OPTIMIZATION APPROACH FOR MULTI-PERIOD FUEL REPLENISHMENT

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แนวทางที่เหมาะสมที่สุดสำหรับการเติมเชื้อเพลิงแบบหลายช่วงเวลา

นายณรงค์กร จารุศักดิ์วงศ์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
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ณรงค์กร จารุศักดิ์วงศ์ : แนวทางที่เหมาะสมที่สุดสำหรับการเติมเชื้อเพลิงแบบหลายช่วงเวลา (OPTIMIZATION APPROACH FOR MULTI-PERIOD FUEL REPLENISHMENT) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ. ดร.มาโนช โลหเตปานนท์, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: ผศ. ดร.ธารทัศน์ โมกขมรรคกุล, หน้า.

ในงานศึกษานี้ผู้วิจัยได้นำเสนอแบบจำลองคณิตศาสตร์ และแนวทางที่เหมาะสมที่สุดสำหรับการเติมเชื้อเพลิงแบบหลายช่วงเวลา โดยแบบจำลองมีวัตถุประสงค์เพื่อค้นหาเส้นทางการจัดส่งน้ำมันเชื้อเพลิงในช่วงเวลาที่กำหนด คำนวณปริมาณน้ำมันเชื้อเพลิงที่เติมลงในแต่ละช่องเติมรถ (vehicle compartment) ของรถขนส่งน้ำมันเชื้อเพลิง และรวมไปถึงการกำหนดการจ่ายน้ำมันเชื้อเพลิงลงในถังกับเก็บน้ำมันของสถานีบริการน้ำมัน และลูกค้าอุตสาหกรรม เพื่อให้ได้ต้นทุนการขนส่งต่อหน่วยที่ต่ำที่สุด ทั้งนี้แผนการเติมเชื้อเพลิงที่ได้จากแบบจำลองนั้นจะต้องไม่ฝ่าฝืนข้อจำกัดต่างๆ ที่ได้กำหนดไว้ อย่างไรก็ดี เนื่องจากขนาดของแบบจำลองนั้นมีอัตราการเพิ่มแบบชี้กำลังเมื่อมีจำนวนสถานีบริการน้ำมัน ลูกค้าอุตสาหกรรม รถขนส่งน้ำมันเชื้อเพลิง และช่วงเวลาที่เพิ่มขึ้น ดังนั้นการแก้ไขปัญหาแบบจำลองด้วยวิธีแม่นตรง (Exact algorithm) จึงไม่สามารถที่จะทำได้ ฉะนั้นการศึกษานี้ผู้วิจัยจึงได้นำเสนอวิธีฮิวริสติก (Heuristic approach) สองวิธีคือ two-phase method (2PM) และ Three-phase method (3PM) โดยวิธี 2PM นั้นได้ถูกคิดค้นมาเพื่อจัดการกับแบบจำลองที่มีขนาดเล็ก ในส่วนของวิธี 3PM นั้นมีลักษณะวิธีการที่คล้ายคลึงกับวิธี 2PM แต่สามารถจัดการกับแบบจำลองที่มีขนาดใหญ่กว่า ผู้วิจัยได้ทำการทดสอบวิธี 2PM และ 3PM ด้วยสถานการณ์จริง และสถานการณ์จำลอง ตามลำดับ ผลการศึกษาพบว่าทั้งสองวิธีที่ได้นำเสนอนั้นสามารถจัดการกับปัญหาได้อย่างมีประสิทธิภาพ และได้ผลลัพธ์ที่ดีกว่านักวางแผนซึ่งมีประสบการณ์ในการวางแผนการเติมเชื้อเพลิงมากว่าสิบปี นอกจากนี้ผลการวิจัยยังชี้ให้เห็นว่าการวางแผนการเติมเชื้อเพลิงโดยพิจารณาในหลายช่วงเวลานั้นได้ผลลัพธ์ที่ดีกว่าการวางแผนการเติมเชื้อเพลงโดยพิจารณาเพียงช่วงเวลาเดียว

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ปีการศึกษา 2558	ลายมือชื่อ อ.ที่ปรึกษาหลัก ....
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KEYWORDS: MULTI-PERIOD FUEL REPLENISHMENT PLANNING PROBLEM / PETROLEUM PRODUCTS / TRANSPORTATION UNIT COST / EXACT ALGORITHM / HEURISTIC APPROACH

NARONGKORN CHARUSAKWONG: OPTIMIZATION APPROACH FOR MULTI-PERIOD FUEL REPLENISHMENT. ADVISOR: ASST. PROF. MANOJ LOHATEPANONT, Sc.D., CO-ADVISOR: ASST. PROF. TARTAT MOKKHAMAKKUL, Ph.D., pp.

This study proposes mathematical models and solution approaches for solving the multi-period fuel replenishment planning problem. The model aims to search for a set of routes, determining the quantity of several petroleum products to be loaded on individual vehicle compartments, and specifying the quantity to be discharged to customer tanks over a given planning horizon in which multiple constraints are satisfied. The objective function is to minimize the transportation unit cost, equal to the total transportation cost divided by the sum of replenished quantity. As the model size grows exponentially when the number of customers, vehicles, and time period increases, an exact algorithm is not feasible. Hence, in this study, we propose two heuristic approaches: two-phase method (2PM) and three-phase method (3PM). The 2PM is primarily designed for solving small problems whereas the 3PM adopts a similar approach but has the ability to solve larger problems. The proposed solutions were tested using a real-life scenario and randomly generated test instance. The results showed that our solution outperforms the solution constructed by experienced planners who possess more than ten years of planning experience, and also proved that considering multiple periods when devising the fuel replenishment plan, gives superior results in comparison to single periods.

Field of Study:	Logistics Management	Student's Signature	....
Academic Year:	2015	Advisor's Signature	....
		Co-Advisor's Signature	....

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CHAPTER 1

INTRODUCTION

1.1 Background

The supply chain management in the petroleum industry is remarkably complex. It consists of a high number of processes, lead times and distributions from the beginning of the supply chain to the end users. The petroleum industry typically divides its sector into two levels: upstream level and downstream level. The upstream level generally refers to the process of petroleum exploration and sourcing, but in some case, it can also refer to importing of crude oil from the Organization of Petroleum Exporting Countries (OPEC). In other words, the upstream level includes the searching for potential underground/underwater oil and gas fields, drilling of exploratory wells and brings the crude oil or natural gas to the surface. For the downstream level, it refers to the refining of crude oil, distribution of the finished products to the distribution center, and distributes finished products to the petrol stations or industrial customers. Figure 1.1 presents the high-level picture of the petroleum supply chain.

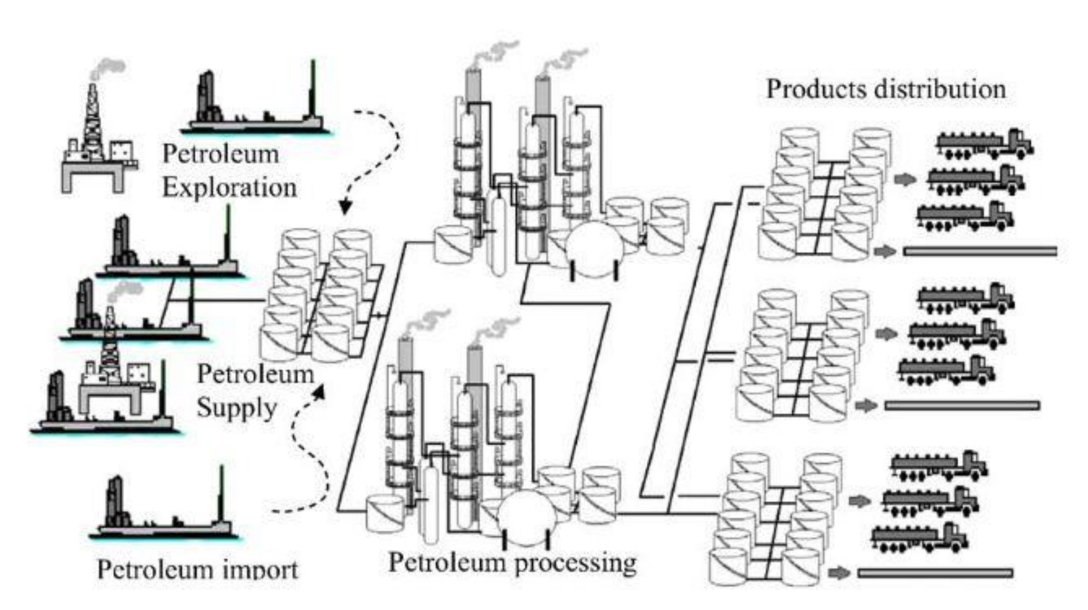

Figure 1.1 The petroleum supply chain (Neiro and Pinto, 2004)

The crude oil is typically distributed to the refinery by barge transport, and then the refinery refines into a variety of products, which can be categorized into two main types: light/white and heavy/black products. Light/white products refer to gasoline, kerosene, diesel, aviation fuel etc., where heavy/black products refer to base stock for lubricants, residual oil, fuel oil etc. These products are usually shipped in bulk from the refinery to the distribution center or so-called fuel terminal by various modes of transport: pipeline, ship, barge, rail etc. From the fuel terminal, these products are distributed to petrol stations or industrial customers by tank trucks. However, there is also a case where Heavy/Black products are shipped directly to the lube plants. Figure 1.2 shows the distribution chain of refined products.

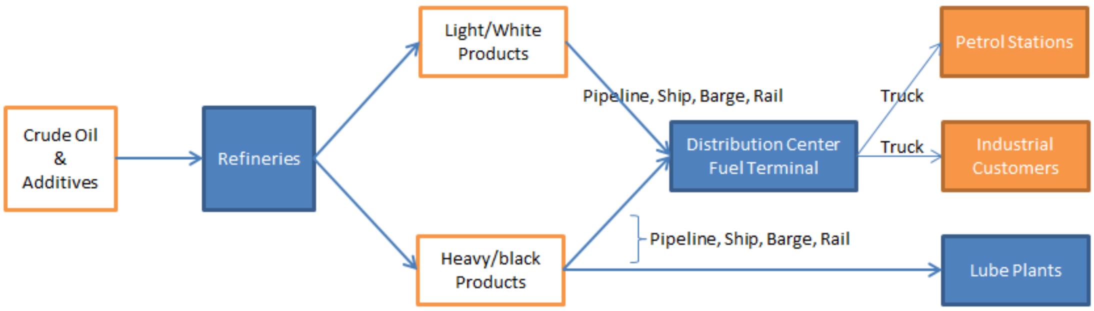

Figure 1.2 Distribution chain of refined products

The distribution of the finished products from a refinery to fuel terminal is primarily transported through a pipeline which is the most efficient mode regarding liquid/gas product distribution, but apparently requires a very high cost for investment. In contrast, the fuel replenishment from a fuel terminal to the petrol stations/industrial customers usually uses tank trucks as the main transport mode due to a huge number of customer sites, where they are located in different locations throughout the fuel delivery network.

