Developing decision support systems for last mile transportation problems

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Abstract

Last mile transportation is the most problematic phase of transportation needing additional research and effort. Longer waits or search times, lack of navigational directions and real-time information are some of the common problems associated with last mile transportation. Inefficient last mile transportation has an impact on the environment, fuel consumption, user satisfaction and business opportunities. Last mile problems exist in several transportation domains, such as: the landing of airplanes, docking of ships, parking of vehicles, attended home deliveries, etc. While there are dedicated inter-connected decision support systems available for ships and aircraft, similar systems are not widely utilized in parking or attended handover domains. Therefore, the scope of this thesis covers last mile transportation problems in parking and attended handover domains. One problem area for parking and attended handovers is due to lack of real-time information to the driver or consumer. The second problem area is dynamic scheduling where the handover vehicle must traverse additional distance to multiple handover locations due to lack of optimized routes. Similarly, during parking, lack of navigational directions to an empty parking space can lead to increased fuel consumption and CO2 emissions. Therefore, aim of this thesis is to design and develop decision support systems for last mile transportation problems by holistically addressing real time customer communication and dynamic scheduling problem areas. The problem areas discussed in this thesis consists of persistent issues even though they were widely discussed in the literature. In order to investigate the problem areas, microdata analysis approach was implemented in the thesis. The phases involved in Microdata analysis are: data collection, data processing, data storage, data analysis and decision-making. Other similar research domains, such as: computer science or statistics also involve phases such as data collection, processing, storage and analysis. These research domains also work in the fields of decision support systems or knowledge creation. However, knowledge creation or decision support systems is not a mandatory phase in these research domains, unlike Microdata analysis. Three papers are presented in this thesis, with two papers focusing on parking domains, while the third paper focuses on attended handover domains.

The first paper identifies available smart parking tools, applications and discusses their uses and drawbacks in relation to open parking lots. The usage of cameras in identifying parking occupancy was recognized as one of the suitable tools in this paper. The second paper uses a thermal camera to collect the parking lot data, while deep learning methodologies were used to identify parking occupancy detection. Multiple deep learning networks were evaluated for identifying parking spaces and one method was considered suitable for acquiring real time parking occupancy. The acquired parking occupancy information can be communicated to the user to address real-time customer communication problems. However, the decision support system (DSS) to communicate parking occupancy information still needs to be developed. The third paper focuses on the attended handovers domain where a decision support system was reported which addresses real-time customer communication and dynamic scheduling problems holistically. Based on a survey, customers accepted the use of mobile devices for enabling a real-time information flow for improving customer satisfaction. A pilot test on vehicle routing was performed where the decision support system reduced the vehicle routing distance compared to the route taken by the driver. The three papers work in developing decision support systems for addressing major last mile transportation problems in parking and attended handover domains, thus improving customer satisfaction, and business opportunities, and reducing fuel costs, and pollution.

Keywords: parking spaces, attended handovers, user satisfaction, pollution, business opportunities

List of Papers

This thesis comprises of the following papers, which are referred to in the text by their Roman numerals:

I – Paidi, V., Fleyeh, H., Håkansson, J., & Nyberg, R. G. (2018). Smart parking sensors, technologies and applications for open parking lots: a review. *IET Intelligent Transport Systems*, *12*(8), 735–741.

II – Paidi, V., Fleyeh, H. & Nyberg, R. G. (2019). Deep learning-based vehicle occupancy detection in an open parking lot using thermal camera. Submitted, under review.

III – Paidi, V., Nyberg, R. G. & Håkansson, J. (2019). A holistic decision support system to address attended last mile handovers. Submitted, under review.

My contributions to the papers were as follows:

Paper I – Literature review, analysis, writing and revising the manuscript.

Paper II – Data collection, data processing, methodology development, data analysis, writing the manuscript.

Paper III – Data collection, data processing, methodology development, data analysis, writing the manuscript.

Note: The papers listed above are not appended in the online version of the thesis.

