the 4th quarter of 2015 were valued at 89.1 billion U.S. dollars. Compared to 2014, the net revenue in 2015 was an increase by 14.7% from the previous year [2]. The popularity of digital devices, growth of internet, alternative payment systems, short delivery time are some of the factors which have contributed to the popularity and growth of this sector. The e-commerce growth trend has

been observed all over the world. For example, the markets in Europe, Asia and upcoming economies such as India and China have all witnessed this trend. The revenue earned in Germany alone in the e-commerce sector is estimated at 61,938.8 million U.S. dollars in 2016 by [3]. In the Asian market, for example in China and India, the total revenue earned is estimated to be 300,468.3 million U.S. dollars and 17,547.2 million U.S. dollars respectively by 2016 [3]. In India alone the e-commerce is estimated to acquire a market share of 32,862.1 million U.S. dollar by 2020 at an annual growth rate of 16.98% [3]. However although the potential of growth is immense developing economies like India do not have the required infrastructure and logistics to support growth in this sector. Therefore, the motivation behind this study lies to study the feasibility of using existing resources, to support the delivery process of the distribution phase.

II. RESEARCH OBJECTIVE AND SCOPE OF STUDY

A. Problem Description

This study has considered a delivery-planning problem 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 to ensure eco-friendly transport options. 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 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 plan generation phase. 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 system during the section of the journey which proposes travel by public transport. The Courier Service tries to closely execute the plan as proposed by the Information System. The tour is considered successful if all locations are visited within the specified service time window within the 24 hour day.

III. RESEARCH QUESTIONS

a) To develop a simulation model for the delivery of small and medium packaged goods using inter-modal transport system which uses a combination of existing public transport

infrastructure facility of a city and e-bikes for goods delivery.

b) To investigate the efficiency of the proposed model and study the parameters of service time duration, cost to compare the feasibility of the proposed model with existing approaches, and to find out its suitability in real-life applications.

IV. RELATED RESEARCH

The delivery problem considered in this study falls into the category of a “*Travelling Salesman Problem with time windows*” with dynamic edges or the Tourist Planning Problem (TPP). The Travelling Salesman Problem (TSP) 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 TSP (Travelling Salesman Problem) is in fact a category of the TSPTW with service time window $[0, \infty]$. The TSP problem is also closely related to the Vehicle Routing Problem (VRP) which has a single carrier. The TSPTW is formally described in [4].

TSPTW deals with the design of a minimum cost function for the path travelled by a vehicle/salesman which visits a set of nodes. Every node is visited exactly once and service at a node is allowed within the earliest and latest permissible time for service. If the delivery agent arrives earlier, it needs to wait until service can begin. Dumas et al.[4] studied the dynamic programming method for finding a feasible solution to increase the performance and minimize the total cost in a TSPTW problem. Savelbergh (1985) has shown that even a feasible solution to the TSPTW is considered a NP complete problem. The paper [5] 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 [5] studies Genetic Algorithm methods for finding an optimal solution in the multi vehicle pickup and delivery problem. The TPP [7] which is more closely related to the application studied is described 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 [8] paper defines the TPP as an itinerary planning problem that utilizes the public transport system for routing and scheduling. Although substantial work has been carried out in the field of operational research for optimization of the delivery process in logistics, previous research has mostly focused on route optimization which relies on use of using vehicles for transport. 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 system for delivery rather than advocating introducing additional fleet into the network for purpose of delivery.