Fuel replenishment planning from the depot, often called fuel terminal, to customers, in this case, petrol stations and industrial customers, is exceptionally complicated. The petrol station's inventory level and fuel replenishment plan are generally controlled by the supplier through the vender management inventory (VMI). In other words, the supplier decides the quantity of petroleum products to be delivered and time of delivery. Industrial customers manage the inventory level themselves and place orders to the supplier before the order cutoff time, specifying the quantity and delivery time window. Then, the supplier decides which vehicle to deliver the product and when the product should be delivered based on the vehicle availability, given that products must arrive at the customer location according to the requested delivery time window.

To describe further the fuel replenishment plan, one has to determine the set of routes, approximate delivery time (trip), vehicles to be used for delivering petroleum products for those routes, quantity of the product to be loaded on each vehicle compartment and specify how and when to discharge to each customer's storage tank following the safety guidelines and country regulations. Moreover, the planners need to ensure that the replenishment plan satisfies the following constraints:

- The inventory level of all petrol stations' storage tanks must be maintained above the minimum requirement (safety stock level) at any given planning horizon.

- Each vehicle cannot be operated over its allowable operating hours, and must not exceed the allowable number of trips.

- Every vehicle compartment must be loaded with at least 85% of its compartment size, otherwise be emptied.

- Each vehicle cannot be loaded over its regulated weight limit.

In addition to the above constraints, there are many other factors that further complicate fuel replenishment planning, including:

- **Multiple product grades:** There are many product specifications available in the market, but the common products are super unleaded, unleaded and diesel. The specific gravity of these products varies, reflecting the difference in weight per liter. Also, each vehicle compartment can only carry one product at a time and product contamination of the storage tank is strictly prohibited.

- **Heterogeneous fleet characteristic:** Several vehicle types are used, differing in terms of size, vehicle compartment configuration, number of compartments, compartment size and existence of other specialist equipment such as pump, evaporator etc. Planners have to match the vehicles to the customers' characteristics and requirements. Besides, vehicle compartments are not equipped with a flow meter therefore the product must be entirely emptied once the unloading has started.

- **Limited number of vehicles/drivers:** The petroleum industry usually subcontracts fuel delivery services to a private transport company, where the number of contracted vehicles/drivers is agreed and reviewed periodically.

- **Heterogeneous customer characteristics:** Customers are located in different locations, and have different vehicle size accessibility. Each customer has a different number of storage tanks, storage tank size, and set of petroleum products. Some customers require a vehicle equipped with a pump as their storage tanks are located above ground.

- **Multiple delivery time windows:** In the metropolitan area, heavy vehicles are prohibited during the daytime, especially on weekdays. Moreover, each customer has its own specified delivery time windows.

- **Limited terminal operating hours:** Some fuel terminals do not operate 24 hours, so the vehicle must load the products within the operating hours.

- **Limited route selection:** There are many cases where the vehicle visits multiple customers on the same trip. To select the route or customer combination, planners need to follow the routes that are pre-defined according to road safety guidelines.

Further complication may arise when the number of customers increase, consequently leading to a higher number of vehicles, storage tanks, routes, trips, etc.

To understand the problem clearly, we prepared an illustrative fuel replenishment diagram as shown in Figure 1.3, in which there are one fuel terminal, two vehicles with three vehicle compartments each (V1 and V2) and three customers with three storage tanks each (A, B and C). The solid arrows represent the route of each vehicle, and each dotted arrow represents the product movement from terminal to vehicle compartment, and to customer storage tank.

Now, let A1, A2, … represent customer A's tanks 1, 2, and so on. And B1, B2, … be customer B's tanks. Let V1.1, V1.2, … be vehicle V1's compartments 1, 2, and so on. And V2.1, V2.2, … be vehicle V2's compartments. Each storage tank contains different types of petroleum product: tank 1, 2, … contains product type 1, 2, and so on.

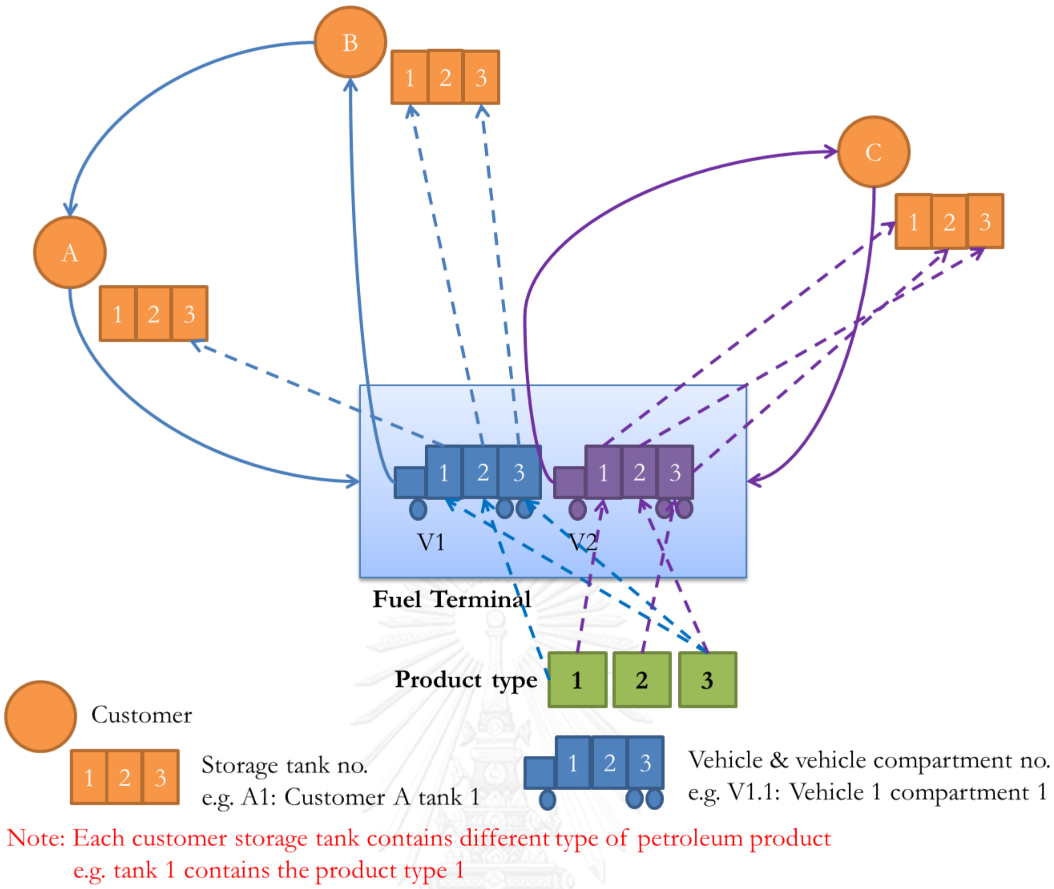

Figure 1.3 Illustrative fuel replenishment diagram

Figure 1.3 shows that vehicle V1 is loaded with product type 3, 1 and 3 into vehicle compartment 1, 2 and 3 respectively. It departs to customer B and discharges the products individually from vehicle compartments 2 and 3 into customer B tank 1 and 3. Next, vehicle V1 visits customer A and discharges the remaining compartment (V1.1) into customer A tank 3, finally returning to the fuel terminal to prepare for the next delivery. Similarly, vehicle V2 is loaded with product type 1, 3 and 2 into vehicle compartments 1, 2 and 3 respectively. It departs to customer C and discharges compartment 1, 2 and 3 into customer C tank 1, 3 and 2. Lastly, it returned to the fuel terminal to prepare for the next delivery. For simplicity, the unloading patterns are summarized as follows:

1. V1.2 -> B1 (Product type 1)
2. V1.3 -> B3 (Product type 3)
3. V1.1 -> A3 (Product type 3)
4. V2.1 -> C1 (Product type 1)
5. V2.2 -> C3 (Product type 3)
6. V2.3 -> C2 (Product type 2)

In this example, it looks simple and straight forward, yet, in order to come up with the completed fuel replenishment plan, planners need to determine the set of routes, estimated time of arrival for each route, vehicles to be used for delivering petroleum products for those routes, quantity of the product to be loaded in each vehicle compartment and specify how and when to discharge to each customers' storage tank.

In general, the replenishment plan is usually created on a day-to-day basis (e.g., if today is 1st January, the planner creates the fuel replenishment plan for 2nd January). In the example below, let today = d and tomorrow = d+1, we describe how to determine the fuel replenishment quantity required at period d+1 for a petrol station.

<u>Example</u>

Given:

Tank capacity	30,000 liters
Tank safety stock level	9,000 liters
Start inventory level at period d	15,000 liters
Estimated fuel consumption at period d	7,000 liters
Estimated fuel consumption at period d+1	8,000 liters
Planned replenishment quantity at period d	5,000 liters

Firstly, the estimated start inventory level at period d+1 is determined by subtracting the estimated fuel consumption at period d from the start inventory level at period d, and adding the planned replenishment quantity at period d.

Estimated start inventory level at period d+1 = 13,000 liters (15,000 – 7,000 + 5,000)

By understanding both the estimated start inventory level at period d+1, as well as the estimated fuel consumption at period d+1, we can simply determine a feasible fuel replenishment quantity by subtracting the inventory level from the tank capacity, taking the estimated fuel consumption into account.

Feasible fuel replenishment quantity at the beginning of period d+1 = 17,000 liters (30,000 – 13,000)

Feasible fuel replenishment quantity at the end of period d+1 = 25,000 liters (30,000 – 13,000 + 8,000)

In this example, the feasible fuel replenishment quantity ranges between 17,000 and 25,000 liters. The maximum replenishment quantity at the beginning of period d+1 is 17,000 liters and it is 25,000 liters at the end of period d+1. However, it can be anticipated that the inventory level will reach the tank safety stock before the end of period d+1. Hence, the range of feasible replenishment quantity at period d+1 is adjusted to 17,000 and 21,000 liters and the storage tank must be replenished before it reaches the tank safety stock level.

The above example depicts the estimation of the feasible fuel replenishment quantity for only one storage tank in a single period, when in reality, we generally determine it for all tanks simultaneously and, routes, vehicles and vehicle compartments are also considered at the same time. This type of problem is often called as an inventory routing problem (Cordeau et al., 2007).

As detailed above, fuel replenishment planning is considerably complicated, requiring many planners and lead time to complete the fuel replenishment plan. Another challenge is that planners need to submit a completed fuel replenishment plan to the transport company by the agreed timeline; otherwise, they will not have sufficient time for vehicles'/drivers' planning and preparation. Due to the time constraints, it is challenging for planners to devise a fuel replenishment plan that minimizes transportation costs while satisfying all the constraints and requirements.

Additionally, considering fuel replenishment in a single period does not necessarily guarantee the minimum cost in the long term. It may provide the best solution for the first day, but it could potentially give a poor solution on the following day because it is a sequential decision. The solution is to holistically consider multiple periods when planning for the fuel replenishment. Hence, in this study, we propose mathematical models and solution approach for solving the multi-period fuel replenishment planning problem. The objective is to minimize the transportation unit cost over a given planning horizon. The transportation unit cost refers to the total transportation cost divided by the sum of delivered quantity.

To explain further regarding the multi-period fuel replenishment planning, we prepared the multi-period fuel replenishment planning approach as shown in Figure 1.4.

