

REVIEW AND GAP ANALYSIS ON MATHEMATICAL PROGRAMMING MODELS FOR URBAN E-GROCERY DELIVERY

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ABSTRACT

Online grocery shopping or e-grocery has becoming more relevant nowadays when consumers' shopping habit changed due to pandemic COVID-19 while e-Commerce rapidly transformed consumers' lifestyle and buying behaviour in recent years, Consumers' expectation for faster, better and cheaper delivery put e-grocers under rising pressure to improve delivery speed, achieving environmentally friendly delivery methods and addressing issues of making profit. There have been studies worldwide on development of more efficient e-grocery delivery system. However, studies concerning e-grocery delivery in Malaysia are still lacking especially on those utilizing mathematical programming models for delivery optimization. Our study focuses on the formulation of mixed integer goal programming (MIGP) models for vehicle routing problem with time windows for homogeneous and heterogeneous fleet of vehicles. This paper presents a structured review of past studies and gap analysis on some selected mathematical programming models. The review and gap analysis provide vital information on main characteristics for models of our study. Results presented would be useful for studies that concern with finding optimal solutions, innovative approaches and the most practical techniques for urban e-grocery deliveries. These strategies could lead to time and costs savings and enhance the effectiveness and efficiency of delivery operations that benefits both e-grocers and consumers.

Keywords: E-Grocery Delivery, Mathematical Programming Model, Optimization, Last Mile Logistics, Vehicle Routing Problems with Time Windows.

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1. Introduction

Internet connectivity has widened the range of digital activities and responsible for paving ways for e-commerce and changing consumers behaviour towards online shopping. E-commerce has a tremendous impact on e-grocery, one of the fastest-growing categories of e-commerce. E-grocery or online grocery is the term used for digital purchase of food and household items through websites or mobile apps where customers received the items through home delivery or pickup. E-grocery offers customers the experience of convenient grocery shopping and more efficient and cost-effective replacement for traditional grocery. Globally, the online grocery market size has grown exponentially in recent years, increasing from \$542.72 billion in 2024 to \$659.7 billion in 2025, complemented by ultrafast delivery services, growing sustainability



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efforts, improved last-mile logistics and enhanced payment solutions (The Business Research Company, 2025). The pandemic COVID-19 also has fueled the massive boom in delivery services for groceries by causing a major shift on consumers' shopping habits from shopping at stores to e-grocery shopping with the convenience of home delivery. Increase in demand for e-grocery services come with customers' preferences of fast deliveries or within certain preferred time windows, low delivery charges and same-day delivery for their orders. These expectations put e-grocers under increasing pressure to improve delivery speed, achieving environmentally friendly delivery methods and addressing issue of making profit. To feed enormous growing demands and time and efficiency factors that customers preferred, many online grocers concentrate their efforts that include rethinking distribution network models, designing more efficient routes for vehicles, and more sustainable operations.

Studies on the development of more efficient e-grocery delivery system have been carried out worldwide. In Malaysia, however, such studies are still lacking especially on those that involve mathematical programming models for delivery routes optimization. Our study focuses on the formulation of mixed integer goal programming (MIGP) model for vehicle routing problem with time windows for both homogeneous fleet of vehicles. This paper aims at presenting a review of related past studies and gap analysis on key components of mathematical programming (MP) models proposed by some selected studies. Results presented in this paper describes some vital information on main characteristics to be considered in the MIGP model proposed by our study. These results would also be useful for any studies for urban e-grocery deliveries, especially those concerning the Vehicle Routing Problem with Time Windows (VRPTW). The remainder of this paper is organized as follows. Section 2 presents some related literatures that highlight issues and challenges in e-grocery deliveries. Section 3 presents the methodology concerning the gap analysis on the on main characteristics of the MP models of selected past studies. The results and discussion, are presented in Section 4, which highlights the research gaps and the proposed model of our study. Finally, Section 5 concludes the paper.

2. Literature Review

Online grocery businesses were first introduced in 1990s. It encountered a downturn from 2001 to 2006 due to low profitability caused by high costs logistics operations and poor customers' trust and acceptance (Seitz, 2013). Owing to enhanced ICT and internet availability, the online grocery industry made a comeback from 2007 onwards where it changed customers' behaviour to liking this shopping trend and attracted them with improved delivery infrastructure (Melis et al., 2016). Online grocery shopping in Malaysia was pioneered by PasarBorong.com, SubangGrocer.com, CGdeMart.com, and Citrasspicemart.com (Md. Zaini et al., 2011). Nowadays, more e-grocers and online grocery delivery services are available in cities which include Tesco Online (now Lotus's Groceries), Mydin, Jaya Grocer, HappyFresh, GrabMart, BigBox Asia, Lalamove, and BungkusIt. Increasing popularity of e-grocery shopping with home delivery or pick-up services, for example, in the United States, is indicated by soaring percentage of grocery stores involved, from 30% in 2017 to over 52% in 2019 (Conway, 2020).