Papers not included in the thesis:

Paper I – Paidi, V., Fleyeh, H., Håkansson, J., & Nyberg, R. G. (2018). Smart Parking Tools Suitability for Open Parking Lots: A Review. In *VEHITS* (pp. 600-609).

Paper II – Paidi, V., Fleyeh, H. (2019). Parking occupancy detection using thermal camera. In *VEHITS*

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Introduction

The last mile in transportation is referred to as the final phase of travel in reaching a destination. It can be the case of an airplane reaching the airport, a ship reaching the dock, a vehicle reaching an empty parking space or attended parcel handovers. In parking, the driver or user looks for parking spaces at locations such as: a shopping mall, hospital or airport. These locations serve as destinations, while the search and route taken in reaching a parking spaces is considered the last mile transportation problem in reaching a destination. Similarly, when a delivery vehicle departs from the distribution centre or retail centre, the driver needs to handover multiple parcels at multiple locations, which is the destination, and problems associated with the handovers, such as missed deliveries, the route taken to reach the destination are considered as last mile transportation problems. This is considered as the most problematic phase of any type of transportation (Gevaers, Van de Voorde, & Vanelslander, 2014; Visser, Nemoto, & Browne, 2014). In attended handovers, high volume of low value handovers to multiple locations and handovers at low density regions increase operational costs to the retailer or logistic company. The customer receiving the parcel might not be at home which would result in repeated handovers, thus increasing operational costs; similarly, a delay might occur in landing a plane, due to long queues, thus increasing fuel costs. In parking, search for a parking space lead to frustration, pollution and congestion. Extra effort should be made to avoid these problems as they can lead to loss of business opportunities, increased fuel costs and pollution. Dedicated decision support systems are already utilized in ships and aircraft domains, while similar decision support systems are not widely used in parking and attended handover domains. Therefore, this thesis identifies the need for holistic decision support system for addressing major last mile transportation problems in these domains, thus enabling efficient usage of parking spaces while improving business opportunities in the case of attended handovers.

There are two major problem areas in last mile transportation: real time customer communication and dynamic scheduling (Leung et al., 2018). Three papers are presented in this thesis, with two papers focusing on parking domains while the third paper focuses on attended handovers domain. In traffic dense environments, up to 50% of drivers look for free parking spaces (Boltze & Puzicha, 1995; Gallivan, 2011; Polak & Vythoulkas, 1993; White, 2007). Vehicles traverse at low speeds near a parking lot area searching for parking spaces and this also slows down adjoining vehicles. Therefore, lack of real-time parking occupancy information and dynamic navigational directions to the empty parking space leads to user frustration, congestion and increased pollution. Open parking lot is focussed on in the parking domain. An open parking lot consists of freely available parking spaces unlike a closed parking lot which consists of paid parking spaces. Since, an open parking lot is freely available and in high demand, vacant parking space and navigational directions should be iteratively updated in real-time, based on availability. In the parking domain, lack of parking occupancy information falls under the real-time customer communication problem area, while lack of navigational directions falls under scheduling.

In attended handovers, real-time customer communication problems involve problems such as customer satisfaction (Hübner, Kuhn, & Wollenburg, 2016), and missed handovers (Dell'Amico & Hadjidimitriou, 2012). These problems can lead to loss of business opportunities and increased operational costs. Similarly, dynamic scheduling involves problems such as vehicle routing and availability of loading bays which can lead to increased fuel costs, or pollution, due to lack of optimized delivery routes. Lack of occupancy information of loading bays can lead to wastage of time and delay in adjoining deliveries. Due to these complexities, the current attended handovers implement long delivery windows making them less attractive to customers. There is also no standard procedure involved for attended handovers. Every company has its own business model for last mile transportation, which varies with the size of parcels and distances.