V. ALGORITHM DESCRIPTION

A. Nested Monte Carlo Search

The TSPTW is associated with a cost function $C = c_{ij}$, and time duration t_{ij} , which is the time taken to travel between the arcs a_{ij} which connects the various locations in the tour. The tour is expressed as a network of nodes and connected edges. It is defined as graph $G = (V, A)$ where V is the set of nodes $\{1, 2, \dots, n\}$ and A is the set of feasible paths between the nodes. Since the cost function is dependent on the varying time-table schedule of the public transport system, it is expressed as c_{ij}^t , which includes the earliest arrival time between the nodes based on time table schedule of public transport. The TSP is an important optimization problem used for benchmarking optimization algorithms. In this research the scenario is studied as a TPP problem with time window and it implements the well known Nested Monte Carlo (NMC) search algorithm for tour planning. 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 often large and 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 problem solving. NMC has been very successful in establishing world-records in games such as Morpion Solitaire or Same Game etc. The NMC algorithm uses several levels in its search space. At each level the result of the lower level is evaluated to determine the next move. At level 0 of NMC, a random playout take place until a final position is reached, Fig 1 in .line 6 At each step of the NMC the move which has the highest score in its lower levels is selected, Fig.1 Line 9. The algorithm tries out all possible moves at every step, and it invokes a nested search for the lower levels after each move (Fig.1 Line 8). The sequence of moves which produced the best scores in the lower level searches are memorized. 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 previous searches yield a good result. 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 the current best score, that move is played; else it is updated with the new sequence (Fig 1, Line 9, 10, 11). The algorithm implemented in this study uses policy adaption, with nesting levels $n \geq 2$ and a fixed number of iterations. [9][10][11].

