

Quality of Service Aware Order Allocation for Inter-Regional Online Food Delivery Systems

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Abstract—The allocation of orders in an online food delivery system that maximizes Quality of Service (QoS) to customers by assuring long distance delivery is a challenging problem because of the different order completion properties and service expectations. Existing works in the literature are constrained by focusing either on reducing order completion time or minimizing costs associated with order delivery within a predetermined region. In this paper, we have developed a framework for optimal order allocation of inter-regional food delivery orders as an optimization function which minimizes service time to escalate QoS of the system with required constraints. The results of performance studies depict that the proposed system achieves competitive service time as well as enhances the number of orders of the system.

Index Terms—Crowdsourcing, Online Food Delivery, Order Allocation, Service Time Minimization, Inter-Region Delivery.

I. INTRODUCTION

The development of smart devices with embedded sensors has resulted in a significant increase in the number of mobile users and the introduction of new applications. The applications that facilitate crowdsourcing are rapidly turning into an important component of our everyday life [1]. The hectic pace of modern life has led a significant number of people to favor the option of having their food delivered to either their house or their place of work. As a result, in recent years, food delivery through the use of spatial crowdsourcing has arisen at a rapid pace [2] [3]. The rising popularity of online food delivery services in Bangladesh offers up new doors of convenience for customers; yet, for this system to be a sustainable technology, it requires extensive research to address the complex challenges [4].

The fundamental aspects of the food delivery service include the customers placing their orders via web portals or mobile applications connected to an online platform. After that, the platform will assign available workers to pick up the order from the restaurants, and then bring it to the customer's preferred location of delivery within the predicted time required for delivery. The workers are registered with platform to receive delivery order and to complete it by a short period of time on payment. A food delivery system consists of customers, platform, restaurants, and the crowdsourced workers or riders as depicted in Fig.1. Customers of OFD systems are generally given choices for food from nearby restaurants that fall within the delivery platform's limited range. Workers typically deliver orders within the specified regions due to the knowledge on the routes to ensure service

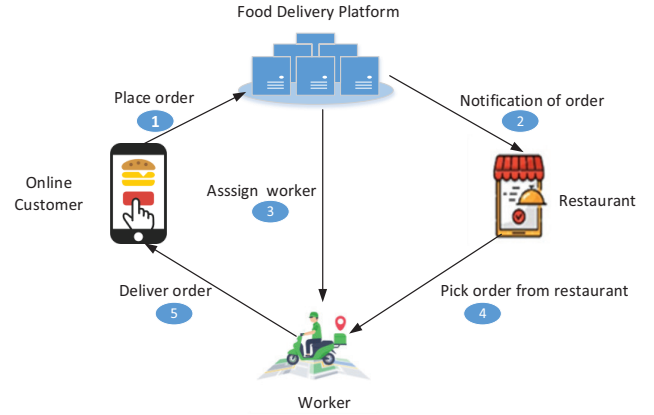


Fig. 1: A crowdsourced food delivery system

efficiency. As the competitive market of the Online Food Delivery (OFD) sector intensifies, the platforms have developed numerous new approaches to address the various requirements of customers and improve delivery efficiency. It is a great concept to provide customers more choices for placing their orders with expanding delivery service area beyond specific region. In reality, some times customers may prefer to place orders from restaurants located outside of their local region, which requires the restaurant's own delivery service rather than OFD to transport the food. Therefore, it is important for OFD platforms to do research on providing customers the inter-regional food delivery facility to enhance the Quality of Experience of end users of the system.