Research in last mile attended handovers have mainly discussed customer communication or dynamic scheduling problem areas individually even though the problems are dependent on each other. Addressing only one problem area is not beneficial to either the driver, customer or retailer. Therefore, aim of this thesis is to design and develop decision support systems to simultaneously address real time customer communication and dynamic scheduling problems in attended handovers and parking domains. The thesis contributes by emphasizing the importance of holistically addressing major last mile transportation problems. The three papers work in developing decision support systems to address major last mile transportation problems and each paper addresses one research question. The first research question is to identify suitable methods to acquire real time parking occupancy on an open parking lot. There is scarce in literature which discussed suitable methods for an open parking lot. The second research question is to acquire parking occupancy using thermal camera and deep learning methodologies. A thermal camera was identified suitable for open parking lots as it can be used in any environmental conditions and large number of parking spaces can be covered using one camera. Such similar studies in the literature were found using data generated by colour camera but were scarce using thermal camera. Usage of deep learning methodologies on thermal camera data was also found be scarce in the literature. The third research question is to identify the major problems with last mile handovers and design, develop a decision support system to address these problems. No previous studies were found proposing a decision support system holistically addressing major last mile transportation problems. The coming sections discuss the relation of the thesis to Microdata analysis, present a summary of the work done in the three papers and conducts a concluding discussion.

Microdata Analysis

The papers in the thesis are in the research domain of Microdata analysis. Microdata analysis is a multidisciplinary field which involves artificial intelligence, decision support systems, data modelling, geographic information systems and optimization (Dalarna, 2019). The domain covers the whole process from data collection to decision making with the use of collected and processed data to generate knowledge as shown in Figure 1. There are several other research domains, such as computer science or statistics, which also involve similar phases, as mentioned in Figure 1. However, decision support systems were not a mandatory phase in these research domains, unlike Microdata analysis. Therefore, Microdata analysis is a suitable research domain for this thesis which contributes to developing decision support systems for last mile transportation problems.

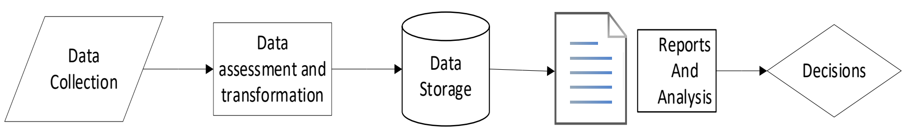

Figure 1. Microdata analysis stages

Papers relation to Microdata Analysis

In relation to the elaborated Microdata analysis phases as mentioned in Figure 1, this section discusses relation of three papers to the phases of Microdata Analysis.

Data collection

The first paper involves data collection in the form of literature which was searched and stored. In the second paper, data in the form of videos was collected using a thermal camera. The motion detection videos were captured using the camera, and the videos were collected using an application. The size of the collected data was approximately 30 gigabytes. Therefore, the camera captured many short interval videos. Storage and communication problems were overcome to access and download the data from the application. In the third paper, expert group interviews and workshops were conducted to design the decision support system. A survey was conducted with the customers of a retailer to understand the customer's acceptance of using mobile communication devices. Two drivers' routing data was captured using GPS applications. Each driver carried the mobile GPS application while performing the handovers. The drivers departed from the distribution centre to make the handovers, and each driver made an average of 10 handovers on each trip to several places in Dalarna County in Sweden. They traversed an average of 300 kms during the handover trip. Therefore, long stretches of handover routes were collected using the GPS application in CSV format.

Data transformation and storage

In the first paper, the collected literature was processed to identify suitable articles which were saved and processed, while irrelevant articles were discarded. As mentioned previously, for the second paper, several videos were collected using a thermal camera. Since, parking occupancy information should be acquired in any environmental conditions, diverse images were collected from multiple videos to create the dataset. The images collected for the dataset were again processed by creating labels for the cars. Automated labelling algorithms did not identify vehicles as they were trained with colour images. Therefore, manual labelling of vehicles was performed on the entire dataset. The dataset was randomized and divided into training and test datasets where 70% of the dataset was used for training, while 30% was used for testing. In this way the dataset was created for the algorithms. The third paper consists of a survey and GPS data. The survey results were processed to generate suitable graphs while the raw GPS data was processed to load the data into a GIS application. The GPS data was captured every 5 seconds; therefore, thousands of GPS points were collected during the trip which were loaded into the GIS application for further analysis.