Let today = d and tomorrow = d+1. At period d, we take into consideration the replenishment plan from period d to period d+n, but the replenishment plan as of period d+1 (tomorrow) will be used and submitted to the transport company. Similarly, on the next day (period d+1), we consider the replenishment plan from period d+1 to period d+n+1, but the replenishment plan as of period d+2 will be used and submitted to the transport company on the following day. The rationale for using a single period fuel replenishment plan is that fuel consumption at every petrol station is stochastic in nature. Therefore, the more recent inventory and sales information obtained from individual petrol stations, the more accurate the replenishment plan.

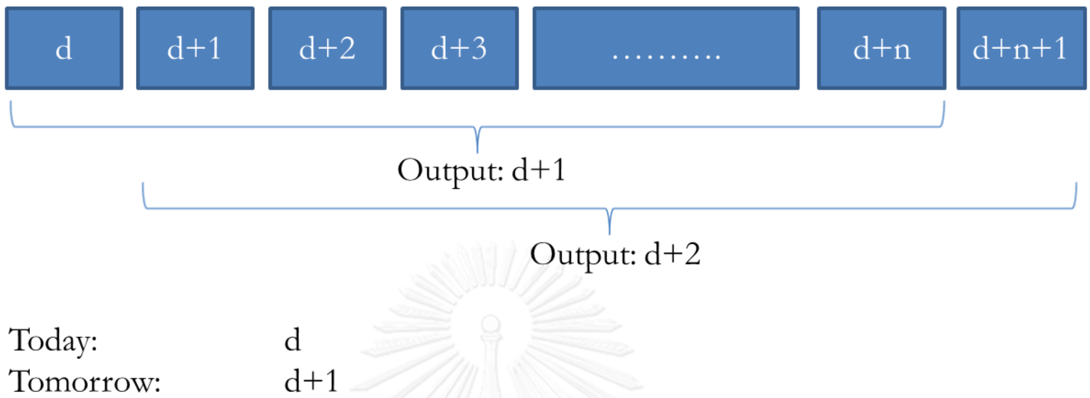

Figure 1.4 Multi-period fuel replenishment planning approach

1.2 Research Objectives

- To develop mathematical models and solution approaches for solving the multi-period fuel replenishment planning problem.

- To prove that considering multiple periods gives a better outcome in comparison to a single period.

1.3 Scope of Study

Supply chain processes and decisional levels for the downstream petroleum supply chain can be classified into three levels, strategic planning, tactical planning and operational level as shown in Table 1.1 (Gayialis and Tatsiopoulos, 2004). In this study, we focus merely on the fuel replenishment planning which is categorized under the operational level. In other words, we focus on determining a set of routes, approximate delivery time for each route, vehicles to be used for delivering petroleum products for individual routes, and quantity of the products to be loaded on each vehicle compartment.

Table 1.1 Supply chain processes and decisional levels (Gayialis and Tatsiopoulos, 2004)

	Supply chain planning	Transportation planning	Shipment planning	Vehicle routing	Warehousing
Strategic	Site location	Site location	Outsourcing	Fleet sizing	Warehouse layout
	Capacity sizing	Fleet sizing	Bid analysis	Service day balancing	Material handling design
	Sourcing	Distribution centers' allocation	Fleet sizing	Frequency analysis	Control systems
Tactical	Production planning	Transportation strategy	Consolidation strategy	Routing strategy	Storage allocation
	Sourcing	Network alignment	Mode strategy	Zone alignment	Order picking strategies
	Inventories planning				
Operational	Material requirements planning—MRP	Load consolidation	Shipment dispatching	Vehicle dispatching	Order picking
	Distribution requirements planning—DRP	Timing and volume of movements			
	Enterprise resource planning—ERP				

Additionally, in this study, we assume fuel consumption for individual petrol stations is deterministic, where fuel consumption forecasting is out of the scope of the study.

1.4 Expected Results

- To obtain mathematical models and solution approaches for solving the multi-period fuel replenishment planning problem.

- The transportation unit cost is reduced comparing to the current practice where delivery plans are created by experienced planners.

- The time used for completing the fuel replenishment planning is reduced.

- The inventory level for individual petrol stations is managed more effectively which could help preventing the product shortage.

1.5 Research Methodology

To conduct this study, we started with defining the research objectives, set the scope of the study, reviewed the past studies and, developed the mathematical models and solution approaches. Next, we prepared the computer programming. In this study, we used three software packages: Microsoft Visual Studio Version 10.0, IBM ILOG CPLEX Version 12.6 and Microsoft Access 2010. After completing the computer programming, we tested the models using real-life scenario and randomly generated test instance. Finally, we compared the results and concluded all findings.

CHAPTER 2

LITERATURE REVIEW

2.1 Vehicle Routing Problem (VRP)

Vehicle routing problem (VRP) was first developed by Dantzig and Ramser (1959), applying a combinatorial optimization and integer programming problem to serve the customers with a fleet of vehicles. VRP is essentially needed in the field of transportation and logistics. The problem is seeking for the optimal route, minimizing the operating costs while maintaining the customer service level agreement. As discovered from the internet, there are more than thousands of papers studying the VRP, but no any author stated that their models are the best solution for solving VRP (Golden et al., 1998), because of disparity and complexity in every business details. However, Kelly and Xu (1999) stated that all VRPs have similarity in the problem structure.

VRP has several variations and specializations, where the well-known problems are briefly explained as follows:

- *Vehicle routing problem with pickup and delivery* (VRPPD): The main objective is to find the optimal routes for vehicles to visit the pickup and drop-off locations, for example, the delivery service between the distribution centers and retail stores.

- Vehicle routing problem with LIFO (Last in first out): This problem is similar to VRPPD, but an additional vehicle loading constraint is involved. The most recent loaded items must be firstly unloaded.

- Vehicle routing problem with time windows (VRPTW): The goal is to find the optimal routes for vehicles to deliver goods within the time constraint. If the products arrive before the allowable time windows, the product might not be able to unload because the inventory level is still high. On the other hand, if the products arrive after the allowable time windows, it could result in the product shortage.

- Capacitated vehicle routing problem with/without time windows (CVRP or CVRPTW): This type of problem is similar to others but it has limited carrying capacity of the goods.

To solve the VRPs, there are several algorithms such as: exact algorithm, heuristic algorithm, meta-heuristic algorithm, genetic algorithm, etc. An exact algorithm is a method that seeks for the true optimal solution, which generally uses Branch-and-Bound technique to solve the problem. Despite the exact method seems to be the best solution as it seeks for the optimal answer, it requires a very high problem-solving time. Laporte (1992) stated that the exact method might not be an appropriate algorithm to solve a large scale problem. Azi et al. (2007) also conducted a study, applying an exact algorithm to solve routing problem where vehicles are allowed to perform several routes over the scheduling horizon. They found that an exact algorithm is very sensitive to the constraints. When the constraints are not tight enough, the number of feasible routes becomes too large to generate the solution.

In some cases, the problems cannot be derived in a Mathematical model due to the complexity of the problem or a large number of variables. Hence, another technique so-called "heuristic algorithm" was introduced into this area. Heuristic algorithm refers to the problem-solving technique that seeks for a near optimal solution within reasonable solving time. Each heuristic algorithm is only made for the particular problem. Thus one algorithm cannot be applied for solving another. This algorithm is usually suitable for the problems that must be timely solved, for instance: an air traffic problem, where the main objective is to minimize the total delay time during the aircraft landing (Indra-Payoong, 2005). Nagy and Salhi (2005) studied the single and multiple depots VRPPD problems, applying the heuristic algorithm and found the good quality solution generated within a few seconds.

2.2 Inventory Routing Problem (IRP)

The *inventory routing problem* (IRP) is the integration of two components in the logistics value chain: vehicle routing and inventory management. In other words, IRP is the extension of the VRP that takes the inventory management into consideration. IRP assumes application of VMI concept where suppliers have an obligation to determine an order quantity and delivery time for each customer. Although the suppliers seem to have a full control of customer's inventory level, they must ensure the inventory level for each customer is maintained at an agreed level.

IRP can be classified into two decision levels, strategic and operational levels. The strategic level generally considers the fleet sizing, insourcing and outsourcing fleet contract, whereas the operational level mainly considers the proper order quantity for stock replenishment, and also considers the vehicle dispatching (Webb and Larson, 1995).

In the IRP, vehicle route, order quantity and delivery time must be determined simultaneously where the common approaches to solving such problem are the exact algorithm, heuristic algorithm, meta-heuristic algorithm, genetic algorithm, etc. similarly to the VRP.

2.3 Fuel Replenishment Problem

There are many articles studied the application of optimization methods for solving the fuel replenishment problem over the last three decades. Before the VMI idea was introduced to this area, Brown and Graves (1981) proposed the optimization algorithm to assign orders to vehicles in order to minimize transportation costs, while honoring vehicle and driver working hour restrictions. In case of violating vehicle and driver working hour restrictions, penalty cost will be charged.

They described the fuel replenishment planning into 6 steps as below, and proposed optimization algorithm to solve the step 3 (Assign orders to vehicles).

General sequence of fuel replenishment planning (Brown and Graves, 1981):

1. Preview of dispatch: Extract customer order and vehicle data, review for special cases, balance general workload, insert new or missing information, etc.
2. Compatible vehicle edit: Determine which vehicles can be used to deliver each order, considering equipment restrictions, vehicle compartment checking, etc. (Transportation cost is not considered in this step)
3. Assign orders to vehicles: The objective is to minimize the operating costs while keeping the vehicles run under the allowable vehicle and driver shift length.
4. Adjust order quantities: Order quantity must be adjusted to fit with the vehicle compartment.
5. Final review: Identify any remaining exceptional conditions, and perform minor adjustments if necessary or return to step 1 with modified conditions.
6. Issue dispatch: Print load documents for each vehicle shift at the fuel terminal.

They developed an integer programming model applying the set partitioning concept to solve step 3. The model assumes customer orders are always full loaded order, and each trip contains only one customer at a time.

They first solved the problems with an exact algorithm but later came up with heuristics to solve real-time problems. The basic idea of the proposed heuristics is to assign the unassigned order to each vehicle, fix the order and determine the projected remaining time. Continue assigning the order for that vehicle until none order can be assigned. Then, move on to next vehicle and repeat the same process.

In this study, customers place orders with the supplier, and the supplier assigns these orders to vehicles. This approach is often called the pull system. In a pull system, customers control their inventory level and place orders to the supplier, indicating their desired delivery time. At the end of the fuel replenishment planning, the order quantity may be adjusted to fit with vehicles' compartments and to fully utilize the vehicle capacity.

Ronen (1995) conducted a similar study and proposed 3 models to solve vehicle dispatching: *set partitioning* (SP), *elastics set partitioning* (ESP) and *set packing* (SPK) models. The objectives of the first 2 models are transportation cost minimization. The ESP model involves a penalty in the case of constraint violations in the model, while the SPK model aims for maximizing the overall profit. Profit, in this case, refers to the cost saving between using the contracted vehicle against the spotted vehicle. The result explains that the SP model is more rigid and requires all tasks to be performed by only contracted vehicle. The ESP and SPK models give more flexibility as they involve the presence of the spotted vehicle, and a penalty for constraint violations. However, the author provided too few details on how the models are solved.