Pandemic COVID-19 further accelerates the online grocery industry, rising from just 3 to 4 percent penetration before the pandemic to 9 to 12 percent, a threefold increase, within a year of pandemic (Aull et al., 2021). In short span of time, e-grocery market garnered consumers and sales that would have taken much longer to achieve. Consumers' perception that e-grocery shopping is easy, convenient, and assuring while offering a wide range of high-quality products indicate that this online shopping trend will continue and e-grocery remains preferred post pandemic (Seo, 2024). Nevertheless, besides dealing with competency pressure, e-grocers have to ensure sustainability and profitability. E-grocers' challenges include order fulfilment, e-grocery last mile delivery solutions and delivery costs, which are operational in nature (Mkansi et al, 2018),

On the other hand, customers expect reasonable delivery fees and delivery time, as well as efficient purchase method and return policies. As customers demand for faster and more efficient delivery options, e-grocery retailers have to work for optimizing home delivery operations, predominantly through the Vehicle Routing Problem (VRP) approaches (Tudisco et al., 2025). The VRP focuses on optimizing routes for distributing goods from depots to destinations, minimizing logistics costs, including per-route transportation costs (Azadiamin &

Masel, 2021). In particular, VRP with time windows (VRPTW) addresses e-grocery home deliveries with customers' time windows constraints (Pahwa & Jaller, 2022) able 1 summarizes some issues and challenges of e-grocery services, which include order fulfilment (Weber-Snyman & Badenhorst-Weiss, 2017; Vazquez-Noguerol et al., 2020; Mkansi, et al., 2021) and delivery time windows, charges and costs (Grashuis et al., 2020; Mkansi, et al., 2021; Van Droogenbroeck & Van Hove, 2021). Offering flexible delivery time windows boosts customers' satisfaction on e-grocery services provided. According to Mkansi et al. (2018, 2021), sustaining competitive delivery windows versus demands and costs are great challenges for e-grocers. Based on Table 1, factors like customers' locations and delivery time windows influence the distance, time and costs for delivery while fluctuating or sudden surge of demands, limited number of vehicles and drivers, the needs for optimal delivery strategies with low impact to environment, traffic congestions and difficult delivery areas post logistical issues to e-grocers. In addition, customers' expectation and competition among e-grocers add more pressure on most e-grocers. Prioritizing fast delivery would result in better customers satisfaction but at higher costs. E-grocers' issues also include products handling to maintain quality of items delivered, cold distribution for perishable grocery items, forward logistical challenges, and reverse logistics challenges to cater for product returns and return policies.

Table 1: Issues and Challenges concerning E-Grocery Services

Authors	Main Focus	E-Grocery Issues & Challenges
Weber-Snyman and Badenhorst-Weiss (2017)	Investigating the challenges in last mile logistics of e-grocery retailers.	• Delivering perfect fulfilment of online orders • Cold distribution chain requirements (item perishability dictates types of vehicles and delivery time) • Forward logistical challenges • Reverse logistics in online grocery retailing (product returns)
Günday et al. (2020)	Pandemic COVID-19 challenges for retailers and customers' satisfaction of German e-grocery	• Delivery of groceries (delivery dates and areas) • Products (availability of products in stock, freshness)
Grashuis et al. (2020)	Study on e-grocery preferences under various scenarios of the pandemic COVID-19	• Delivery time windows and charges • Minimum order requirements • Purchasing methods (in-store pick-up, out-store pick-up or home delivery)
Vazquez-Noguerol et al. (2020)	Minimizing picking- delivery costs and the use of logistics resources by consolidating workloads to avoid idle times and reduce the amount resources required.	• e-fulfilment processes • e-grocery delivery costs • Dealing with perishable products with delivery conditions • Daily allocation of online orders to the different stores and delivery vehicles • Business profitability
Mkansi, et al. (2021)	Investigating whether operating an e-grocery channel by leveraging existing network of stores results in superior business position and sustainability.	• Order fulfilment • Logistics last mile delivery solution • Products handling requirements • Same day, faster, on-time delivery • Transportation costs • Delivery windows / time slots • Proper delivery vehicles
Van Droogenbroeck and Van Hove (2021)	Testing theory for determining the e-grocery's sustainability.	• Determining optimal delivery and optimal routes • Delivery cost, options, and time window • Return policies and operating on scales

Urban last mile delivery for e-grocery delivery services shall take advantage of the

latest technology and digitalization to come up with innovative and systematic approaches to optimize resources and costs and ensuring sustainability of the industry and the cities. Innovative approaches, including high-tech deliveries (using autonomous delivery robots, autonomous delivery vehicles (ADVs), drones, and electric vehicles), can lead to costs-savings and profit in operations and reduce environmental impacts (traffic congestions, carbon emissions and pollutions), to ultimately contribute towards sustainability. Meanwhile, e-grocery delivery designs employed involving delivery vehicles used (lorries, vans, motorcycles, drones, electric vehicles, autonomous robots), delivery methods (professional courier, crowdshipping, collaborative last mile delivery), and types of services (click and collect at pickup points or home delivery) could result in different impacts on operations and sustainability.