The main challenge for OFD system is to fulfill the customers' contemporary demands while working with limited resources. Thus, it is essential to have a proper order allocation mechanism in order to enhance the delivery efficiency. In [5], a real-world historical data were used to build a set of instances of a meal delivery routing problem that decreases costs in terms of time and maximizes worker utilization. Despite this, the system failed to prioritize customer preferences in the order assignment process, which are essential to the long-term success of the OFD. On the basis of the Water Wave Optimization metaheuristic algorithm, the authors in [6] develop a framework for order assignment called WWOFood that simultaneously maximizes profit, lowers the service time of the worker, and enhances customers' satisfaction. However, their approach did not consider inter-regional food delivery. Li et al. in [7] addressed a meal delivery problem based on transfer stations to solve the delivery problem for inter-regional

orders but did not consider different vehicle capacities, and the operational expense of establishing a transfer station facility. This research explores a transfer vehicle-based order allocation strategy for inter-regional online food delivery systems, with the goal of ensuring to satisfy the customers' demand. Moreover, a larger delivery region provides customers with more options, which can lead to an increase in the number of orders, enhancing the profitability for both the platform and the restaurants.

The above discussion demands for offering high-quality services to OFD customers through an efficient and effective technique. In this paper, we explore a transfer vehicle-based order allocation strategy to address the inter-regional online food delivery problem in order to enhance the Quality of Service provided to customers. In this problem, a customer's requirement is fulfilled by providing food delivery within the predefined time limit and by having more options to order food from restaurants in larger regions. The main contributions of this paper are summarized as follows:

- We develop an order allocation strategy based on transfer vehicle for the inter-regional long distance delivery (QUSOL-FD) which can broaden the scope of online food delivery and satisfy the different requirements of customers.
- We formulate an optimization framework that assigns an inter-regional order to a transfer vehicle that enhances number of orders by expanding the delivery region and minimizes the service time.
- We evaluate the performance of the proposed QUSOL-FD and results show improvements over other state-of-the-art works in terms of average increased number of orders and average service time.

The remainder of this paper is organized as follows. In Section II, some state-of-the-art works related to our problem are presented. The system model and assumptions are presented in Section III followed by the formulation of the proposed order allocation framework in Section IV. After that, Section V presents experimental results and comparative analysis. Finally, the paper is concluded in Section VI.

II. RELATED WORK

The problem of efficient allocation of OFD delivery orders has got significant research interests. In [8], the authors proposed a mechanism for grouping orders based on the arrival time and assigning workers to these groups in order to expedite delivery. However, they did not consider locations of order pickup and delivery. Analyzing behavior of workers, a data-driven framework has been developed in [9], which also did not incorporate pickup location of the orders.

The authors of [10] investigated the meal-delivery routing problem (MDRP), outlined in [5], and developed a novel strategy to minimize the delivery time. A dial-a-delivery-rider approach for handling highly unpredictable customer demand is designed in [11] with the goal of reducing riders' service time, but customer satisfaction remains unaddressed. FoodNet [12] assigned conventional taxi drivers to deliver food products

at lower cost. However, food delivery was restricted to taxi routes and was cost prohibitive for long-distance delivery. With sequential order collecting and rider assignment, Wei Tu et.al. [13] developed a mathematical model of the crowdsourced delivery problem to reduce the overall travel costs and delivery delay. Nonetheless, as orders and riders enter the system in a dynamic manner, the sequential approach may result in suboptimal assignment and a large delivery delay.

However, all the aforementioned works only considered a specified delivery region for serving food delivery. To improve the scalability of delivery systems various research focuses on the Pickup and Delivery Problem (PDP) with transshipments. The authors in [14] proposed the PDP taking into account the potential of transshipments between drivers for crowdsourced logistics in last-mile delivery and develop a heuristic solution strategy to solve the problem. Wolfinger in [15] approached the Pickup and Delivery Problem-Time Window (PDPTW) with split loads and transshipments by developing an arc-based mixed integer model that is solved using the large neighbourhood search (LNS) algorithm. Previous studies on the MDRP did not take into account setting up a transfer point for long distance food delivery and instead focuses on optimizing the routes of the workers in traditional delivery mode. Li et al. in [7] addressed a meal delivery problem with order allocation strategy based on transfer stations to solve the cross-regional delivery problem for long-distance orders. As they did not consider a dedicated rider or vehicle for cross-regional delivery, their system suffers from delivery gaps among different couriers.