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1. nestedMonteCarlo(level)
2. best playout+{}
3. best.score=MAX_VALUE
4. while not end of game do
5.   if level is 0 then
6.     move= arg [ _max(play(position,m))]
7.   else
8.     move=arg max(nestedMonteCarlo (play (level-1) ) )
9.     if score of move>best.score
10.      best.score=score after move
11.      best.sequence=sequence after move
12.   else
13.     bestMove=move of the sequences so far
14. return score

```

Figure 1 : Nested Monte Carlo-Planning algorithm
C. Multi-agent Approach to Implementation

The public transport systems which includes several entities such as bus, tram, metro, rail etc. are the key designs for mobility. An urban public transport network is considered a naturally complex system which is a result of interaction between a set of distributed and evolving entities as described in [12]. The complexity of the public transport system is further increased as a result of dynamic parameters such as traffic jams and unexpected events such as accidents and sudden changes in routes within the environment which can affect the planned journey. The size and complexity of the different parameter which influence the outcome makes it very difficult to implement a theoretical model for such systems. Therefore, in this research an approach that uses a Multi-Agent Simulation (MAS) model has been adopted for the purpose of planning, and analysis of the system. The implementation of the delivery process of the Supply Chain Management (SCM) phase is represented as a functional representation using multi-agents. An agent is an entity which has a goal, knowledge of its environment and is capable of performing actions and interacting with its environment to accomplish its goal [13]. The logistics process in a SCM involves interaction between various entities such as warehouse, distribution centers, distribution network, and the customers. Therefore, the logistic process of an SCM is transformed into an 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 and are modeled as agents are discussed 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 The FSM modeling for the Delivery Agent is illustrated in Fig. 2.

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. 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. The system architecture has been discussed in section II.

The system model has been extended from the model architecture used in [15]. The schedule transport agent has been modified to respond to delivery routing and scheduling queries. Moreover, the delivery agent has been also extended from the person agent to include a journey which involves multiple locations instead of one, and with constraints of service time windows

While there are general platforms available for the implementation of MAS, this research uses the PlaSMA Simulation Framework which has been especially developed for, but not limited to, simulating dynamic scenarios in transport logistics described in [14]. The PlaSMA simulation framework built on JADE framework was developed as an agent-based event-driven simulation platform 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.

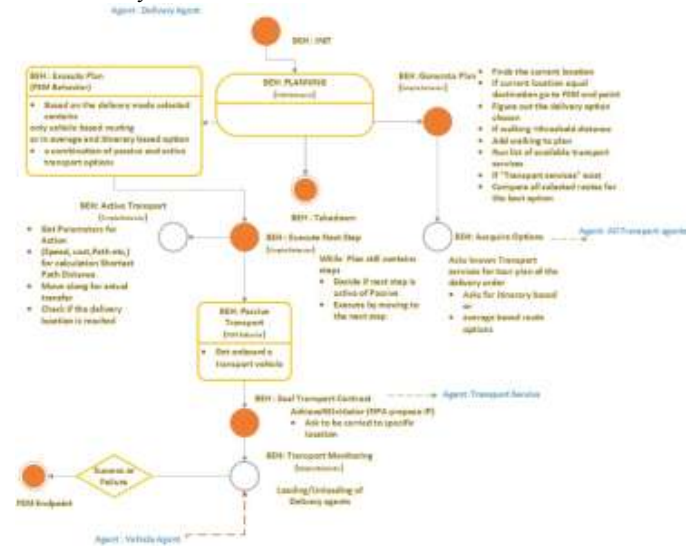


Figure 2: FSM Behavior Modeling of the Delivery Agent

VI. IMPLEMENTATION OF SIMULATION MODEL

A. Experimental Setup and Simulation

To build a fine-grained simulation model that emulates real-world conditions, the road, tram infrastructure modeled for the simulation represents the city of Bremen in northern Germany. The infrastructure network has been reduced to include only a set of connected edges, and nodes which are unreachable had been removed to allow an efficient infrastructure graph structure for the purpose of simulation. The various stops and junctions are modeled as nodes, while