Mathematical optimization models, also known as Mathematical Programming (MP) models, enable different objectives of costs minimization and environmental impact reduction in delivery routing and scheduling optimization problem to fulfil last-mile deliveries, including the e-groceries delivery problems (Tudisco et al., 2025; Shuaibu et al., 2025). In general, MP models can be divided into two broad categories, the Linear Programming (LP) and Nonlinear Programming (NLP) models, in which the VRPTW is often formulated as a Mixed Integer Linear Programming (MILP) model. MP model is characterized by three main components, which are the decision variables, objective function(s) and constraints, which include the constraints concerning the decision variables values. When multiple objective functions are involved, the MP model can be solved using the Goal Programming (GP) technique. As example, the formulation of a Mixed Integer Goal Programming (MIGP) model for the VRPTW can be found in Shuib and Ibrahim (2021).

3. Methodology

Our study analyzes various e-grocery logistics approaches to develop a more efficient method for e-grocery delivery, which considers green transportation, optimal routes for delivering e-grocery orders, and costs savings and profit for e-grocers, while generating practical solutions that result in low delivery fees for customers. In this paper, we present results on gap analysis on characteristics of mathematical programming models concerning e-grocery delivery in urban areas from previous studies which focused on the logistics and delivery operations. The results provide insights on type of optimization model, sets and parameters, decision variables, objective functions, and constraints to be included in the mathematical programming models for vehicle routing problem with time windows for homogeneous and heterogeneous fleet of vehicles for e-grocery delivery proposed by our study. The gap analysis also highlights research gaps that justify methods of our study.

Gap analysis for e-grocery is carried out based on the following selected past studies:

[1] Emeç et al. (2016); [2] Carrabs et al. (2017); [3] Pan et al. (2017); [4] Kodippili and Samarasekera (2019); [5] Madankumar and Rajendran (2019); [6] Martins et al. (2019); [7] Liu et al. (2020); [8] Kuhn et al. (2021). Emeç et al. (2016) proposed a distribution network for e-grocery delivery routing problem (EDRP) where top-quality goods are acquired from external vendors at various locations in the supply network and delivered to customers in a single visit. The proposed binary integer programming (BIP) model is to minimize total distance in the presence of precedence constraints, time windows and capacity constraints and solved using an Adaptive Large Neighbourhood Search (ALNS) algorithm. Carrabs et al. (2017) proposed a mixed integer linear programming (MILP) model, sometimes referred to as mixed integer programming (MIP), for solving the grocery delivery problem in urban areas. The aim is to reduce total distribution costs, enhance operational aspects and environmental concerns, and meet consumer needs. The model was solved using an exact method and computational results show that it minimizes total carbon emission and able to choose suitable vehicles for each time shift which minimizes store's cost.

Pan et al. (2017) introduced an enhanced approach to optimize e-grocery home delivery using customer-related data which estimate a customer's absence probability in order to increase distribution success rates and optimize transportation. The formulated MILP model

for this study was solved using the GNU Linear Programming Kit (GLPK) a very versatile MILP solver ran on GUSEK GUI on a ThinkPad T440. The result of the study shows that the proposed approach can decrease total travel distance by 3 to 20 percent and giving effect of first-round delivery success rates by 18 to 26 percent. Kodippili and Samarasekera (2019) solved a vehicle routing problem with time windows (VRPTW) of fresh produce delivery which minimizes the travelled distance while adhering to some delivery constraints. The initial solution for the BIP model formulated is generated through Dijkstra's algorithm and the optimized solutions were found based on vehicle capacity and soft-time windows

Results, compared to the current manual assignments, indicate that the total travel distance, number of fleets used and overall costs have been reduced. The study by Madankumar and Rajendran (2019) concerned with vehicle routing problem with simultaneous delivery and pickup with time windows (VRPSDPTW).by heterogeneous vehicles. The objective of the study is to minimize total costs which consists of traveling cost and dispatching cost for operating vehicles. The author proposed an MILP model to solve the e-grocery delivery problem. The model was solved using Simulated Annealing (SA) algorithm, in which it minimizes the total costs and also performs better in terms of execution time for each of the randomly generated problem instances as compared to the model by Wang and Chen (2012).

Martins et al. (2019) solved the multi-compartment vehicle routing problems (MCVRPs) that concerns with multi-period setting with a product-oriented time window assignment problem of groceries distribution which allows retailers to transport products together with different temperature requirements. The problem was formulated as MIP model and solved using ALNS algorithm of Emeç et al. (2016) and benchmark instances for the consistent vehicle routing problem (ConVRP) along with generated instances based on a grocery distribution problem. Results indicate a higher variety of possible delivery times for the stores. Liu et al., (2020) carried out a study that applied two-echelon VRP with mixed vehicles (2E-VRP-MV) by formulating a nonlinear programming model with a nonlinear objective function that minimizes total transport costs and minimizes total carbon emission. The first echelon is the delivery route from depot to satellite (intermediate depots) locations by conventional vans and the second echelon is delivery route from satellites to customers by ADVs. The model was solved using a hybrid Genetic Algorithm and Particle Swarm Optimization (GA-PSO) in which results indicate that when customers' density is low and the depot is located inside the customers' area, the minimum transport costs and minimum carbon emission are achieved. Finally, Kuhn et al. (2021) conducted a study on integrated order batching and vehicle routing operations in grocery retail involving a General ALNS (GALNS) algorithm. The authors implement order batching, order picking and delivery operations. The formulated MILP model minimizes the total tardiness of all stores' orders and GALNS was used to solve the model. Results showed that GALNS approach outperforms the ALNS algorithm for the problem instances used.