The key philosophy of this work is to provide customers the flexibility of expanding the delivery area in order to increase the number of orders and food diversity for customers. Therefore, the allocation of order should be carried out in such a way that the service time of the delivery should be minimized to enhance the Quality of Service of the system. What follows next is the design detail of the proposed framework.

III. SYSTEM MODEL AND ASSUMPTIONS

We consider an inter-regional online food delivery system with different components such as customer, platform, restaurant, transfer vehicle and worker. The platform serves as the central coordinator for the system, while the remaining components are linked to the platform through a registration procedure. Customers able to order ready foods through mobile apps or web portal of a platform to their preferred restaurants and select the type of delivery.

Customers are allowed to choose from various delivery options when placing food orders. A customer can place food order from a local restaurant which is considered as intra-region order or place order from a distant restaurant beyond his/her region which is considered as inter-region order. Let, J denote the set of orders received from the customers. Each order $j \in J$ is a five parameter tuple, $\langle l_j^p, l_j^d, S_{max} \rangle$, where, l_j^p is the pickup location, l_j^d is the delivery location and S_{max} is maximum delay tolerance of order j . We assume an order $j \in J$ is placed by a customer with a chosen delivery type based

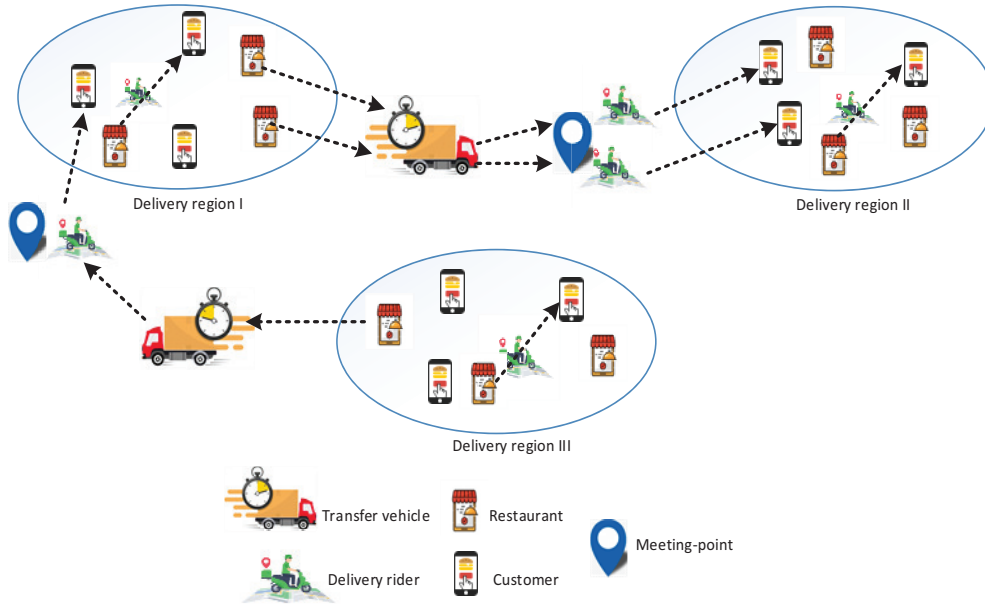


Fig. 2: Inter-regional Online Food Delivery Systems Architecture

on region to a restaurant in a particular area at t_o through platform. The platform estimates an expected delivery time t_j time based on t_o . However, t_j varies based on the traffic condition/ time of a day and volume of order j .

In case of inter-region delivery, dedicated vehicles are used for transferring orders to the workers of delivery regions at a mutual meeting-point for delivering the orders to the respective customers. We assume a transfer vehicle is always available in the pool; if not, customers whose orders are associated with this vehicle should be notified. This transfer vehicle based inter-region and intra-region strategy is illustrated in Fig. 2. For intra-region orders the platform assigns an available worker k to deliver that particular order j to a customer. Each transfer vehicle $v \in V$ is attributed by a four parameter tuple $\langle R_v, l_v, q_v, \omega_v \rangle$, where R_v indicates the region to which this particular vehicle is dedicated to transfer the orders, l_v is the current location, q_v is the maximum carrying capacity, ω_v is the current workload of the vehicle. Transfer vehicles or workers are not restricted to any particular provider or customer. Platform, restaurants and workers get their appropriate portion of revenue when an order is completed successfully.