Abdelaziz et al. (2002) investigated the fuel replenishment problem by taking vehicles with multiple compartments into consideration. They developed a model in order to minimize the total transportation cost subject to several constraints. In comparison with the previously described articles, this model is more complex and realistic as it considers the vehicle compartment allocation. Moreover, in this study, they allow up to two customers in the same route, which reflects the reality that most vehicles contain from four to seven compartments, and each customer typically has three to four underground tanks.

The model assumptions and constraints are described as follows:

- The fleet is heterogeneous.
- Each customer except the fuel terminal is visited exactly once by exactly one vehicle.
- All vehicle routes start and end at the fuel terminal.
- The weights of any vehicle route should not exceed the vehicle capacity.
- Each compartment is allocated exactly once.
- All customer orders must be satisfied.

However, they found that solving the problem to optimality is considerably difficult due to the high number of constraints and variables. Therefore, they proposed the *variable neighborhood search* (VNS) heuristics in order to reach a near optimal solution.

Avella et al. (2004) studied the exact and heuristic methods for solving the problem of satisfying customers' orders on the desired delivery date from one fuel terminal with a limited number of heterogeneous fleet vehicles. The vehicle dispatching constraints in this study are described as follows:

- Each client must be visited only once a day.
- The travel time for each vehicle must not exceed the allowable working hour.
- Each vehicle cannot load product over its capacity.

To solve the problem to optimality, they proposed a Branch-and-Price algorithm based on a set partitioning concept. It is well understood that the performance of the Branch-and-Price algorithm strongly depends on the initial set of columns (Lobel, 1998).

Therefore, they proposed the heuristic approach to obtain a good initial solution before applying Branch-and-Price algorithm.

There are four main steps to solve the problem which can be explained step-by-step as below.

1. Route generation (column generation): The set partitioning formulation requires set of all possible routes matrix. Each row indicates the customer who must be visited in a day, while each column represents all possible routes of each vehicle (Figure 2.1). The maximum number of customers to be visited per route is 4 customers. Once all routes are generated, the cost of each route is then computed based on the shortest Hamiltonian cycle.

←……………Truck 1……………→ ←……………Truck 2……………→ ←……………Truck 3………

1,……………………, *ncol(1)*,……………………, *ncol(2)*,……………………

1	-	…	-	1	1	…	-	1	1	…	-	…	1	-	…	-	1	1	…	-	1	1	…	-	…	1	-	…	-	1	1	1	…
-	1	…	-	1	-	…	-	1	1	…	-	…	-	1	…	-	1	-	…	-	1	1	…	-	…	-	1	…	-	1	-	-	…
-	-	…	-	-	1	…	-	1	-	…	-	…	-	-	…	-	-	1	…	-	1	-	…	-	…	-	-	…	-	-	1	-	…
-	-	…	-	-	-	…	-	-	1	…	-	…	-	-	…	-	-	-	…	-	-	1	…	-	…	-	-	…	-	-	-	1	…
-	-	…	-	-	-	…	-	-	-	…	-	…	-	-	…	-	-	-	…	-	-	-	…	-	…	-	-	…	-	-	-	-	…
-	-	…	-	-	-	…	-	-	-	…	-	…	-	-	…	-	-	-	…	-	-	-	…	-	…	-	-	…	-	-	-	-	…
-	-	…	-	-	-	…	-	-	-	…	1	…	-	-	…	-	-	-	…	-	-	-	…	1	…	-	-	…	-	-	-	-	…
-	-	…	-	-	-	…	1	-	-	…	1	…	-	-	…	-	-	-	…	1	-	-	…	1	…	-	-	…	-	-	-	-	…
-	-	…	1	-	-	…	1	-	-	…	1	…	-	-	…	1	-	-	…	1	-	-	…	1	…	-	-	…	1	-	-	-	…

Figure 2.1 A scheme of customer-route incidence matrix (Avella et al, 2004)

2. Column elimination: As the number of columns grows exponentially which begins to exceed 100,000 when there are more than 25 customers. Therefore this step is mainly to eliminate routes that do not satisfy the following tests.

- Vehicle capacity test: the sum of the volume must not exceed vehicle capacity.
- Order satisfaction test: the sum of the volume must be covered by the tank vehicle compartments.
- Route cost test: the travel time for each route must not exceed the allowable working hour.

- Saving test for each route: the cost of the route 0-i-j-0 must be less than the summation of 0-i-0 and 0-j-0.

3. Seek the initial solution: The heuristic approach is used to define a good initial solution before applying the Branch-and-Price algorithm. The basic concept is to consider each vehicle separately starting from the biggest to the smallest. Concurrently, consider each order starting from the largest order quantity and assign to available vehicles. If the vehicle has no residual capacity, move on to the next vehicle.

4. Branch-and-Price algorithm: This algorithm starts from the initial solution obtained in the previous step, then check the reduced costs for all other columns of the set partitioning formulation. If the negative reduced costs are found, add the column to the master problem and solve the new problem. Continue the step until there is no negative reduced cost.

Although this approach seems to be effective in solving the problem to optimality, it is still unclear if this approach can solve the larger instances within a reasonable computing time.

Other studies have taken into account the VMI concept (sometimes referred to as the push system). In a push system, a supplier manages customer's inventory levels by placing the order quantity associated with the customer's inventory level. Not only is the order quantity for each customer managed by the supplier, but also the delivery time. A push system improves vehicle utilization, and the supplier has more control over the customers than a pull system. The following reviews explain how to deal with the fuel replenishment problem with the VMI concept.

Cornillier et al. (2008a) proposed two model formulations to solve the fuel replenishment problem, where these two models have totally different model's objectives and are solved sequentially. The first model is the SP problem which is used to select routes for all customers requiring a delivery. The objective of the SP model is to minimize overall transportation costs. The second model is the *tank truck loading problem* (TTLP) where it is used for determining order quantity for each tank corresponding to the customer's inventory level and tank truck compartments. Considering these two models, they have named this type of problem as *petrol station replenishment problem* (PSRP).

The PSRP refers to the finding of minimum delivery cost to a set of stations which must be supplied once by a heterogeneous fleet of vehicle, subject to the quantity of each product must be sufficient to fulfill the demand (The inventory level for each tank must not exceed the tank capacity, also ensure the inventory level is above the tank safety stock).

Solving the set partitioning problem to optimality is not feasible due to a large number of possible routes. However, the problem can be solved to optimality if the number of customers visited per route is limited to two stations, which is a very common practice in North America.

Cornillier et al. (2008a) proposed two strategies to solve the PSRP. The first strategy is to enumerate all feasible routes, solving the TTLP for each route, and then solve the set partitioning to optimality. The second strategy is based on a column generation approach. It starts with finding the initial solution from assigning the least fixed cost vehicle to each route. The feasibility test is then performed to check TTLP for each route. If all routes are feasible, ends the iteration. Otherwise, solve again with the new matching. In the second strategy, numerous iterations may have to be performed but the number of calls to the TTLP is likely to be much less than the first strategy.

In contrast to the previous articles that merely consider fuel delivery in a single period, (Cornillier et al., 2008b) proposed a heuristic algorithm to optimize the delivery of several petroleum products to a set of petrol stations over a given planning horizon. This problem is defined as *multi-period petrol station replenishment problem* (MPSRP). In this problem, the objectives are to determine the quantity of each product to be delivered to each station, how to fill these products into vehicle compartments, and how to plan vehicle routes that give the maximum total profit. The term profit refers to the revenue minus the sum of total transportation cost. This type of problem is slightly different in comparison to the problem addressed in this paper. The MPSRP merely involves the petrol stations where the multi-period fuel replenishment planning problem comprises petrol stations and industrial customers.

The MPSRP consists of determining the following for each period *t* of the planning horizon:

- The set of petrol stations which deliveries should be made to.
- The quantity of each product to be delivered to each station.
- The loading of each product into vehicle compartments.
- The feasible route to each station.
- The assignment of routes to available vehicles.

The problem can be formulated as a large scale mixed integer problem, but the problem is too large to be solved. Therefore, they have proposed the heuristic approach to solve MPSRP. The proposed heuristic starts with the first period $t = 1$ of the given planning horizon then follows the following steps as shown in Figure 2.2.

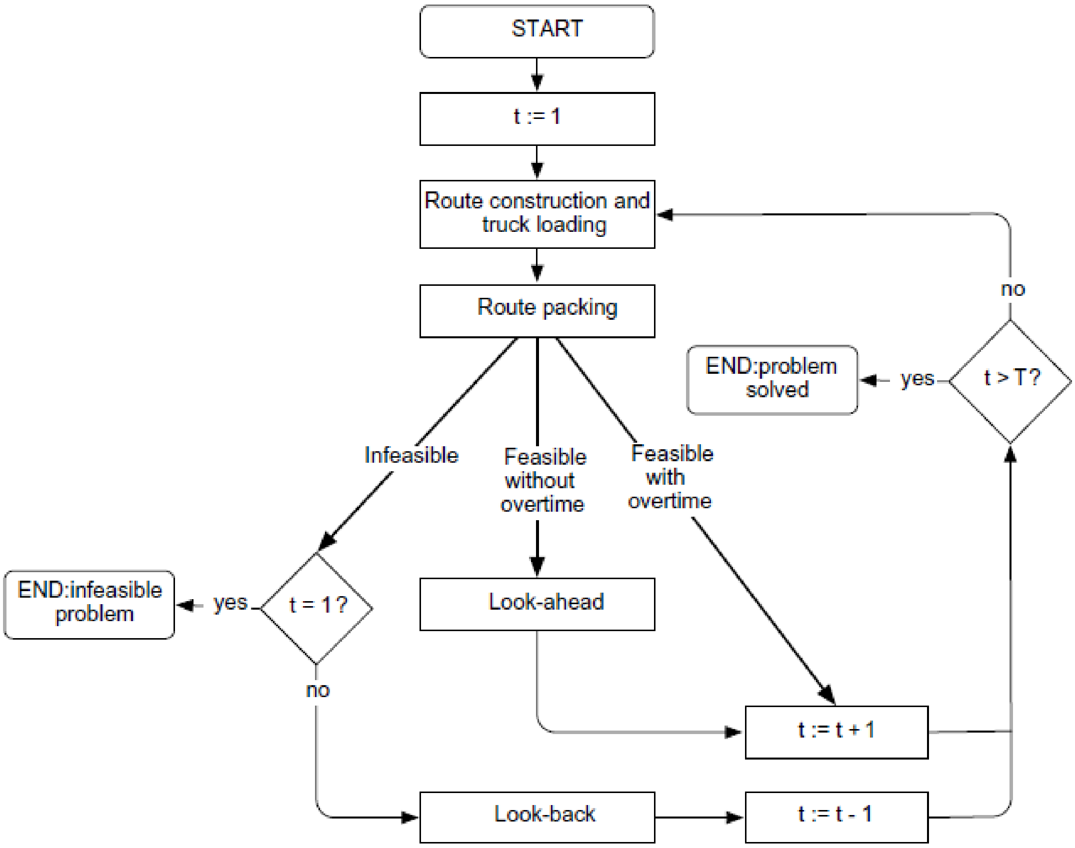

Figure 2.2 Flowchart of the heuristic solving MPSRP (Cornillier et al., 2008b)

1. Route construction and vehicle loading: Construct the routes consisting of all stations that would run out of stock for at least one product if there is no delivery planned in period *t*, and also includes any stations selected by the look-back and the look-ahead procedure (Step 3 and 4). The routes will then be checked the vehicle loading feasibility by the tank truck loading problem (TTLP) initiated by Cornillier et al. (2008a).