4. Results and Discussion

Based on eight (8) selected studies, characteristics of these studies are identified and summarized which include analysis on type of mathematical programming (MP) model, objectives functions, sets and parameters, main constraints and solution methods used. Table 2 shows the analysis on mathematical programming models formulated for e-grocery delivery problems in past studies. From this analysis, five out of eight studies formulated MILP models for the e-grocery delivery problem, while Emeç et al. (2016) and Kodippili and Samarasekera (2019) used BIP model whereas Liu et al. (2020) proposed an NLP model to solve the problem. Our study proposes a mixed integer goal programming (MIGP) model for VRPTW of e-grocery delivery which minimizes total routing costs, minimizes total delivery time, minimizes total Carbon Dioxide (CO₂) emission and minimizes total number of vehicles used, solved using preemptive goal programming (GP) method. MIGP refers to MILP with multiple objective functions and is often solved using certain GP approach. For example, Shuib and Ibrahim (2021) proposed a MIGP model for VRPTW to find optimal routes of blood collecting vehicles that adhere collection time windows at blood donation sites. The model minimizes total distance, minimizes total travel time, minimizes total waiting time of vehicles and minimizes number of vehicles (routes) and solved using preemptive GP technique.

Table 2: Analysis of MP model used for e-grocery delivery

	Type of MP Model	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	Our Study
1	Binary Integer Programming (BIP)	√			√					
2	Mixed Integer LP (MILP)		√	√		√	√		√	
3	Nonlinear Programming (NLP)							√		
4	Mixed Integer Goal Programming (MIGP)									√

Note: [1] Emeç et al. (2016); [2] Carrabs et al. (2017); [3] Pan et al. (2017); [4] Kodippili and Samarasekera (2019); [5] Madankumar and Rajendran (2019); [6] Martins et al. (2019); [7] Liu et al. (2020); [8] Kuhn et al. (2020).

Table 3: Analysis of MP model's objective function(s)

	Objective Function	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	Our Study
1.	Minimize the total distribution cost that is associated with total distance traveled	√		√	√					√
2.	Minimizes total routing costs (loading, travelling and unloading costs, penalty)					√	√			√
3.	Minimize total tardiness of all store orders.								√	
4.	Minimize the total travel costs		√					√		
5.	Minimizes total delivery time									√
6.	Minimize the total carbon dioxide emission		√					√		√

Note: [1] Emeç et al. (2016); [2] Carrabs et al. (2017); [3] Pan et al. (2017); [4] Kodippili and Samarasekera (2019); [5] Madankumar and Rajendran (2019); [6] Martins et al. (2019); [7] Liu et al. (2020); [8] Kuhn et al. (2020).

Objective function of an MP model represents a real-valued function whose value is to be either minimized or maximized subject to the model's constraints. Table 3 displays the analysis on objective function(s) of MP models of the selected studies. Many studies concern with minimizing the total distribution costs determined by the total distance travelled (Emeç et al., 2016); Carrabs et al., 2017); Kodippili and Samarasekera, 2019) and total delivery costs covering loading, travelling and unloading costs, plus the penalty cost (Madankumar & Rajendran, 2019); Martins et al., 2019). The objective functions of MP model of Carrabs et al. (2017) and Liu et al. (2020) concerns with minimizing total travel costs and minimizing total carbon dioxide emission. MP model by Kuhn et al. (2021) minimizes the total tardiness of all store orders. Our study embarks on formulation of MP models with multiple objective functions, as indicated in Table 3.

Table 4 presents the list of sets involved in the MP models for e-grocery delivery problem in past studies. These sets are associated with decision variables, objective function(s) and constraints of the models. The most common sets are set of nodes, arcs, vehicles and delivery time windows. Some studies also consider set of days (weekdays or weekends), set of compartments in the vehicle (dry, chill, frozen, etc.) or set of order pickers and the sequences. Parameters of the MP models in e-grocery delivery problem are displayed Table 5. Main parameters number of nodes, number of vehicles, capacity of vehicles, loading and unloading costs, delivery time windows, and the volume of online grocery orders to be delivered. Our study which focuses on VRPTW with homogeneous fleets of vehicles for e-grocery delivery problem formulated as MIGP model also considers different vehicles' capacities and class of weight of vehicles.