After reception of an order j , the platform sends the request to the restaurant to accept or cancel the order. Based on their food processing capacity and/or availability of ordered item, the restaurant accepts or cancel the order, consequently the platform sent a confirmation/ cancellation notification to customer.

For inter-region orders, the platform generates an initial set of orders based on the region of delivery. Then, after being allocated by platform, the transfer vehicle collects orders from restaurants and delivers them to the corresponding workers at the meeting-point within the time t_j for delivering the orders to the respective customers' locations. The time-weighted

TABLE I: List of Notations

Symbol	Meaning
J	The set of orders placed by all customers
l_j^p	Location of the pick up point for j -th order
l_j^m	Location of the meeting-point for j -th order
$t_{j,k}$	Estimated time to deliver j -th order
V	The set of workers available in the system
l_v	Location of the transfer vehicle at the starting time
q_k	Maximum capacity of the v -th worker
$s_{j,v}$	Time required by a transfer vehicle to travel from the service point to location of meeting-point
M	The set of meeting points
S_{max}	Maximum delay tolerance of an order

Manhattan distance is calculated to estimate the position (x, y) of meeting-point of transfer vehicles and workers while taking into consideration the characteristics of the complicated urban road network traffic state as in [7]. In the proposed system, it is envisioned that, based on the distance between surrounding intra-regions, there will be several meeting points to ensure faster delivery.

In this work we emphasis on the allocation of inter-region orders, thus we consider the spatial information of only inter-region orders and transfer vehicles. We provide the main notation used throughout the paper in Table 1.

IV. OPTIMAL ORDER ALLOCATION FRAMEWORK

Service time of delivering an order is a critical point because it has significant impact on the performance of the system. To address this issue, we calculated the service time of a transfer vehicle to deliver an order from one region to another. This section details the calculation of service time that is required by a transfer vehicle for picking up all the inter-regional orders from the restaurants and dropping those at the meeting-point to the workers for delivering at the customers' location. After that, we design an objective function to minimize the total

service time for a particular order considering maximum delay tolerance of customer and carrying capacity of vehicle.

A. Estimating an Individual Order Pick Up Time

The service time of a transfer vehicle $v \in V$ to pick an individual inter-region order $j \in J$ from a restaurant is calculated as follows,

$$\tilde{s}_{j,v} = [\max(\tilde{t}_{j,v}^p, \tilde{t}_{j,v}^w)] \quad (1)$$

where, $\tilde{t}_{j,v}^p$ is the travelling time that is required to travel from the location of a transfer vehicle l_v to the pick up point location of an order l_j^p and $\tilde{t}_{j,v}^w$ is the time that is required to prepare an online food order. The platform forecasts the duration of $\tilde{t}_{j,v}^p$ using Google Maps API (Application Programming Interface) which depends heavily on the distance covered by the road network. The system can also estimate the order processing time of a certain order, $\tilde{t}_{j,k}^w$ from the past historical data. Note that, the food preparation time may advance simultaneously with the traveling time to reach at the pick-up location. Hence, we consider the time that is the longer of the two requisite times.

Consider that if multiple orders at the same restaurant are assigned to a single transfer vehicle, the pick up time calculation for the current order takes into account only the food processing time of the current order. In the case that multiple orders from different restaurants are assigned to a transfer vehicle, for each subsequent order, the pick up time estimation considers the travelling time from the transfer vehicle's current to the pick up location of the orders and order processing time.