2. Route packing: Assign routes to vehicles with the objective to maximize the total revenue minus the overtime cost. To solve this step, they proposed heuristic approach. The heuristic starts with sorting all routes in an ascending order of the number of vehicles which they could be feasibly assigned to (The route that is difficult to assign appears earlier in the list). The routes are then sequentially assigned to vehicles to maximize the objective function. After completed the route

packing then proceed to step 3 if the solution is infeasible, or proceed to step 4 if the solution is feasible without overtime.

3. Look-back procedure: This step is applied in case the working time of at least one vehicle exceeds the allowable working time. The procedure iteratively shifts some stations from period *t* to period *t*-1 and return to step 1 and 2 respectively until obtaining the feasible solution in period *t*.

4. Look-ahead procedure: The purpose is to increase the workload at period *t* by increasing the number of stations visited at period *t*. It returns to step 1 and 2 similarly to the look-back procedure. However, the new solution must not exceed the allowable working time for all vehicles.

Once completes these steps, move to the period *t* + 1 and repeat the same until complete all fuel delivery planning for the given planning horizons.

Later, Cornillier et al. (2009) proposed a heuristic approach to solve the PSRP in a single period with specified time windows or *petrol station replenishment problem with time windows* (PSRPTW). The study aims to optimize the delivery of several petroleum products to a set of petrol stations using a limited heterogeneous fleet of vehicles in order to maximize the overall profit (the difference between revenue and routing costs), subject to the conditions that delivery is made within the specified time windows and the order quantity must be calculated associated with vehicle compartments. The PSRPTW consist of determining:

- The quantity of each product to be delivered to each station (Quantity must lie between minimum and maximum allowable delivery amount).
- The loading of these products into vehicle compartments. (TTLP)
- Delivery routes to customers.

- Routes assignment to available vehicles.
- The departure time of each trip.

To solve the problem, they proposed two heuristic approaches. The first heuristic approach aims to reduce the number of routes by preselecting a subset of all feasible arcs. It starts with generating a minimum spanning tree on the initial graph, and then removes the selected edges and repeats itself as long as the graph is connected. Besides, all arcs linking the fuel terminal to customers in both directions are also included.

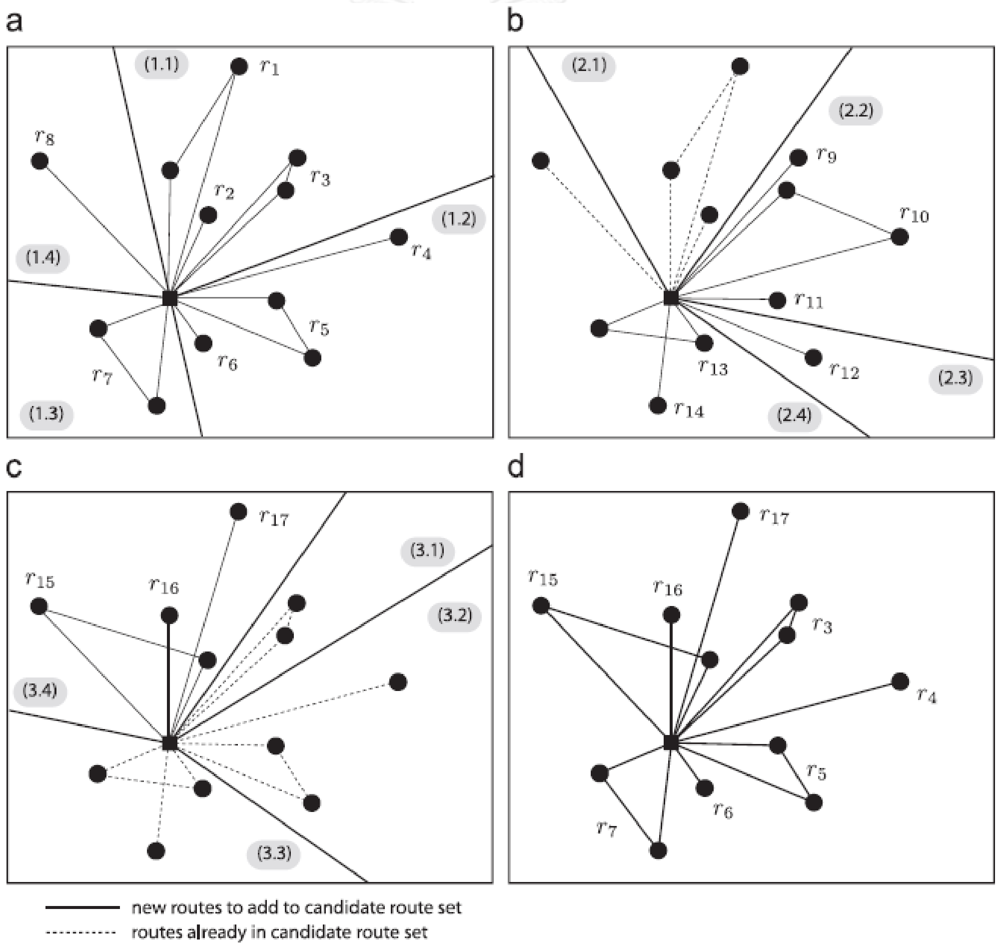

Figure 2.3 A decomposition heuristic using successive partitions (Cornillier et al. ,2009)

The second heuristic approach is to decompose the geographical space to obtain the local optimal routes which will be used in the entire problem. It starts with decomposing the sector, and solve for the optimal routes for each sector. Keep the solutions and recompose the sector. Repeat the same procedure until it completes the required loop. Figure 2.3 illustrates how a decomposition heuristics is performed. Figure 2.3a shows a first partition which the routes for each sector (1.1)-(1.4) are separately solved to optimality. Figures 2.3b and 2.3c show the optimal routes are selected from each sector (2.1)-(2.4) and (3.1)-(3.4) respectively. Finally, bring all preselected route set from all partitions to the entire problem, and solve to optimality (Figure 2.3d).

Popovic et al. (2011) and Hanczar (2012) conducted a similar study to Cornillier et al. (2008b) but proposed different approaches. Both studies considered these problems as the inventory routing problem since the supplier has full control of customer’s inventory level, including determining order quantity as well as the delivery period.

Popovic et al. (2011) proposed the mathematical model with an objective to minimize both inventory costs incurred by delivered quantity and routing costs over a planning horizon. They applied new heuristic approaches by decomposing the problem in two phases. In the first phase, they solved the relaxed MIP model without considering the routing cost and associated constraints. They observed that the computing time for solving the first phase is very short as the routing part is ignored. The main objective of this phase is to move the delivered quantity from days with higher volume to the preceding days with lower volume. The iterations are stopped when the number of routes for each day can be served by the available vehicles. The feasible solution is now obtained and to be further improved in the next phase. The main objective of the second phase is to move the deliveries to the day that gives a lower total cost (inventory-routing cost). Similarly, the iterations are stopped when no more delivery movement can be made to reduce the total costs. Lastly, they used a simulation approach to analyze the results.

Hanczar (2012) proposed the heuristic approach consisting of 2 steps “first cluster – second route”. The first step is to solve the set partitioning problem to obtain the partitioning of customers, dates and delivered quantity that minimizes the total distribution and inventory cost over a planning horizon. The next step is to solve the traveling salesperson problem to obtain optimal routes for each partition.

Cornillier et al. (2012) conducted a further study to solve the PSRPTW with multi-depots. This problem is called *multi-depot petrol station replenishment problem with time windows* (MPSRPTW). In the MPSRPTW, several interrelated decisions must be made simultaneously, the set of feasible routes, the departure depot for each route, the quantity of each product, the routes assignment to vehicles, the schedule for each trip and the product allocation to vehicle compartments.

In this study, the objective of the replenishment plan is to maximize the overall net revenue, equal to the amount paid according to the quantities delivered minus the overall transportation cost. They proposed a new heuristic algorithm to solve the problem by using trips, not routes as in their previous studies. In this case, a route is referred to a tour that starts and ends at the same depot, whereas a trip is a combination of its route and the vehicle used. From this statement, it implies that multiple trips can have the same route.

Popovic et al. (2012) proposed VNS heuristics to solve multi-product multi-period inventory routing problem in fuel delivery. Their proposed technique is based on a constructive heuristic or random feasible solution. Then, a shaking procedure and the randomized variable neighborhood descent (RVND) local search procedure are applied to improve the solution. Recently, Vidovic et al. (2014) also proposed a similar approach to Popovic et al. (2012), but the way they obtained the initial solution, as well as improving the solution are different. Firstly, they partially solved the MIP model (relaxed MIP model) to obtain the initial solution, and improve the solution by using variable neighborhood descent (VND) search.

Referring to all the above literatures, most of these studies proposed heuristic approaches to solve the fuel replenishment problem, due to the fact that the exact method might not be an appropriate approach to solve large scale problems (Laporte, 1992). To give a better understanding of the past studies, we have summarized their main characteristics in Table 2.1.

Table 2.1 Main characteristics of past studies vs this study

Authors	No. of vehicle	No. of customers	No. of visit per customer per day	VMI Concept	Fuel Terminal	Period	Time windows
Brown and Graves (1981)	Limited	One	One	No	Several	Single	No
Ronen (1995)	Limited	One	One	No	One	Single	No
Abdelaziz et al. (2002)	Limited	Up to two	One	No	One	Single	No
Avella et al (2004)	Limited	Several	One	No	One	Single	No
Cornillier et al. (2008a)	Unlimited	Up to two	One	Yes	One	Single	No
Cornillier et al. (2008)	Limited	Up to two	One	Yes	One	Multi	No
Cornillier et al. (2009)	Limited	Several	One	Yes	One	Single	Yes
Popovic et al. (2011)	Limited	Up to two	One	Yes	One	Multi	No
Popovic et al. (2012)	Unlimited	Up to three	One	Yes	One	Multi	No
Hanczar (2012)	Limited	Several	One	Yes	One	Multi	No
Cornillier et al. (2012)	Limited	Several	One	Yes	Several	Single	Yes
Vidovic et al. (2014)	Unlimited	Up to four	One	Yes	One	Multi	No
This study	Limited	Up to two	Several	Yes	One	Multi	Yes*

*use trip sequence to specify time windows in range (e.g. 1st trip: 8:00 - 12:00)

As shown in Table 2.1, it is obvious that approximately half of the previous studies have considered the fuel replenishment problem with multiple periods. However, we found none of them have proved that solving the model considering multiple periods outperforms those with a single period. In addition, to the best of the author' knowledge, none of these studies allow customers to be visited more than once per day, which does not reflect the real-life situation where high demand customers could be served several times per day.