Table 4: Analysis of sets in MP model

	Sets	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	Our Study
1.	Set of nodes (customers, outlets/stores)	√	√	√	√	√	√	√	√	√
2.	Set of arcs	√	√	√	√	√	√	√	√	√
3.	Set of regular customers	√								
4.	Set of premium customers	√								
5.	Set of premium products	√								
6.	Set of vehicles	√	√	√	√	√	√	√	√	√
7.	Set of external vendors	√								
8.	Set of compartments in a vehicle						√			
9.	Set of segments						√			
10.	Set of days						√			
11.	Set of delivery time windows	√	√	√	√	√	√	√	√	√
12.	Set of order pickers					√			√	
13.	Set of positions in sequence of picking batches of an order picker					√			√	
14.	Set of satellites							√		
15.	Set of Scenarios			√						

Note: [1] Emeç et al. (2016); [2] Carrabs et al. (2017); [3] Pan et al. (2017); [4] Kodippili and Samarasekera (2019); [5] Madankumar and Rajendran (2019); [6] Martins et al. (2019); [7] Liu et al. (2020); [8] Kuhn et al. (2020).

Table 5: Analysis of parameters of the MP model

	Parameters	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	Our Study
1.	Number of nodes	√	√	√	√	√	√	√	√	√
2.	Number of vehicles	√	√	√	√	√	√	√	√	√
3.	Number of satellites							√		
4.	Capacity (load) of vehicles	√	√	√	√	√	√	√	√	√
5.	Capacity of satellites							√		
6.	Loading cost		√	√	√	√	√		√	√
7.	Unloading cost			√	√		√		√	√
8.	Service time for store order delivery	√	√	√	√	√	√	√	√	√
9.	Delivery slots (time windows)	√	√	√	√	√	√	√	√	√
10.	Volume of grocery orders to be delivered	√	√	√	√	√	√	√	√	√
11.	Number of batches that include store order					√			√	
12.	Class of weight of the vehicles		√			√				√
13.	Types of emissions		√							√

Note: [1] Emeç et al. (2016); [2] Carrabs et al. (2017); [3] Pan et al. (2017); [4] Kodippili and Samarasekera (2019); [5] Madankumar and Rajendran (2019); [6] Martins et al. (2019); [7] Liu et al. (2020); [8] Kuhn et al. (2020).

Table 6: Analysis of the main constraints of the MP model

	Constraints	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	Our Study
1.	Vehicle starts its route at the depot/ distribution centre	√	√	√	√	√	√	√	√	√
2.	Each customer is visited once	√	√	√	√	√	√	√	√	√
3.	Each route terminates at the depot	√	√	√	√	√	√	√	√	√
4.	Each customer/store is served within a specified time window	√	√	√	√	√	√			√
5.	Vehicles capacities are not violated	√	√	√	√	√	√	√	√	√
6.	Store deliveries performed by vehicles owned by e-grocers				√	√	√			√
7.	The departures from the distribution central/ depot at time zero	√	√	√	√	√	√	√	√	√
8.	The tours do not exceed the maximum duration established.	√	√	√	√	√	√	√	√	√
9.	Penalty cost incurred if delivery made is not within the time window specified.						√			√
10.	Demand volume requested	√	√	√	√	√	√	√	√	√
11.	Each store order has to be assigned to exactly one vehicle				√	√	√	√	√	
12.	The arrival time at a store location	√	√	√	√	√	√	√	√	√
13.	The non-negative tardiness					√			√	
14.	A feasible batch can be assigned at most once and each order is processed in exactly one batch					√			√	
15.	Vehicle is allowed to travel corresponding to its class of weight		√			√				√
16.	Limit on number of vehicles	√	√	√	√	√	√	√	√	√
17.	Limit of satellite capacity							√		

Note: [1] Emeç et al. (2016); [2] Carrabs et al. (2017); [3] Pan et al. (2017); [4] Kodippili and Samarasekera (2019); [5] Madankumar and Rajendran (2019); [6] Martins et al. (2019); [7] Liu et al. (2020); [8] Kuhn et al. (2020).

Another key component of an MP model is the constraints. Constraints used in the models of the selected past studies are summarized in Table 6. These constraints are mostly concerned with the number of vehicles available, vehicle's capacity limit, volume of demand, establishment of routes (begin at depot, serve customers and return to depot), each customer is visited once, and vehicle's departure from the depot at time zero and delivery tours do not exceed the maximum duration allowed. Other constraints include customers are served within certain time windows, penalty costs incurred if delivery made is not within time window specified, delivery made by e-grocers' vehicles, and for cases where heterogeneous fleets of vehicles are used, a vehicle is allowed to travel corresponding to its class of weight (load capacity and load assignments). Heterogeneous fleet of vehicles are considered in the studies by Carrabs et al. (2017), Madankumar and Rajendran (2019).

Table 7: Analysis on solution method used to solve the MP model

	Constraints	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	Our Study
1	Dijkstra's algorithm				√					
2	Exact method (unspecified)		√							
3	Adaptive Large Neighborhood Search (ALNS) metaheuristic	√					√			
4	General Adaptive Large Neighborhood Search (GALNS) metaheuristic								√	
5	Cluster-based hybrid Genetic Algorithm (GA)							√		
6	Particle Swarm Optimization (PSO)							√		
7	Simulated Annealing (SA) metaheuristic					√				
8	GNU Linear Programming Kit (GLPK)			√						
9	MATLAB <i>intlinprog</i> (MILP solver)									√

Note: [1] Emeç et al. (2016); [2] Carrabs et al. (2017); [3] Pan et al. (2017); [4] Kodippili and Samarasekera (2019); [5] Madankumar and Rajendran (2019); [6] Martins et al. (2019); [7] Liu et al. (2020); [8] Kuhn et al. (2020).