Data analysis and reporting

In the first paper, suitable technologies and sensors were evaluated for their suitability on an open parking lot. An online search was performed to find if any decision support system was available for open parking lots. In the second paper, four deep learning algorithms were evaluated with the same dataset. Vehicle occupancy detection using thermal camera was not performed in the previous literature. Therefore, the performance of various deep learning object detection algorithms was evaluated using thermal data. Algorithms performance was evaluated using miss rates and a false negatives curve. Regarding the third paper, the processed data was uploaded to the GIS application for analysis. Optimized routes for all the handover locations were generated. The actual route was then compared with the optimized route and the distance for each handover was compared to identify improvement.

Decision

An open parking lot is traditionally placed outdoors which is subjected to external environmental conditions. Therefore, in the first paper, technologies or sensors which were not dependent on environmental conditions and which do not consume high expenditure to install and maintain were proposed. In the second paper, based on the results and analysis, one algorithm was identified with minimal miss rates and run-time efficiency which can perform real-time vehicle occupancy. In the third paper, the survey results identified customers' acceptance of using mobile communication devices to improve real-time communication. The optimized routes provided by the decision support system reduced vehicle distance in reaching the handover locations. The decision support system can improve customer satisfaction and reducing operations costs for the logistic company. Knowledge is thus created for further studies where parking occupancy information for several days can be used to create a probability of parking occupancy, along with navigational directions to the estimated vacant parking space. Similarly, based on the knowledge of missed handovers or negative feedback from the customers, the retailer can take additional precautions in specific areas to improve customer satisfaction and reduce operational costs.

Papers included in the thesis

The previous section emphasizes on the paper's relation to Microdata Analysis. Therefore, this section presents a summary of all the three papers briefly discussing about the aim, method and conclusion sections.

Identifying suitable approaches for vehicle detection – Paper I

This study reviews the smart parking applications and tools for open parking lots. An open parking lot does not support the reservation of parking spaces and is freely available, while a closed parking lot supports reservation and is paid for. There is extensive previous literature which discusses smart parking applications for closed parking lots but there is a lack of research focussing on open parking lots (Paidi, Fleyeh, Håkansson, & Nyberg, 2018). No previous studies discussing smart parking applications on an open parking lot were found. Even though an open parking lot is higher in demand compared to a closed parking lot, there were no smart parking applications available for providing real-time parking occupancy information. Therefore, this study aims at identifying suitable tools for acquiring parking occupancy which can be used to develop a decision support system.

The available smart parking applications focus only on closed parking lots. Real-time parking occupancy information for an open parking lot was not provided by any available applications which can be due to the lack of return investment. Expenditure on smart parking tools used to identify parking occupancy information can be returned using a closed parking lot. Therefore, the smart parking tools for an open parking lot must use less expenditure for installation and maintenance activities. There were several smart parking tools available to monitor parking occupancy. Technologies such as computer vision, vehicular ad hoc networks, multi-agent systems, neural networks can be used to identify parking occupancy which were reviewed. Similarly, sensors such as ultrasonic sensors, magnetometers, radio frequency tags, microwave radar were also reviewed in the study. Not all the tools are suitable for open parking lots as they were subjected to external environment and due to high installation and maintenance activities. The study discusses the pros and cons of using the smart parking tool on an open parking lot. Magnetometers and microwave radars were suitable for open parking lots, but expenditure would be high for installation and maintenance activities. Machine vision is one of the suitable tools for acquiring parking occupancy information due to its low expenditure in installation and maintenance activities and because a single camera can cover many parking spaces.