Hence, in this study, we propose heuristic approaches to solve the multi-period fuel replenishment planning problem that allows customers to be visited several times per day. We use a real-life scenario and randomly generated test instance to demonstrate that considering multiple periods gives a better outcome in various aspects in comparison to a single period.

2.4 Linear Programming Relaxation

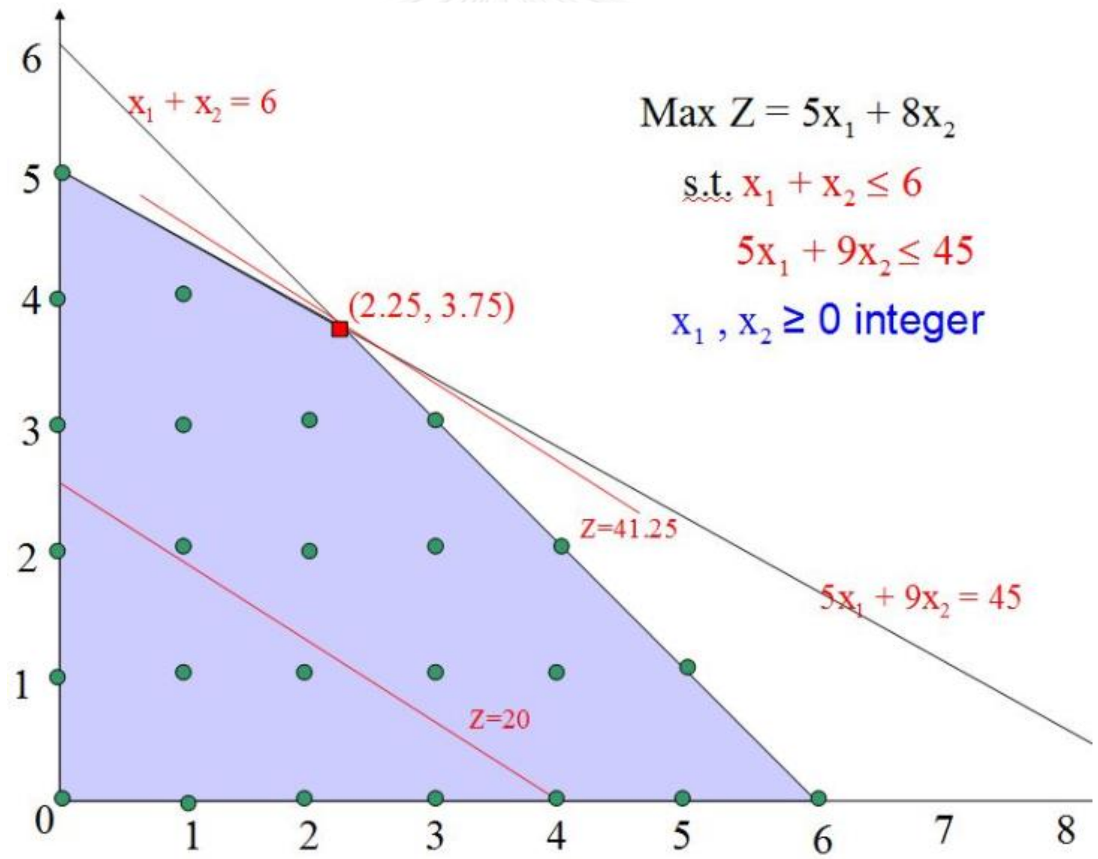

Figure 2.4 Integer programming vs linear programming relaxation

(Department of Mathematics and Computer Science Emory University, 2015)

The linear programming relaxation technique was first introduced by Lovasz (1975) for the set covering problem. This technique fundamentally transforms an integer programming problem into a linear programming problem which is solvable in a polynomial time. Figure 2.4 illustrates the comparison between integer programming and linear programming relaxation (Department of Mathematics and Computer Science Emory University, 2015). As seen, the results obtained from linear programming relaxation (x1 = 2.25, x2 = 3.75) contain a decimal number, and thereby infeasible for integer problem. Despite, these solutions are not feasible, but it can be used as an indication or initial step to further obtain the solution of the original problem.

There are many researchers studied the application of linear programming relaxation in solving various problems. Rosing et al. (1979) applied this technique to solve p-Median and plant location problems. They found that it resulted in the significant reduction in the computational time, allowing the larger scale problem to be solved to optimality. Benson (1991) used relaxation algorithm to find a globally optimal solution for the problem, and developed algorithm to find a true optimal solution after a number of iterations. Al-Khayyal (1992) applied linear programming relaxation technique as a sub-problem to solve the bilinear programming problem. Gouveia (1996) studied the use of linear programming relaxations for multi-commodity flow models for spanning trees with hop constraints. Gouveia (1996) provided some evidence that the relaxation technique gives a shape bounds for this hop constrained problem. They also derived several Lagrangian based procedures to achieve a better bound. Chudak and Hochbaum (1999) proposed a new linear programming relaxation for scheduling precedence-constrained jobs on a single machine problem. They discovered that the new relaxation technique is simple where the optimal solution can be found using a minimum cut computation. Weber et al. (2003) and (Schoenemann et al. (2009)) used the linear programming approach for problems relating to X-ray projections and image segmentation respectively. Both studies found the relaxation technique could provide good approximated solutions.

According to the above, it is observable that the linear programming relaxation technique can be used as a supplement to solve various problems. In this study, we also applied this method to our study area where we will describe more details in the next chapter.

CHAPTER 3

METHODOLOGY

In this study, we present mathematical models for solving multi-period fuel replenishment planning problem. The problem aims to optimize the delivery of several petroleum products to both petrol stations and industrial customers over a given planning horizon using the limited heterogeneous fleet of vehicles. The objective of this problem is to minimize the transportation unit cost, equal to the total transportation cost, divided by the total delivery volume. As the model size grows exponentially when the number of customers, vehicles, and time period increase, thus, the exact algorithm is infeasible. Hence, in this study, we propose two heuristic approaches: *two-phase method* (2PM) and *three-phase method* (3PM). The 2PM is primarily designed for solving small problem whereas the 3PM offers a similar approach but has an ability to solve a larger problem.

3.1 Problem Statement

The problem statement for the multi-period fuel replenishment planning problem is as follows:

"Given one fuel terminal with an unlimited supply of multiple grade products, two sets of customers, (i) petrol stations and (ii) industrial customers, a limited number of heterogeneous multi-compartment vehicles, consumption rate of each product at each petrol station, order quantities and delivery time windows at each industrial customer over the planning horizon, find the delivery plan minimizing transportation unit cost specifying vehicle routes and product-compartment-customer assignment and approximate delivery time (trip), such that all consumptions and demands are met within the storage allowance (safety stock level and tank capacity). The vehicle route is

defined as a sequence of visits respecting specified time windows at customer sites. Each vehicle route must honor the vehicle's weight limit. Each vehicle operates within the driver's allowable working hours. The product-compartment-customer assignment specifies product quantity to be loaded in the vehicle's compartment and it's discharging destination tank."

3.2 Study Area

To conduct the study, we use the real-life case and randomly generated test instances to test our proposed algorithms. The actual instance consists of one fuel terminal, 27 customers dispersed in the area and 3 heterogeneous vehicles. There are two types of customers in this real-life case: petrol stations and industrial customers, where a vast majority of the fuel replenishment volume is from the petrol stations. Each site locates in different locations and therefore differs regarding vehicle size accessibility. Some of the customers' sites have above ground storage tanks, thereby require vehicles equipped with a pump for making the fuel replenishment. Also, each customer has a different number of storage tanks where the tank capacity varies between 3,000 and 35,000 liters.

Since the problem size of this real-life case is considerably small, hence, we randomly generated a larger test instance based on the real-life conditions to test if the proposed algorithms can handle a larger problem size. The randomly generated test instance consists of one fuel terminal, 50 petrol stations with approximately 5 times higher in replenishment volume comparing to the real-life case, and 6 vehicles. The tank capacity varies from 10,000 to 30,000 liters.

Anyhow, we describe more details regarding the data used in this study in the next chapter.

3.3 Model Assumptions

To avoid any ambiguity in this study, we made the following assumptions:

- Only one fuel terminal is considered.
- No product shortage at the fuel terminal.
- Fuel terminal operating hours is known.
- Product density is known.
- Limited heterogeneous fleet of vehicles.
- Weight limit, volume capacity, and compartment configuration for each vehicle are known.
- Maximum vehicle operating hours and maximum number of trips are known.
- Vehicle compartments are not equipped with flow meter. They must be completely emptied once the unloading has started.
- Each vehicle compartment must be loaded at least to 85% of its capacity due to the safety reasons, otherwise be emptied.
- Possible routes are pre-defined.
- Daily sales consumption for all petrol stations storage tanks is deterministic.
- Each customer tank contains only one product, and product crossover is not allowed.
- Customer tank capacity and safety stock level for individual customer tanks are known. Customer inventory level must not exceed the tank capacity and must not fall below the safety stock level.
- Individual customers can be visited several times on any given planning horizon.
- Several trips can be assigned to the same vehicle.
- Up to two customers can be visited in the same trip.
- Total time (including travel, loading and unloading time) for each trip is known.
- Transportation cost for all routes associated with each vehicle is known.

3.4 Notations

Sets

V	is the set of vehicles, indexed by v.
K	is the set of vehicle compartments, indexed by k.
R	is the set of possible routes, indexed by r.
I	is the set of customers, indexed by i.
J	is the set of customer tanks, indexed by j.
D	is the period (day), indexed by d.
T	is the set of trips, indexed by t.

Parameters

a_{ij}	is the safety stock level of tank j of customer i.
b_{ij}	is the capacity of tank j of customer i.
c^{vr}	is the total cost of route r using vehicle v.
g_{ij}	is the product density associated to product of tank j of customer i.
h^{vr}	is the total time for visiting route r using vehicle v.
o_{ijdt}	is the estimated inventory level of tank j of customer i during trip t at period d.
q^{vk}	is the compartment size of compartment k of vehicle v.
s_{ijdt}	is the estimated sales consumption of tank j of customer i during trip t at period d.
H_d^v	is the maximum allowable vehicle operating hour of vehicle v at period d.
N^v	is the total amount of compartment of vehicle v.
W^v	is the maximum weight limit of vehicle v.
M	is a scaling coefficient.

<u>Variables</u>

x_{ijdt}^{vkr} is the quantity of product loaded into compartment k of vehicle v, to be discharged to tank j of customer i in route r during trip t at period d.

y_{ijdt}^{vkr} equals to 1 if compartment k of vehicle v is assigned to tank j of customer i in route r during trip t at period d, otherwise 0.

z_{dt}^{vr} equals to 1 if route r is delivered by vehicle v during trip t at period d, otherwise 0.