Table 7 shows the solution methods employed in solving the MP models proposed by each study, which include exact methods (Carrabs et al., 2017; Kodippili & Samarasekera, 2019) or metaheuristics (Emeç et al., 2016; Martins et al., 2019; Madankumar and Rajendran, 2019; Martins et al., 2019; Liu et al., 2020; Kuhn et al., 2020). Exact solution methods guarantee optimal solution whereas metaheuristic is an approximate algorithm which sometimes produce global optimum but more often produces near-optimal solutions for large problem within a reasonable computing time. Pan et al. (2017) used the GNU Linear Programming Kit (GLPK) package for solving large-scale problem based on mathematical programming models such as linear programming (LP) and mixed integer programming (MIP) models. GLPK supports the GNU MathProg modelling language, which is a subset of the AMPL language. Besides the exact methods and metaheuristics, heuristics algorithms have also been applied to solve the e-grocery delivery problems. For example, Truden et al. (2022) solved the MILP model for attended home delivery (AHD) problem of grocery home-delivery services using simple insertion heuristic, ANS heuristic, and TSP with structured time windows (TSPsTW) insertion heuristics. Our study employs MATLAB optimization solver (*intlinprog*) which involves exact methods, including Branch and Bound (B&B) method and LP Relaxation, and heuristics such as cut generation to determine optimal solutions for the proposed MIGP model.

4.1 Research Gaps

The gap analysis enables our study to determine the research gaps. Among the research gaps are as the following.

- Many of the past studies formulated the e-grocery delivery problems using MILP models. Our study basically formulates a MILP model, however with multiple objective functions.
- Most of the MP models, with the exception of Carrabs et al. (2017) and Liu et al. (2020), formulated the problem as MP model for VRPTW with single objective function. Studies involving multi-objective MILP model, as in our study, are still lacking.
- The most common sets involved in MP models for e-grocery delivery problem are set of nodes, arcs, vehicles and delivery time windows, thus these will be included in our model.
- The main parameters in the MP models of e-grocery delivery problem which are number of nodes, number of vehicles, capacity of vehicles, loading and

- unloading costs, delivery time windows, and volume of orders to be delivered will be applied in our proposed model.
- v. Selected past studies share common necessary constraints in their models such as restrictions on the number of vehicles, vehicle's capacity, and other VRPTW constraints. These constraints are also included in our proposed model.
- vi. Most of the selected past studies involved developing algorithms, either using heuristics or metaheuristics. However, our proposed MIGP model is solved using an optimization solver, particularly the MATLAB MILP solver, *intlinprog*.

Based on the gap analysis, the main characteristics of the proposed model for our study, that concerns with routing and scheduling optimization for e-groceries deliveries using the VRPTW approach, have been identified. Our study focuses on MP model for VRPTW with homogeneous fleets of vehicles for e-grocery delivery problem formulated with multiple objective functions solved using the GP technique, thus, known as the MIGP model. Most past studies assumed homogeneous vehicles for e-grocery deliveries. Utilizing heterogeneous vehicles could reduce CO₂ emission significantly but on the expense of increased total distance and number of vehicles used. Thus, our study utilizes homogeneous fleet of vehicles. Studies on the VRPTW application using MIGP model for e-grocery delivery problems is relatively new, and potentially capable of producing a more effective approach with optimum and practical solutions for the e-grocery delivery problems. Our study aims to propose optimal strategies based on optimum solution found using the proposed model for e-grocery delivery problem in Malaysia. The MIGP model will address multiple objective functions which are to minimize the Total Distance (TD), to minimize the Total Traveling Time (TT), to minimize the Total Delivery Costs (TDC), to minimize the total delivery time, and to minimize the Total CO₂ Emission (TCE). Our study solves the MIGP model using preemptive GP method in which prioritizing multiple objectives by ranking them in order of importance, and focusing on satisfying the highest-priority goal first before moving on to the next lower-priority goal, will be applied.

4.2 Proposed MP Model of the Study

Our study proposes a homogeneous VRPTW-based Mixed Integer Goal Programming (HMVRPTW-MIGP) model for sustainable e-grocery deliveries with time-zone approach. The model formulation is as follows:

HMVRPTW-MIGP Model for e-Grocery Deliveries

Notations

Set:

N	:	set of nodes, $N = \{0, 1, 2, \dots, n, n + 1\}$. Depot is labelled 0 or $n + 1$
K	:	set of vehicles, $K = \{1, 2, \dots, m\}$
C	:	set of customers (set of nodes excluding depot), $C = \{1, \dots, n\}$
A	:	set of arcs $A = \{1, \dots, n_A\}$