Vehicle detection using thermal camera – Paper II

This study serves as a continuation of the previous study where machine vision was used to acquire parking occupancy information. The test study was performed on an open parking lot in Sweden. Varying environmental conditions exist in Sweden where there are very few daylight hours during winter and more than 20 daylight hours during summer, which makes it a challenge for normal cameras. Therefore, a thermal camera which can be used in any environmental or lightning conditions was chosen to collect parking data. A normal camera is dependent on lightning conditions and needs a good amount of light to detect vehicles in dark conditions. The thermal camera facilitates in detecting vehicles based on the amount of heat emitted from the objects, irrespective of the lightning or environmental conditions. A thermal camera was permitted to be used in public places without any privacy restrictions as no person or vehicle can be recognized using the camera. A thermal camera is expensive compared to a normal camera, but installation and maintenance activities were minimal which makes it a one-time investment. The aim of this study was to detect vehicles and identify parking occupancy using a thermal camera in an open parking lot.

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The parking lot selected in this study was a university parking lot in Sweden, containing multiple parking spaces. However, the first four rows of the parking lot were identified as the region of interest, as marked by the green rectangle in Figure 2. The camera was placed on top of a two-story building and the elevation could not be increased due to height restrictions of the building. A higher elevation of the camera would cover a greater number of vehicles without occlusion.

Figure 2. Region of interest in the parking lot

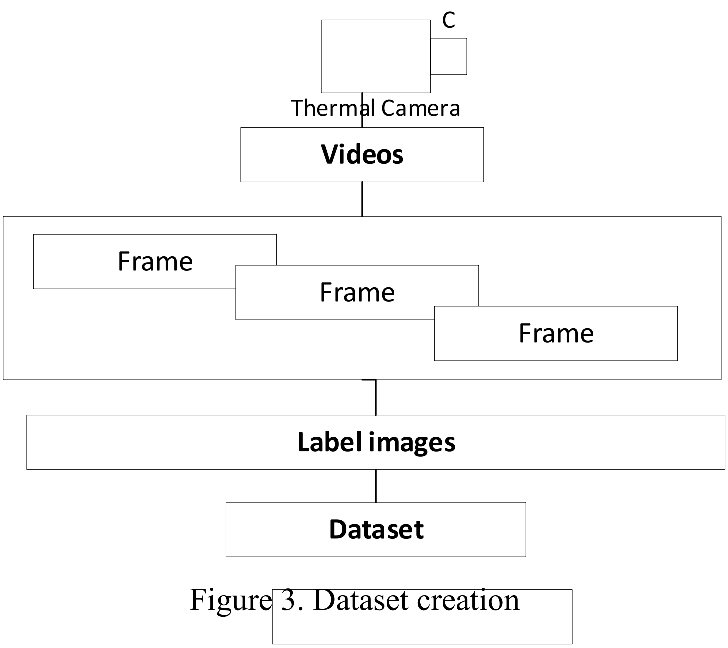

Figure 3. Dataset creation

As illustrated in Figure 3, the thermal camera captures videos when it detects a motion. This feature was enabled to save memory. When a person or vehicle moves within the frame of the camera, it saves the video until the motion is ended. These videos were saved temporarily on a memory card installed on the camera which can be accessed using an application. The videos would be stored for a duration of 45 days before being replaced. The videos were downloaded from the application every week to an external hard disk to avoid missing videos. The size of the collected data was approximately 30 Gigabytes which represents various environmental conditions. Frames from these diverse videos were extracted to create the dataset. During early morning the vehicles were warm and can be easily identified. However, when the heat in the vehicles gradually diminishes the vehicles over a period become dark and hard to recognize, which was a drawback of using a thermal camera. A total of 7777 labels were created from varying images to generate a dataset.