3.5 Model Formulations

From the notations, parameters and variables defined previously, we can formulate the *Multi-Period Fuel Replenishment Planning Problem* (MPFRP) as follows:

Objective function:

Maximize
$$\sum_{v\in V}\sum_{r\in R}\sum_{d\in D}\sum_{t\in T}\left[\sum_{k\in K}\sum_{i\in I}\sum_{j\in J}x_{ijdt}^{vkr} - Mc^{vr}z_{dt}^{vr}\right] \qquad (1)$$

Subject to:

$$a_{ij} \le o_{ijdt} \qquad \forall i \in I, \forall j \in J, \forall d \in D, \forall t \in T \qquad (2)$$

$$o_{ijdt} + \sum_{v\in V}\sum_{k\in K}\sum_{r\in R}x_{ijdt}^{vkr} \le b_{ij} \qquad \forall i \in I, \forall j \in J, \forall d \in D, \forall t \in T \qquad (3)$$

$$o_{ijd,t+1} = o_{ijdt} - s_{ijdt} + \sum_{v\in V}\sum_{k\in K}\sum_{r\in R}x_{ijdt}^{vkr} \qquad \forall i \in I, \forall j \in J, \forall d \in D, \forall t \in T \qquad (4)$$

$$-0.15q^{vk} \le x_{ijdt}^{vkr} - q^{vk}y_{ijdt}^{vkr} \le 0 \qquad \forall v \in V, \forall k \in K, \forall r \in R, \forall i \in I, \forall j \in J, \forall d \in D, \forall t \in T \qquad (5)$$

$$\sum_{r\in R}\sum_{i\in I}\sum_{j\in J}y_{ijdt}^{vkr} \le 1 \qquad \forall v \in V, \forall k \in K, \forall d \in D, \forall t \in T \qquad (6)$$

$$(1-N^v) \leq \sum_{k\in K}\sum_{i\in I}\sum_{j\in J} y_{ijdt}^{vkr} - N^v z_{dt}^{vr} \leq 0 \qquad \forall v\in V, \forall r\in R, \forall d\in D, \forall t\in T \qquad (7)$$

$$\sum_{r\in R}\sum_{t\in T} h^{vr} z_{dt}^{vr} \leq H_d^v \qquad \forall v\in V, \forall d\in D \qquad (8)$$

$$\sum_{r\in R} z_{dt}^{vr} \leq 1 \qquad \forall v\in V, \forall d\in D, \forall t\in T \qquad (9)$$

$$\sum_{k\in K}\sum_{r\in R}\sum_{i\in I}\sum_{j\in J} g^{ij} x_{ijdt}^{vkr} \leq W^v \qquad \forall v\in V, \forall d\in D, \forall t\in T \qquad (10)$$

$$x_{ijdt}^{vkr} \in \mathbb{R}^+ \qquad \forall v\in V, \forall k\in K, \forall r\in R, \forall i\in I, \forall j\in J, \forall d\in D, \forall t\in T \qquad (11)$$

$$y_{ijdt}^{vkr} \in \{0,1\} \qquad \forall v\in V, \forall k\in K, \forall r\in R, \forall i\in I, \forall j\in J, \forall d\in D, \forall t\in T \qquad (12)$$

$$z_{dt}^{vr} \in \{0,1\} \qquad \forall v\in V, \forall r\in R, \forall d\in D, \forall t\in T \qquad (13)$$

Our objective is to minimize the transportation unit cost, which is equal to the total transportation cost divided by the sum of replenished quantity. This implies simultaneously maximizing the vehicle loaded quantity and minimizing the total transportation cost. To combine these two objectives in the objective function, we employed a scaling coefficient (M) to maintain the balance between the two objectives as shown in the equation (1). The value of this coefficient can be determined from the interactive method described in Chapter 4.

Constraint (2) ensures that the inventory level for individual tanks must not fall below the minimum requirement (safety stock level) in any given planning horizon. Constraint (3) guarantees that the inventory level after replenishment does not exceed the tank capacity. Constraint (4) ensures the stock equilibrium between connecting trips. Constraints (5) and (6) specify that one vehicle compartment can only be assigned to one customer tank for each trip. If a vehicle compartment is used, it must be loaded at least 85% of its compartment size. Constraint (7) ensures that vehicle v visit route r only if at least one compartment is assigned. Constraint (8) ensures that each vehicle must not be operated over the maximum allowable operating hour. Constraint (9) specifies that one route can only be assigned to one trip. Constraint (10) guarantees each vehicle is not carrying products over its weight limit.

3.6 The Two-Phase Method (2PM)

As the model size grows exponentially as the number of customers, vehicles, and time period increase, the exact algorithm is apparently not feasible to solve equations (1)-(13). In this study, we propose two heuristic approaches: *two-phase method* (2PM) and *three-phase method* (3PM). The 2PM is primarily designed for solving small problems whereas the 3PM offers a similar approach but has the ability to solve larger problems. The details of 2PM are outlined below and 3PM is outlined in the following section.

3.6.1 2PM Phase I

The 2PM is a heuristic approach that solves the multi-period fuel replenishment planning problem by decomposing the solution process into two phases. A flowchart of 2PM is shown in Figure 3.1. In phase I, the linear programming relaxation technique is applied, transforming constraints (12) and (13) into (14) and (15) respectively. Next, we solve the equations (1)-(11) and (14)-(15) to optimality.

$$0 \leq y_{ijdt}^{vkr} \leq 1 \qquad \forall v \in V, \forall k \in K, \forall r \in R, \forall i \in I, \forall j \in J, \forall d \in D, \forall t \in T \qquad (14)$$

$$0 \leq z_{dt}^{vr} \leq 1 \qquad \forall v \in V, \forall r \in R, \forall d \in D, \forall t \in T \qquad (15)$$

Despite the fact that the results obtained from phase I are not feasible in the real world, they indicate which customers should be serviced during the considered planning horizon, especially those customers that need to be replenished tomorrow. As described earlier in Chapter 1, the replenishment plan is usually created on a day-to-day basis (e.g., if today is 1st January, the planner creates the fuel replenishment plan for 2nd January) since the fuel consumption is stochastic in nature. The more recent inventory and sales information obtained from individual petrol stations, the more accurate the replenishment plan.

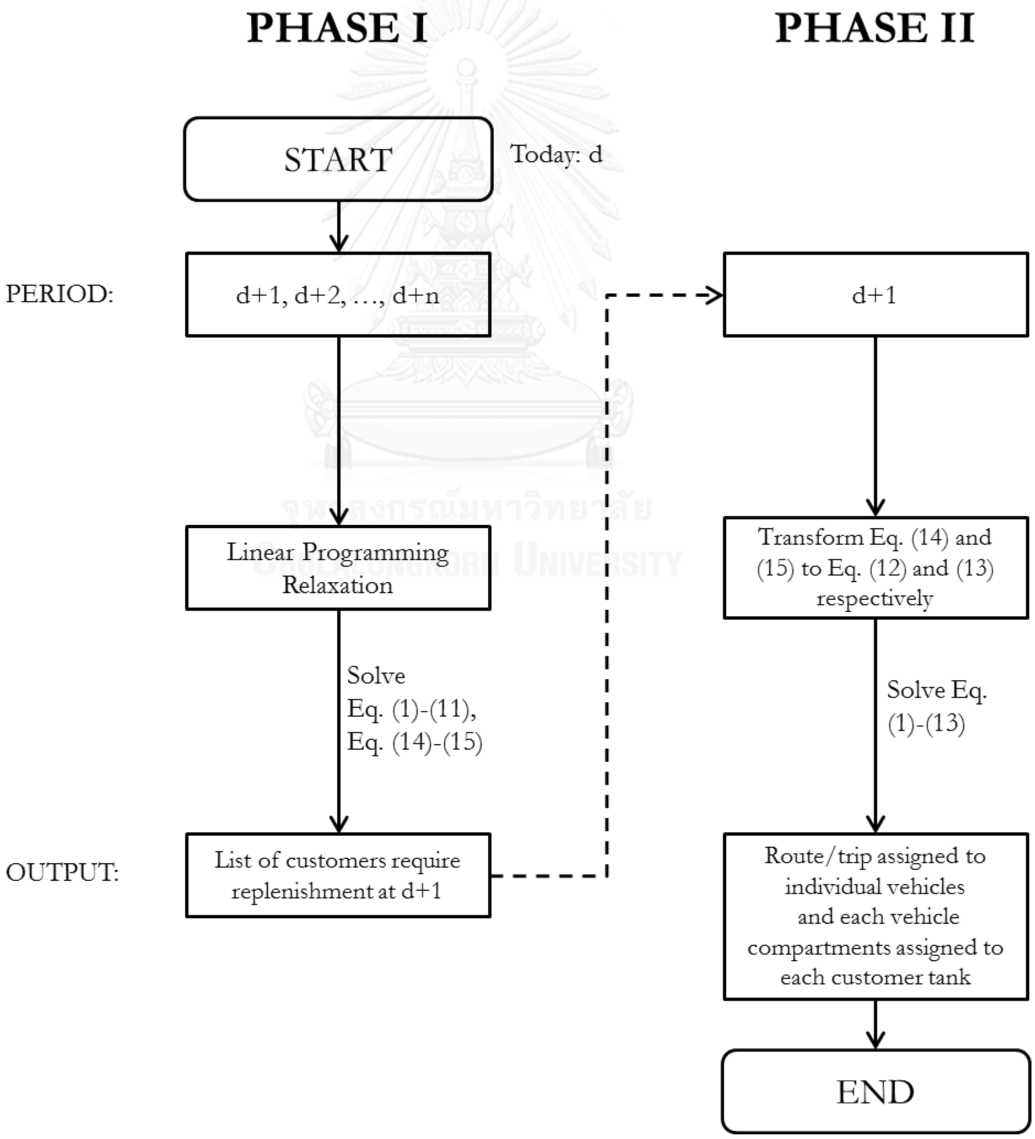

Figure 3.1 A Flowchart of the 2PM

3.6.2 2PM Phase II

In phase II, only the customers requiring replenishment in period d+1 (tomorrow) as obtained from phase I are considered, all other customers are eliminated. By considering only the period d+1 and removing some customers from the problem, the size of the model is significantly reduced and solving the problem to optimality is now practical. Next, the equations (1)-(13) are solved to optimality using the branch-and-bound algorithm.

3.7 The Three-Phase Method (3PM)

The 3PM is fundamentally similar to 2PM, but composed of three phases as shown in Figure 3.2.