Parameters:

n	:	total number of customers (nodes).
m	:	total number of available vehicles
n_A	:	number of arcs in the road network ($n_A = 210$)

Indices and Input Variables:

i	:	indices for nodes where $i = 0, 1, 2, \dots, n$
j	:	indices for nodes where $j = 1, 2, \dots, n, n + 1$
k	:	index for the vehicle, $k = 1, 2, \dots, n_v$
d_{ij}	:	travel distance (in km) from i to j
t_{ij}	:	direct traveling time from i to j
f_i	:	service time (5 minutes per customer), and no service at depot
e_{ij}	:	Carbon Dioxide (CO ₂) emission from a vehicle (kg/km) from i to j ,

where,

$$e_{ij} = d_{ij} \left[\left(\frac{e_{fl} - e_{el}}{Q} \right) q_i + e_{el} \right]$$

e_{fl}	:	CO ₂ emission of fully loaded (by weight) HDV truck, $e_{fl} = 1.096$ kg/km.
e_{el}	:	CO ₂ emission of empty vehicle which is $e_{el} = 0.772$ kg/km for HDV truck
c_{ij}	:	traveling cost per km from i to j ; $c_{ij} = (p)(d_{ij})$ and $p = \text{RM}0.50/\text{km}$ (constant)
Q	:	maximum capacity in kilogram (kg) of groceries for a vehicle ($Q = 800$ kg)
q_i	:	demand (in kg) of customer i where $i \in C$
T	:	maximum tour duration or the scheduling horizon, $T = 180$ mins
a_i	:	the earliest the service must begin at i
b_i	:	the latest time for the service to finish at i
$[a_i, b_i]$	:	time window for service for customer i
L_0	:	fixed loading cost at depot (node 0) for each customer, $L_0 = \text{RM}2$
U_i	:	fixed unloading cost at customer i , $i = 1, 2, \dots, n$, $U_i = \text{RM}2$

Decision Variables:

x_{ijk}	=	$\begin{cases} 1, & \text{if vehicle } k \text{ travel from } i \text{ to } j \\ 0, & \text{otherwise} \end{cases}$
t_i	=	arrival time at customer i where $i = 0, 1, 2, \dots, n$ and $t_0 = 0$
w_i	=	waiting time at i , $i = \{0, 1, 2, \dots, n, n+1\}$ and $w_0 = 0$ (no waiting time at depot)

Objective Functions:

$$\text{Minimize } TD = \sum_{i=0}^n \sum_{j=1}^{n+1} \sum_{k=1}^m d_{ij} x_{ijk} \quad i \neq j \quad (4.1)$$

$$\text{Minimize } TT = \sum_{i=0}^n \sum_{j=1}^{n+1} \sum_{k=1}^m (t_{ij} + w_j + f_j) x_{ijk} \quad i \neq j \quad (4.2)$$

$$\text{Minimize } TDC = \sum_{i=0}^n \sum_{j=1}^{n+1} \sum_{k=1}^{n_V} [L_0 + U_i + c_{ij}] x_{ijk} \quad i \neq j \quad (4.3)$$

$$\text{Minimize } TCE = \sum_{i=0}^n \sum_{j=1}^{n+1} \sum_{k=1}^m e_{ij} x_{ijk} \quad i \neq j \quad (4.4)$$

subject to (constraints):

$$\sum_{j=1}^n x_{0jk} = 1 \quad k = 1, 2, \dots, m \quad (4.5)$$

$$\sum_{i=1}^n x_{i,n+1,k} = 1 \quad k = 1, 2, \dots, m \quad (4.6)$$

$$\sum_{j=1}^{n+1} \sum_{k=1}^m x_{ijk} = 1 \quad i = 1, 2, \dots, n, i \neq j \quad (4.7)$$

$$\sum_{i=0}^n \sum_{k=1}^m x_{ijk} = 1 \quad j = 1, 2, \dots, n, i \neq j \quad (4.8)$$

$$\sum_{i=0}^n x_{ihk} - \sum_{j=1}^{n+1} x_{hjk} = 0 \quad \begin{matrix} h = 1, \dots, n; i \neq h, \\ h \neq j, k = \\ 1, 2, \dots, m \end{matrix} \quad (4.9)$$

$$\sum_{i=1}^n \sum_{j=1}^{n+1} q_i x_{ijk} \leq Q \quad i \neq j, k = 1, 2, \dots, m \quad (4.10)$$

$$a_i \leq t_i \leq b_i \quad i = 1, 2, \dots, n \quad (4.11)$$

$$a_i \leq t_i + w_i + f_i \leq b_i \quad i = 1, 2, \dots, n \quad (4.12)$$

$$t_i + (w_i + f_i)x_{ijk} - M(1 - x_{ijk}) \leq t_j \quad \begin{matrix} i, j = 1, 2, \dots, n; i \\ \neq j; \\ k = 1, \dots, m \end{matrix} \quad (4.13)$$

$$\sum_{i=0}^n \sum_{j=1}^{n+1} (f_i + t_{ij})x_{ijk} \leq T \quad k = 1, 2, \dots, m \quad (4.14)$$

$$x_{ijk} = \{0,1\}; t_i, w_i \geq 0 \quad \begin{matrix} i, j = 1, 2, \dots, n; i \\ \neq j; \\ k = 1, \dots, m \end{matrix} \quad (4.15)$$