the roads and tram ways are modeled as the arcs which connect those nodes, which has been discussed in [16]. The infrastructure map includes all relevant highways, motorways and tramways, bus and tram stops found in the Open Street Map (OSM) of Bremen. The modeled graph includes 26126 vertices and 59957 edges which are used in the simulations. The OSM importer tool allows the OSM data to be loaded into PlaSMA. Three different approaches were utilized for comparison of the efficiency of the solution in terms of effective distance travelled using passive mode (distance travelled using public transport) and active mode (distance travelled using an e-bike).

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 currently. 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 solely on the list of delivery locations to be visited. Since the PTS is not involved, the time-schedule information of the PTS do not play any role in the plan generation and therefore this method is reduced to a route planning problem.

Case II - Average Route planning algorithm - 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.

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. Therefore, once a query arrives with a list of destinations to travel, 48 shortest path distance matrices are constructed based on the list of locations the delivery agent wishes to travel, which is then passed to the Monte Carlo Solver. The Path Solver used for building the cost matrix in all the three methods is discussed in [13]. Once the matrix is constructed the NMC is invoked for tour order generation. The Monte Carlo Solver is also adapted from the previous approaches, and the makespan is updated to include the travel start-time. 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.

The simulated scenario represents a 24 hour period of a Monday morning. The courier service delivery lies between 9:00 hours to 18:00 hours. Tours which do not visit all the locations in a given run are considered infeasible solutions. Every order is associated with a start location and a delivery location for its fulfillment. Orders are feasible only for medium to small packaged goods, and delivery of large goods such as television, washing machines etc are not considered. capacity which would mean delivery of 20/30 The highest priority for this delivery agent is to ensure all

the locations are travelled, second highest priority is to ensure that the route of the tour plan includes minimum distance travelled using active mode. 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.

VII. RESULTS OF EXPERIMENTS

Experiment set - I

Delivery location controlled - Delivery locations were selected by based on knowledge of city

The results of the experiments are presented in this section.

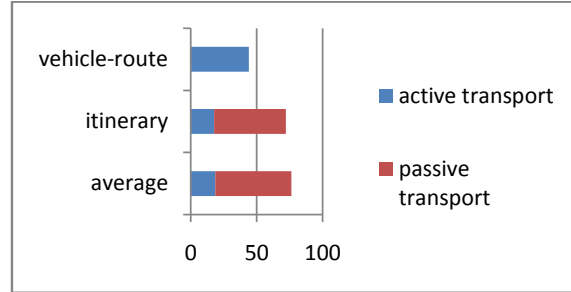


Figure 3 : Results of experiment when 9 delivery locations are selected in controlled environment. All values are in km

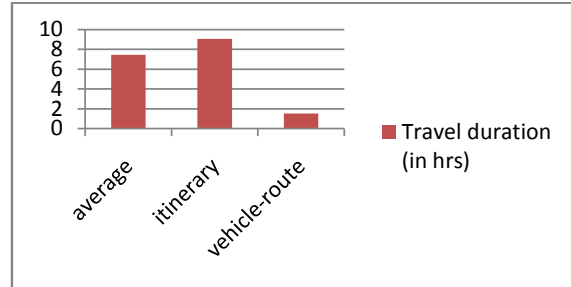


Figure 4 : Travel duration when 9 delivery locations are selected in controlled environment. All values are in hrs.

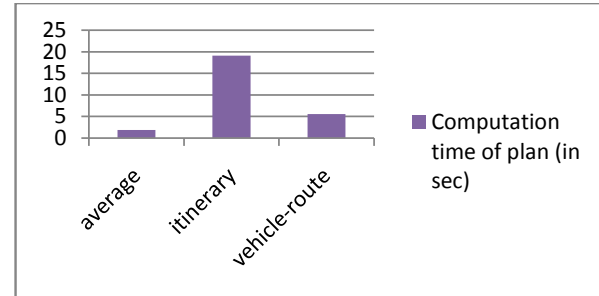


Figure 5 : Computation time when 9 delivery locations are selected in controlled environment. All values are in sec.

In Fig. 3 and Fig. 4, represents the total distances travelled and total duration of travel by the delivery agent when 9 different locations have been considered. Fig 3 describes the total journey as a combination of active transport mode and passive transport modes for all the three methods studied. The full time schedule for all available transportation networks was available for the calculation of the tour plan.

The results of the experiments show a great deal of reduction in the active mode of journey, when inter-modal transportation approach (Case II, and Case II) are used, compared to the distance travelled in vehicle routing approach (Case I). It was found out that the tour generated by the Information system service was similar to a tour which would be made by traveler who has a good knowledge of the city and its public transport routes. The finding validates the assumption that the plan generated could be a feasible one. Fig.4 represents the total duration of time taken to complete the entire tour for all three methods. The duration was least in Case I and higher for the other two cases. Fig.5 illustrates the plan computation time for all three cases, and it is least for average-routing and highest for Case III which is more computationally intensive.