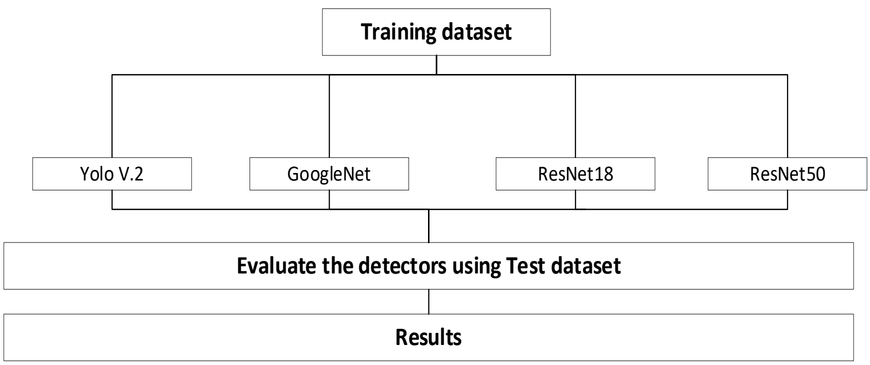

Figure 4. Detectors implemented

The dataset consists of 527 images, where the training dataset contains 70% of the images while the testing dataset contains the remaining 30%. As shown in Figure 4, deep learning algorithms such as Yolo, ResNet18, ResNet50 and Googlenet layers were implemented for vehicle detection. Yolo and GoogleNet had a higher number of miss rates and false negatives per image. ResNet architectures performed better compared to other detectors. However, ResNet18 took less processing time compared to ResNet50, due to a smaller number of layers. The detected vehicles were compared with a template and parking occupancy information was captured. ResNet18 was a suitable detector for performing real-time parking occupancy.

Address last mile handover issues – Paper III

This study focused on the design and development of a decision support system for last mile transportation problems in attended handovers. Last mile transportation is the last phase of supply chain logistics and is assumed to be the most problematic phase. Attended handovers consists of the delivery or pickup of parcels to or from the customers. Last mile handover costs can go up to 50% of the total logistic costs (Kuhn & Sternbeck, 2013; Vanelslander, Deketele, & Van Hove, 2013). According to one study, 5% of the customers were unable to track the delivery status, 15% missed the home deliveries and 13% faced delay in deliveries (Eurobarometer, 2013). Retailers lose money and value due to the problems faced in last mile handovers. The major problems in the last mile handovers discussed in this study were real-time customer communication and dynamic scheduling. Real-time customer communication deals with problems related to missed handovers, long-time windows for handovers and customer satisfaction in relation to the handover. Dynamic scheduling deals with problems related to vehicle routing, long idle time for drivers and access to load/unloading zones. The current literature discusses these problems individually, but there is a scarcity of literature discussing a decision support system, or similar tools addressing last mile handover problems holistically. Therefore, the aim of the study was to design a holistic solution to address last mile handover problems.

An information flow should be established between the stakeholders: the retailer, logistic company and the consumer (Petrovic, Harnisch, & Puchleitner, 2013). The proposed holistic decision support system enables such an information flow between customers, drivers and retail or logistics companies. The decision support system focuses on the interoperability of these stakeholders in addressing the problems. We conducted expert group interviews and workshops with the logistic companies and development companies. Therefore, a decision support system was proposed which holistically involves the stakeholders, as mentioned in Figure 5.