Model Description:

The first objective function (Goal 1) of the model, Equation (4.1), aims at minimizing the Total Distance (TD) travelled by all vehicles. Equation (4.2) presents the second objective function (Goal 2) which is to minimize the Total Travel Time (TTT). The third objective function (Goal 3) represented in Equation (4.3) is to minimize the total delivery cost (TDC). Meanwhile, the last objective function (Goal 4) stated as Equation (4.4) is to minimize the total CO₂ emission for all vehicles. In this model, Equation (4.5) and Equation (4.6) represent the constraints that guarantee each vehicle starts from the depot, travels for deliveries to customers and returns to the depot. Constraint given in Equation (4.7) restricts for each vehicle k , only one arch (edge) emanates from each node i . On the other hand, Eq. (8) is the constraint that ensures for each vehicle k , only one arc enters j . Equation (4.7) and Equation (4.8) are necessary constraints to ensure each vehicle k visits each node exactly once. Constraint given by Equation (4.9) controls each of the vehicles such that it leaves the depot, arrives at a customer, serves this customer, and leaves this customer, and proceeds similarly until finally going back to depot. Equation (4.10) is the constraint to ensure that a vehicle does not exceed its capacity (Q). Constraint, denoted as Equation (4.11), guarantees time window for each customer is adhered to. Meanwhile, constraint in Equation (4.12) indicates that service at any customer i must be within the given time window for this customer, i.e., $a_i \leq t_i + w_i + f_i \leq b_i$. Equation (4.13) presents the constraint that ensures time taken from arrival time plus waiting time and service time at Customer i is less than or equal to the arrival time at the next customer (Customer j). Constraint given by Equation (13) ensures that total travel time for a vehicle does not exceed the maximum route time (scheduling horizon) for deliveries to all customers for all vehicles. Eq. (14) specifies binary integer values for x_{ijk} and non-negativity constraints for t_i and w_i .

5. Conclusion

E-grocery business had gradual growth due to slow customers' acceptance and higher costs and challenges in logistics operations. The steady growth of e-grocery in the last decade was largely due to widened internet coverage and expanding e-commerce with massive applications of digital technologies across logistics last-mile deliveries (Kellermayr-Scheucher et al., 2022). Changing consumer habits towards online shopping and COVID-19 pandemic were responsible for fast-growing demands of e-groceries home delivery services, even after the pandemic. Increasing e-grocery orders with delivery services caused a growing number of delivery vehicles on the roads resulting in traffic congestion, high carbon emissions and harmful environmental impacts which affect the long-term sustainability of cities. This paper presents some issues and challenges faced by e-grocers in ensuring fast and economical deliveries. Since transportation always accounts for the significance portion of costs incurred, determining optimal routes which minimize transportation costs and environmental effects of e-grocery delivery services must be sought. Optimization models serve as necessary tools in finding solutions to routing and scheduling optimization problem for costs minimization (minimum total distance. minimum delivery time, minimum total delivery charges, etc.) and minimizing environmental impact of delivery operations. Results presented through the gap analysis in this

paper offer valuable insights on main characteristics for the model proposed by our study and useful for other studies that concern with finding optimal solutions and the most practical strategies for urban e-grocery deliveries involving VRPTW.

In this paper, the gap analysis on the key components of the MP models of some selected past studies concerning e-grocery delivery has been presented. This includes the analysis on type of MP model used for e-grocery delivery, analysis on MP model's objective function(s), analysis on sets in MP model, analysis on parameters of the MP model, analysis on main constraints of the MP model, and the analysis on solution method used to solve the MP model. The review and gap analysis on MP models cover critical aspects of online grocery delivery problems and provide some insights on the e-grocery delivery routing optimization that can be addressed by our study, which could also be useful for other related studies. The proposed MIGP models for VRPTW of e-grocery delivery problem with four objective functions has also been presented. The model aims at finding optimal solution that leads to more efficient e-grocery deliveries. More effective e-grocery delivery services, in general, may lead to operational costs' reductions, higher operational efficiency, and improved customers' satisfaction through prompt deliveries within chosen time windows and lessening the harmful environmental effects through reduced empty miles and more economical fuel consumption. In the context of Malaysia, future research can focus on VRPTW using electric vehicles (EV) and autonomous delivery robots in e-grocery services which could lead to potential benefits such as reduced costs, faster and more convenient deliveries, lower carbon emissions, and improved customers' satisfaction.

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Author Contribution

Both authors have contributed in gathering articles and references for the review and writing the paper. Adibah is responsible in deciding the theme and structure of this paper. She has also written the Introduction and Methodology sections. Nur Hazimah has been responsible in organizing items to be included in tables in which she has written the Literature Review section of this paper. Both authors have prepared the Results and Discussion section and References together. Adibah has written the Conclusion.

Conflict of Interest

The authors have no conflicts of interest to declare.

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