B. Estimating Total Pick Up Period for a Transfer Vehicle

A transfer vehicle picks up the orders from the restaurants of a particular region and delivers those to the workers of designated delivery region. Now, consider S_p is the set of orders that have been sorted to determine the sequence of the orders to be picked up and J_v is the set of orders of transfer vehicle $v \in V$. At first, the estimated pick up time, $\tilde{s}_{j,v}$ of each order in J_v is calculated, then they are sorted according to ascending order of the values of $\tilde{s}_{j,v}$. A set of orders, S_p is generated to pick up the orders from the respective restaurants accordingly.

Following the sequence determined in S_p , the designated transfer vehicle collects the orders from the restaurants for delivering to the workers at meeting-point. Thus, the total pick up time of a transfer vehicle $S_{j,v}^v$ for inter-regional orders is calculated as follows,

$$S_{p_j}^v \leftarrow \arg \max_{j \in S_p} (\tilde{s}_{j,v}) \quad (2)$$

The estimated total pick up period for a transfer vehicle should be the maximum pick up time of an order in the set S_p .

C. Calculation of Total Service Time of Transfer Vehicle

In this system, a transfer vehicle v is allowed to carry multiple orders at a time considering its carrying capacity, pick up point and meeting-point locations associated to the orders. After the arrival of the transfer vehicle at the meeting-point, the orders will be transferred to the workers so that they can deliver those to customer locations. As there are multiple adjacent meeting-point locations, the system must determine the feasible meeting-point where the transfer vehicle will drop off the orders to the workers. Let, M denotes the set of adjacent meeting-points for inter-region orders. The selection of a location of meeting point for a specific regional set of orders should be based on the shortest distance between the locations of meeting-point and current locations of transfer vehicle. Thus, a meeting-point, m_r , for dropping off the inter-regional orders of a particular delivery region is selected as follows,

$$m_r^j \leftarrow \arg \min_{\forall m \in M} (d_{l_{m_r}, l_v}), \quad (3)$$

where, $d_{l_{m_r}, l_v}$ is the distance between the locations of meeting points l_{m_r} and current location of transfer vehicle l_v . The traveling time that is required by a transfer vehicle to travel the aforementioned distance for delivering an order j to the meeting-point is defined as $S_{m_j}^v$. Thus, the total service time of a transfer vehicle to arrive at meeting point of an inter-regional order is calculated as follows,

$$S_{(p_j, m_j)}^v = S_{p_j}^v + S_{m_j}^v. \quad (4)$$

After collecting the orders from the transfer vehicle, assigned workers of intra-region deliver them to the customers' location. This approach will have the effect of decreasing the delivery time of inter-regional food delivery systems by transferring orders from one region to another in the shortest possible time.

D. Optimal Allocation of Orders

This system aims to assign a transfer vehicle a set of inter-regional orders in a way that reduces the total service time for transferring those from one region to other, accelerating the delivery time of an order. Thus, we formulate optimal allocation of order problem as follows,

Minimize:

$$Z = \sum_{j \in J} \sum_{v \in V} S_{(p_j, m_j)}^v \cdot \alpha_{j,v} \quad (5)$$

Subject to:

$$S_{(p_j, m_j)}^v \leq S_{max}, \quad \forall j \in J, v \in V \quad (6)$$

$$\sum_{j \in J, \forall v \in V} \omega_{j,v} < q_v, \quad \forall v \in V \quad (7)$$

$$\sum_{j \in J} \alpha_{j,v} = 1, \quad \forall v \in V, \forall j \in J \quad (8)$$

where, $\alpha_{j,v}$ is a binary variable when an order j is assigned to a transfer vehicle v , and its value is determined as follows,

$$\alpha_{j,v} = \begin{cases} 1, & \text{if order } j \text{ is assigned to transfer vehicle } v \\ 0, & \text{otherwise.} \end{cases} \quad (9)$$

The constraint (6) is the order deadline constraint that ensures that the estimated service time of a vehicle v to arrive at meeting-point for an inter-region order j must not exceed the maximum delay tolerance time, S_{max} . The constraint (7) is vehicle capacity constraint that guarantees the total assigned orders to a vehicle v must not exceed the carrying capacity of the transfer vehicle, q_v . The constraint (8) confirms that order allocation will be unique to a vehicle. It implicates that a single order will be allocated to a single transfer vehicle.