Experiment Set II - Delivery locations generated using Random function

In the next set of experiments, the delivery locations were generated for the entire city using a random function. Only few of the experiments resulted in complete 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 made available the number of locations reached were fewer compared to the scenario when full-graph PTN was available for plan computation. Although, in both cases the tour wasn't completed, the results are slightly different. Using a random location generator, locations picked were often a combination of distant and near-by location from the depot. Therefore depending on the tour order generated by the Tour Planning algorithm (Solver), it is possible that in absence of a well-connected PTN, it might not be possible to reach all the locations within 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 which led to longer travel time for distant location. However, for Case I when vehicles with a velocity of 30 km/h were used in **vehicle routing approach**, the tour completed every time.

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

In the next set of experiments, random locations were generated within a 6 km radius from the depot. In this case, results were relatively more promising, and tours could be completed successfully when the number of deliveries was limited to 10 for all three cases. Fig. 6 represents the tour as distance travelled in active and passive mode and Fig. 7 represents the total tour duration. Since the locations were selected within a radius of 6 km the distance travelled was found to be less than Experiment II since they are relatively restricted within a radius. The duration of time to complete the tour is also (Fig 7) less compared to the previous set of experiments. Fig. 8 illustrates the computation time for the plan, which is found to be minimum for average –route method and maximum for itinerary based method.

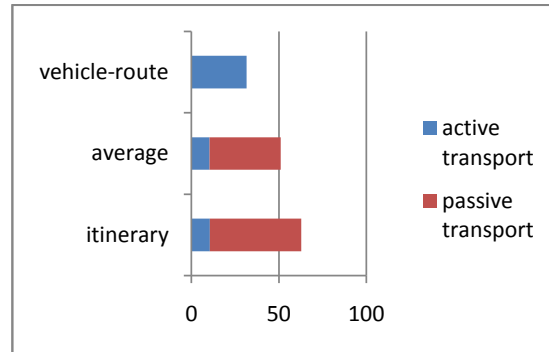


Figure 6 : Distances travelled by active and passive routes for when 10 locations for delivery are picked randomly within a radius of 6km from the depot(distances are in km)

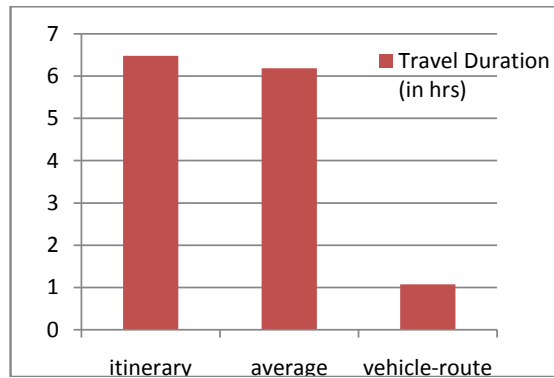


Figure 7 : Travel duration for when the 10 locations for delivery have been picked randomly within a radius of 6 km from the depot

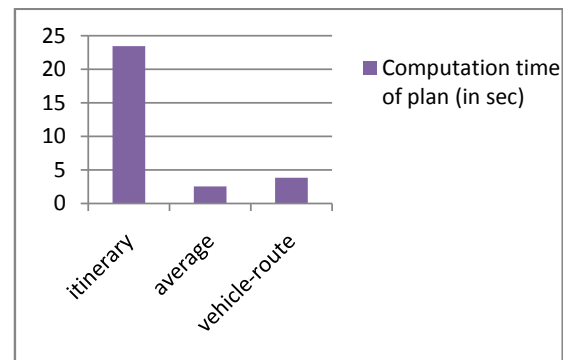


Figure 8 : Computation time of plan (in sec) for 10 random locations selected within a 6 km radius

Experiments with 15 delivery locations were found to be relatively less predictable and all the locations could not be reached within the simulation time although the radius was now further limited to only 5km.

When 15 delivery locations were simulated tours were completed (Fig. 9) only for the average route plan and vehicle routing approaches. The tour was incomplete for the itinerary based approach. Fig. 9 and Fig. 10 illustrate with a comparison of distance travelled and duration of travel for Case I and Case II when 15 delivery locations were selected.

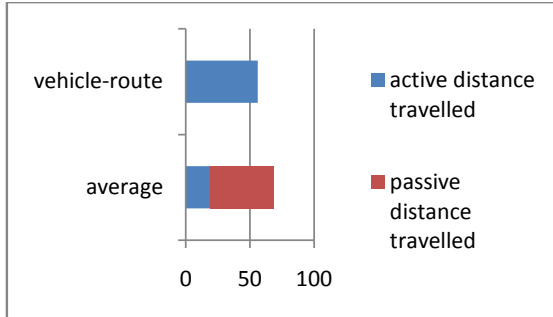


Figure 9 : Active and Passive distance travelled when 15 locations were picked within a 5 km radius of depot

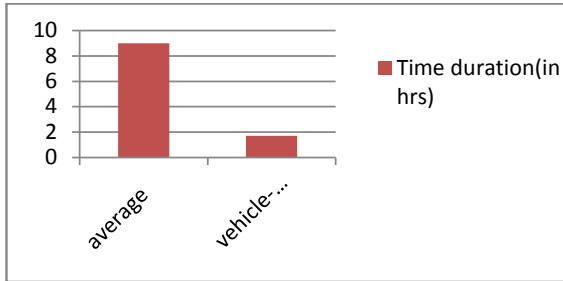


Figure 10: Time duration of delivery to 15 random locations generated within a radius of 5 km from the depot

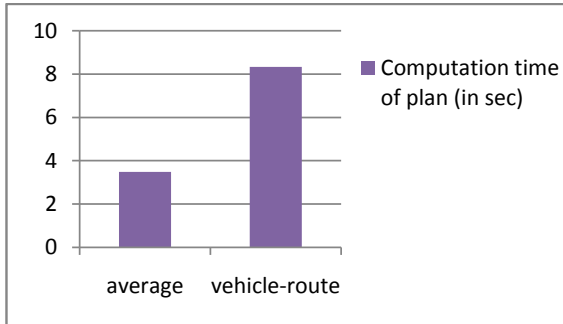


Figure 11: Computation time of plan (in sec) for 15 random locations picked within a 5 km radius from depot

Fig. 11 illustrates the computation time difference for Case I and Case II, which is found to be higher for Case I.

When the random location function generator selected 19 delivery locations within a 5 km radius to the depot the tour was incomplete for Case II and Case III approach.

Experiment Set IV - Random locations selected within 5 km radius from depot with e-bike speed of 13 km/hr

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.