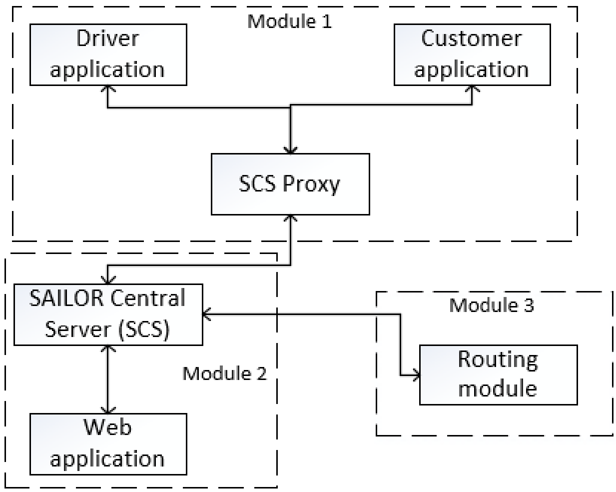

Figure 5. System model

The system consists of driver and customer mobile applications and a web application, as shown in Figure 4. The driver application was used by the driver for fetching the orders and optimized routes to the handover location. The routing module generated the optimized routes for the added orders. The driver updated the mobile application, once the handover was completed. The customer application was used by the customer for fetching product details, delivery status, estimated time of arrival, and for choosing an alternate handover location. A survey was conducted to find out customer acceptance for using the decision support system, where majority of the customers appreciate the usage of the system for improving customer communication. A test of the optimized routes generated by the decision support system was also performed where improvement was observed. Not all the functionalities of the decision support system were tested due to technical difficulties. The holistic decision support system with multi-party communication among the stakeholders facilitates the reduction of operational costs for logistic companies and the improvement of customer satisfaction and business opportunities.

Concluding discussion

The aim of this thesis is to design and develop decision support systems in addressing major last mile transportation problems in parking and attended handover domains. In parking domain, suitable methods to acquire parking occupancy information were proposed considering expenditure and susceptibility to environmental conditions. Thermal camera was identified as a suitable tool due to its dynamic usage in any type of environment. Multiple deep learning algorithms were evaluated, and one algorithm was found suitable to acquire accurate real time information. Deep learning algorithms facilitate in acquiring real time parking occupancy information and address customer communication problem. Real time parking occupancy information would facilitate the driver to take a decision on occupying a vacant parking space which also improves business opportunities and efficient utilization of land resource. In relation to attended handovers, the major last mile transportation problems were identified, and a decision support system was designed and developed to address these problems. The developed decision support system was accepted by the customers which enables real time customer communication and change of handover location. Real time customer communication was enabled between the customer and the logistic company using mobile communication devices. Similarly, availability of optimized vehicle routes to reach multiple handover locations and the functionality to change the handover location addresses dynamic scheduling problems. The decision support system for attended handovers reduces operational costs, improves customer satisfaction and business opportunities. The thesis identifies the need for a holistic decision support system to address major last mile transportation problems.

In parking, a driver would obtain knowledge of parking occupancy at different times of the day while in attended handovers, and knowledge of route complexities and missed handovers. With this knowledge, the time spent in occupying a parking space can be reduced. Similarly, the number of missed handovers can be reduced by communicating with the customer who is involved in a higher number of missed handovers. This knowledge increases customer satisfaction and facilitates business opportunities. However, the use of a decision support system would not completely eradicate all last mile transportation problems. A decision support system will not be of use if the customer chooses not to use it. Traffic roadblocks, vehicle breakdowns, adverse weather conditions might also affect the reliability of decision support systems.

A thermal camera was deployed in acquiring parking occupancy. However, it could not be installed at an increased height which would have led to an improved quality of data. The current height of the camera led to occluded images of vehicles, leading to false classifications with Yolo and GoogleNet deep learning algorithms. Yolo and GoogleNet were computationally efficient deep learning algorithms compared to ResNet. Therefore, the detection rates of these algorithms can be improved further with a larger data set containing diverse images. Since, there were no available thermal vehicle datasets, our own dataset was created leading to a smaller number of training and test images. In the future, navigational directional information for reaching the vacant parking space using the decision support system will be provided. The estimation of parking occupancy for one or more hours would facilitate drivers in planning their arrival, thus leading to increased customer satisfaction. Feedback from the logistic company suggested the inclusion of voice commands with navigational directions and making the DSS integrate with their existing system. Not all the functionalities of the developed decision support system for attended last mile handovers were operational due to technical difficulties. Therefore, not all the used cases were evaluated. Feedback from the logistic company suggested the inclusion of voice commands and making the DSS integrate with their existing system. Therefore, the development of a new decision support system is currently underway which will include feedback from the logistic companies and avoid the technical difficulties faced during the development of the DSS. Valuable lessons were learned during the development of the DSS regarding management of timelines and requirement specifications which are carefully considered in the development of the new DSS.

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