V. PERFORMANCE EVALUATION

In this section, the performances of the proposed QUSOL-FD is evaluated and compared with one of state-of-the-art works, MIP-MDRP [7]. The simulation and experimental evaluations are carried out in Python on a real world data set [5]. The data set contains real world historic experiences of food delivery services and are used in recent works on online food delivery system design including [6].

A. Simulation Setup

We consider an area of $15000 \times 15000 \text{ m}^2$ where the location of restaurants, orders and workers are randomly distributed. The orders, vehicles and restaurants information are extracted from each instance of the dataset. The number of restaurants are kept in 50 and the number of orders, vehicles are varied in $100 \sim 500$, and $5 \sim 30$, respectively. Then, 20% of the total orders are selected based on the fact that the distance between the restaurant node and the customer node is between $3 \sim 10 \text{ km}$. The minimum distance threshold of inter-regional strategy is 5 km. The threshold of 10 km is approximated from the highest value between nearby regions, which is chosen to ensure that customers and restaurants for inter-regional long-distance orders are located in two adjacent regions, rather than crossing numerous regions. We limit transfer vehicle's carrying

load capacity to 20 orders. A summary of the values and ranges of different simulation parameters is provided in Table II. All simulation experiments were conducted on a PC with an Intel Core i7 Processor and 16 GB memory running Ubuntu 20.04.

B. Performance Metrics

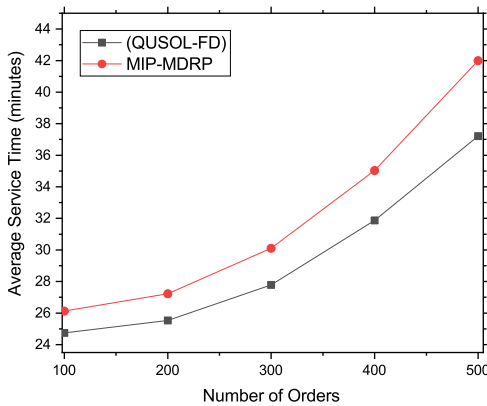
We consider the following metrics to compare the performance of the studied systems.

- *Average service time*: is average interval between the reception of an order and its delivery to the meeting-point by transfer vehicles. The lower value represents better performances.
- *Service delivery improvement*: is the percentage of number of orders that are increased due to the inter-regional orders that are placed on the platform. The higher value indicates the better performances.

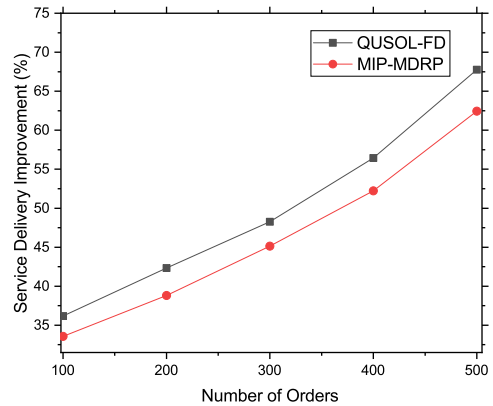
C. Simulation Results

In this section, we present the results of our performance evaluation for varying number of orders and transfer vehicles.