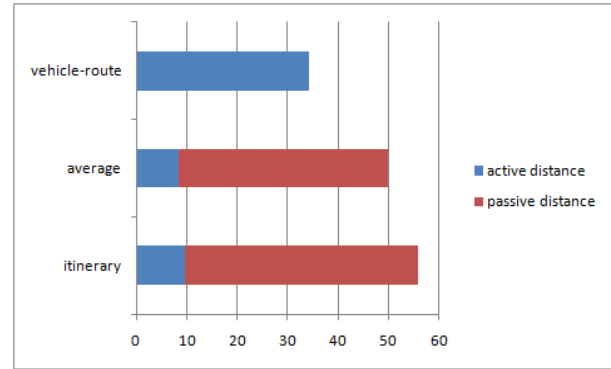


Figure 12: Active and Passive distance for 10 locations picked within 5 km radius

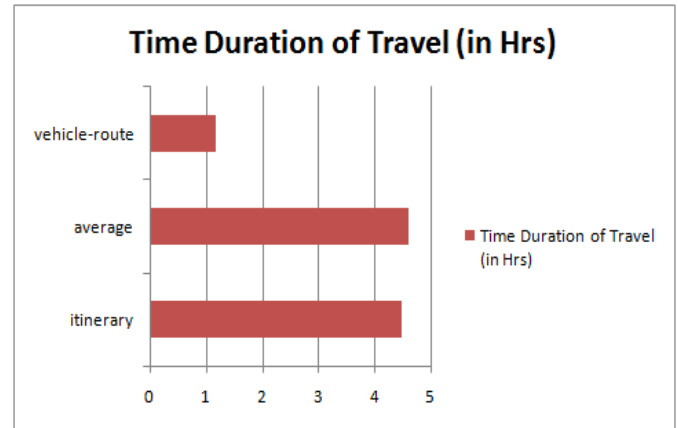


Figure 13 : Travel duration for 10 locations

In the final set of experiments Fig 12, Fig13 illustrate the total distance travelled and time duration of tour when 10 delivery locations were selected within a 5km radius, and the speed of e-bike during active transport mode for the inter-modal approaches was increased to 13km/hr. The results of the experiment improved significantly. It was found that the duration of tour improved for the Case II and Case III methods. 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.

VIII. DISCUSSION AND CONCLUSIONS

The results show a positive correlation between the number of delivery locations and travel duration. When random locations were picked for delivery, the chance of a successful tour using inter-modal transport was reduced. However, in subsequent experiments when random locations were picked within a certain radius of the start or depot point the results improved. The observation leads to appreciation of the significance of delivery location assignment for optimization of the delivery process

The other parameter, studied is the experiments are the computation time of plan. The computation time for plan is the lowest for average route plan based approach and highest for the itinerary based approach. The higher computation

time of itinerary based approach planning method is attributed to the high number of matrices (48) which need to be generated and then scanned in the Solver for generation of a tour plan. The higher computation time of plan ascertain the assumption that of the three approaches itinerary based approach is most computationally intensive.

Among the two approaches studied with-in inter-modal transportation, the average route approach yielded better results in terms of shorter duration of tour and less distance travelled. When more number of delivery locations was picked (15), it was observed the itinerary based tour plan method failed while the average tour-plan method was still successful in generating a valid tour.

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 more immediate time schedule information for tour computation. The second approach can therefore affect the overall tour if any section of the plan is unable to be executed due to unforeseen conditions.

The Fig 14 illustrates a simulation scenario within PlaSMA which consists of several delivery locations, public transport network, modes of delivery and a delivery agent which is responsible for goods delivery.



Figure 14 : A Simulated scenario with several tram /bus and a Courier Service agent for delivery of

The performance of the proposed model studied the inter-modal delivery of goods utilizing three different approaches. The results in the previous section lead to the assumption that in terms of duration of travel the vehicle-route approach was most successful. Although the completion rate of tour is highest for this 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 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 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. The current implementation does not support re-planning of tour. 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 investigated the distance travelled using vehicle and public transportation where it was observed that vehicle-routing approach was a less energy efficient choice compared to inter-modal transport, although it might be a faster choice. 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 reducing urban congestions.

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.

The study is a prototype research concept and it can be further extended with more detailed calculation using real-world data from industries. More extensive results and data would encourage companies to make prudent delivery choices and encourage a shift towards an approach which adopts green logistics [17].

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