1) *Impact of varying number of orders*: Figure 3 depicts the impact of varying number of orders while keeping the number of vehicles and restaurants fixed at 10 and 50, respectively. As illustrated in Fig. 3(a), the average service time for the analyzed mechanisms increases as the number of orders for the vehicles increases. In contrast to MIP-MDRP, the proposed QUSOL-FD system requires less average service time. The correlation between the two factors can be explained by the fact that the number of orders placed in close proximity to one another increases as the average order volume per restaurant increases. This allows the QUSOL-FD system to allocate many orders that are co-located with a transfer vehicle to reduce travel time to the pickup points. In Fig. 3(b), the percentage of inter-region orders increases with increasing number of total orders as the extended delivery region provide customers additional options for ordering food. However, the QUSOL-FD system achieves more percentage of increased orders as the distribution of order and multiple meeting-points

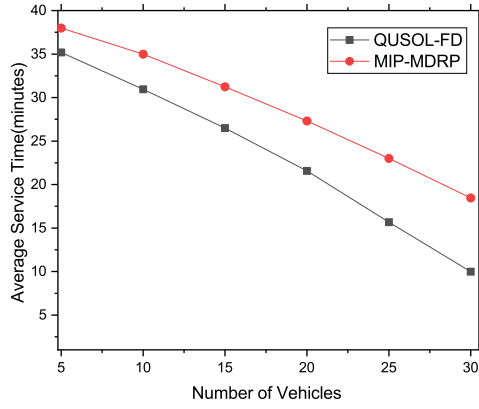


(a) Average Service Time

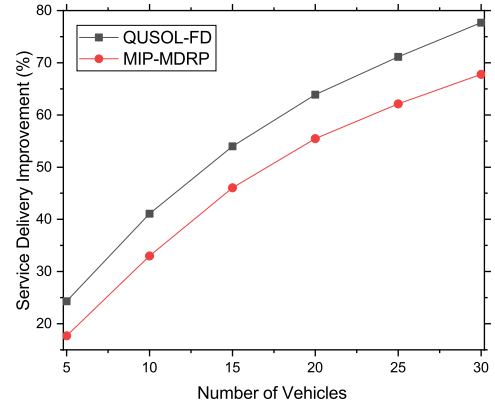


(b) Percentage of Service Delivery Improvement

Fig. 3: Impact of varying number of orders



(a) Average Service Time



(b) Percentage of Service Delivery Improvement

Fig. 4: Impact of varying number of transfer vehicles

TABLE II: Simulation Parameters

Parameter	Description
Simulation area	15000 × 15000 m^2
Number of orders	100 ~ 500
Number of vehicles	5 ~ 30
Max. carrying capacity of transfer vehicle (q_v)	20
Delivery deadline, ($t_{j,k}$)	≤ 30 min
Maximum estimated delivery time, (T_{max})	60 min

are considered while allocating inter-regional orders to the transfer vehicle.

2) *Impact of varying number of transfer vehicle*: In general, increasing the number of transfer vehicles makes it easier for the food delivery system to provide service. Figure 4 demonstrates the system's performance for varied numbers of transfer vehicles, while the number of orders and restaurants remaining constant at 500 and 50, respectively. Fig. 4(a) illustrates that the average service time for the analyzed systems decreases as the number of transfer vehicles increases. However, QUSOL-FD experiences lower service time compared to the MIP-MDRP as QUSOL-FD assigns multiple orders to a transfer vehicle not only based on its carrying capacity but also considering the location of pickup points of the orders which minimizes the service time. In Fig. 4(b), the proposed QUSOL-FD obtains a higher proportion of increased inter-regional orders as the number of transfer vehicles increases, because with designated transfer vehicles and multiple meeting sites, it can serve a larger area with more customers.

VI. CONCLUSION

In this work, we developed an order allocation strategy based on transfer vehicle for the inter-regional online food delivery (QUSOL-FD) that enhances the Quality of Service of the system by increasing number of order while minimizing the service time and expanding the delivery region. Taking into account a transfer vehicle's service time and capacity to deliver an order from one region to another, our order allocation strategy achieves the shortest service time and the highest number of orders. The evaluation results of performance of the proposed QUSOL-FD indicated the improvements over other state-of-the-art works in terms of average service time and

percentage of service delivery improvement. The assignment of workers for intra-regional delivery of orders, taking into consideration all aspects of inter-regional delivery, could be an interesting problem to solve in the future.

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