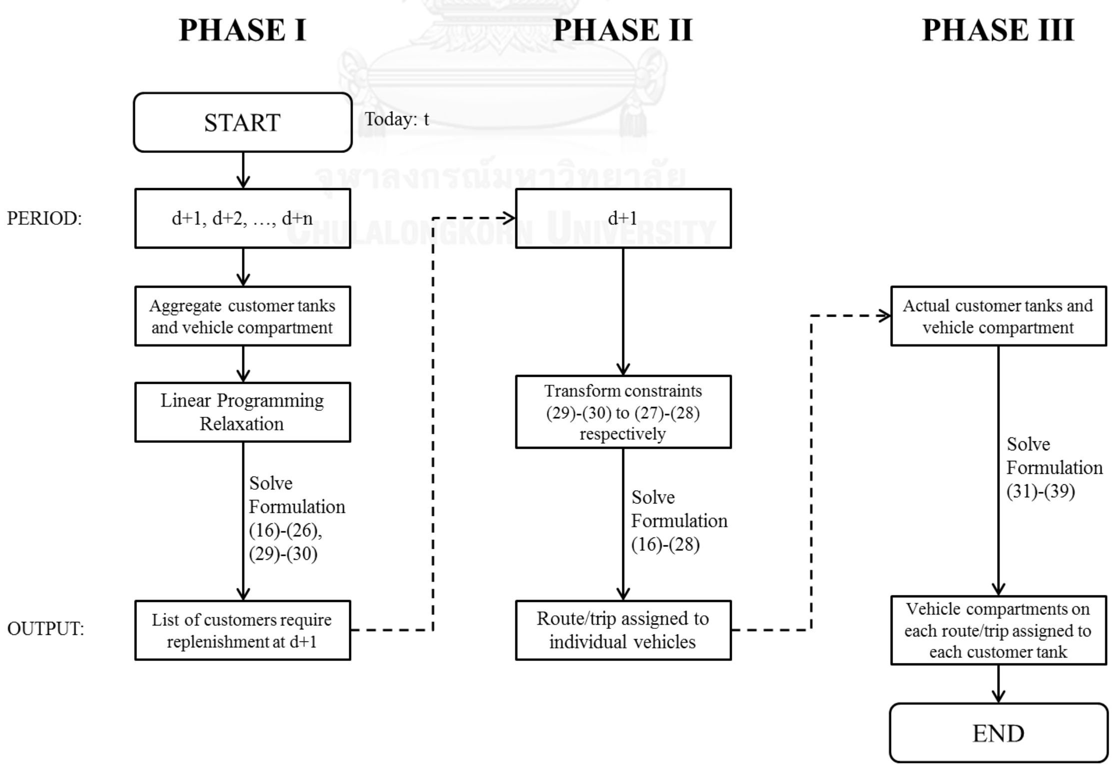

Figure 3.2 A Flowchart of the 3PM

3.7.1 3PM Phase I

In phase I, the main objective is to reduce the model size and to obtain the list of customers requiring replenishment during the considered planning horizon. Firstly, we aggregate the customer storage tanks and vehicle compartments for individual customers and vehicles respectively. The phase I model is then formulated as follows:

Parameters

a_i	is the total safety stock level of customer i.
b_i	is the total capacity of customer i.
c^{vr}	is the total cost of route r using vehicle v.
g_i	is the average product density of customer i.
h^{vr}	is the total time for visiting route r using vehicle v.
o_{idt}	is the estimated total inventory level of customer i during trip t at period d.
q^v	is the maximum loaded volume of vehicle v.
s_{idt}	is the estimated total sales consumption of customer i during trip t at period d.
H_d^v	is the maximum allowable vehicle operating hour of vehicle v at period d.
W^v	is the maximum weight limit of vehicle v.
M	is a scaling coefficient.

Variables

x_{idt}^{vr}	is the quantity of total product loaded into vehicle v, to be delivered to customer i in route r during trip t at period d.
y_{dt}^{vr}	equals to 1 if vehicle v is assigned to route r during trip t at period d, otherwise 0.
z_{dt}^{vr}	equals to 1 if route r is delivered by vehicle v during trip t at period d, otherwise 0.

Phase I Model

Objective function:

Maximize
$$\sum_{v\in V}\sum_{r\in R}\sum_{d\in D}\sum_{t\in T}\left[\sum_{i\in I} x_{idt}^{vr} - Mc^{vr}z_{dt}^{vr}\right] \quad (16)$$

Subject to:

$$a_i \leq o_{idt} \qquad \forall i \in I, \forall d \in D, \forall t \in T \quad (17)$$

$$o_{idt} + \sum_{v\in V}\sum_{r\in R} x_{idt}^{vr} \leq b_i \qquad \forall i \in I, \forall d \in D, \forall t \in T \quad (18)$$

$$o_{id,t+1} = o_{idt} - s_{idt} + \sum_{v\in V}\sum_{r\in R} x_{idt}^{vr} \qquad \forall i \in I, \forall d \in D, \forall t \in T \quad (19)$$

$$-0.15q^v \leq \sum_{i\in I} x_{idt}^{vr} - q^v y_{dt}^{vr} \leq 0 \qquad \forall v \in V, \forall r \in R, \forall d \in D, \forall t \in T \quad (20)$$

$$\sum_{r\in R} y_{dt}^{vr} \leq 1 \qquad \forall v \in V, \forall d \in D, \forall t \in T \quad (21)$$

$$y_{dt}^{vr} - z_{dt}^{vr} = 0 \qquad \forall v \in V, \forall r \in R, \forall d \in D, \forall t \in T \quad (22)$$

$$\sum_{r\in R}\sum_{t\in T} h^{vr} z_{dt}^{vr} \leq H_d^v \qquad \forall v \in V, \forall d \in D \quad (23)$$

$$\sum_{r\in R}\sum_{i\in I} g^i x_{idt}^{vr} \leq W^v \qquad \forall v \in V, \forall d \in D, \forall t \in T \quad (24)$$

$$\sum_{r \in R} z_{dt}^{vr} \leq 1 \qquad \forall v \in V, \forall d \in D, \forall t \in T \qquad (25)$$

$$x_{idt}^{vr} \in \mathbb{R}^+ \qquad \forall v \in V, \forall r \in R, \forall i \in I, \forall d \in D, \forall t \in T \qquad (26)$$

$$y_{dt}^{vr} \in \{0,1\} \qquad \forall v \in V, \forall r \in R, \forall d \in D, \forall t \in T \qquad (27)$$

$$z_{dt}^{vr} \in \{0,1\} \qquad \forall v \in V, \forall r \in R, \forall d \in D, \forall t \in T \qquad (28)$$

The objective function (16) maximizes vehicle loaded quantity while minimizing the total transportation cost. In other words, this objective function aims for minimizing the transportation unit cost. Constraint (17) ensures that the total inventory level for individual customers must not fall below the total safety stock level in any given planning horizon. Constraint (18) guarantees that the total inventory level after replenishment does not exceed the total tank capacity. Constraint (19) ensures the stock equilibrium between connecting trips. Constraint (20) specifies that if a vehicle is used, it must be loaded at least 85% of its size. Constraints (21) and (25) guarantee that one vehicle can only be assigned to one route. Constraint (22) ensures that vehicle v visit route r only if the vehicle is assigned. Constraint (23) ensures that each vehicle must not be operated over the maximum allowable operating hour. Constraint (24) guarantees each vehicle is not carrying products over its weight limit.

Similar to 2PM, the linear programming relaxation technique is applied, relaxing constraints (27) and (28) into (29) and (30) respectively. Next, equations (16)-(26) and (29)-(30) are solved to optimality to obtain the list of customers requiring replenishment in period d+1 (tomorrow).

$$0 \leq y_{dt}^{vr} \leq 1 \qquad \forall v \in V, \forall r \in R, \forall d \in D, \forall t \in T \qquad (29)$$

$$0 \leq z_{dt}^{vr} \leq 1 \qquad \forall v \in V, \forall r \in R, \forall d \in D, \forall t \in T \qquad (30)$$

3.7.2 3PM Phase II

In phase II, the main purpose is to determine the vehicles to be used, trips and routes assigned to individual vehicles where each route indicates the customers to be visited (up to two customers can be visited in the same trip).

Next, only the period d+1 (tomorrow) is considered and the model constructed based on the list of customers requiring a delivery in period d+1 as obtained from phase I. Other customers not on the list are removed from the master problem. The customer tanks and vehicle compartments remain aggregated at this stage. Equations (29) and (30) are reverted to equations (27) and (28) respectively. Next, Equations (16)-(28) are solved using the branch-and-bound algorithm.

3.7.3 3PM Phase III

Upon the completion of phase II, we understand the vehicles to be used and customers to be serviced in each trip and route. Next, we disaggregate the customer tanks and vehicle compartments back to the original, and solve the phase III model to determine how individual vehicle compartments are loaded and assigned to each customer tank in each trip and route. The phase III model is described as follows.

<u>Phase III Model</u>

Objective function:

Maximize $$\sum_{v\in V}\sum_{k\in K}\sum_{r\in R}\sum_{i\in I}\sum_{j\in J}\sum_{d\in D}\sum_{t\in T} x_{ijdt}^{vkr} \qquad (31)$$

Subject to:

$$a_{ij} \le o_{ijdt} \qquad \forall i \in I, \forall j \in J, \forall d \in D, \forall t \in T \qquad (32)$$

$$o_{ijdt} + \sum_{v \in V} \sum_{k \in K} \sum_{r \in R} x_{ijdt}^{vkr} \leq b_{ij} \qquad \forall i \in I, \forall j \in J, \forall d \in D, \forall t \in T \qquad (33)$$

$$o_{ijd,t+1} = o_{ijdt} - s_{ijdt} + \sum_{v \in V} \sum_{k \in K} \sum_{r \in R} x_{ijdt}^{vkr} \qquad \forall i \in I, \forall j \in J, \forall d \in D, \forall t \in T \qquad (34)$$

$$-0.15q^{vk} \leq x_{ijdt}^{vkr} - q^{vk} y_{ijdt}^{vkr} \leq 0 \qquad \forall v \in V, \forall k \in K, \forall r \in R, \forall i \in I, \forall j \in J, \forall d \in D, \forall t \in T \qquad (35)$$

$$\sum_{r \in R} \sum_{i \in I} \sum_{j \in J} y_{ijdt}^{vkr} \leq 1 \qquad \forall v \in V, \forall k \in K, \forall d \in D, \forall t \in T \qquad (36)$$

$$\sum_{k \in K} \sum_{r \in R} \sum_{i \in I} \sum_{j \in J} g^{ij} x_{ijdt}^{vkr} \leq W^{v} \qquad \forall v \in V, \forall d \in D, \forall t \in T \qquad (37)$$

$$x_{ijdt}^{vkr} \in \mathbb{R}^{+} \qquad \forall v \in V, \forall k \in K, \forall r \in R, \forall i \in I, \forall j \in J, \forall d \in D, \forall t \in T \qquad (38)$$

$$y_{ijdt}^{vkr} \in \{0,1\} \qquad \forall v \in V, \forall k \in K, \forall r \in R, \forall i \in I, \forall j \in J, \forall d \in D, \forall t \in T \qquad (39)$$

The objective function (31) maximizes the vehicle loaded quantity for all assigned trips, contributing to the reduction in the transportation unit cost. Constraint (32) ensures that the inventory level for individual tanks must not fall below the minimum requirement (safety stock level) in any given planning horizon. Constraint (34) guarantees that the inventory level after replenishment does not exceed the tank capacity. Constraint (34) ensures the stock equilibrium between connecting trips. Constraint (35) specifies that all vehicle compartments must be loaded at least 85% of its compartment size. Constraint (36) ensures that one vehicle compartment can only be assigned to one customer tank for each trip. Constraint (37) guarantees each vehicle is not carrying products over its' weight limit.

CHAPTER 4

RESULT ANALYSIS

In this chapter, we describe the dataset used for testing the 2PM and 3PM, as well as the results obtained from the proposed algorithms.

4.1 Data

In this study, we used a real-life scenario and randomly generated instance to test the 2PM and 3PM respectively. Firstly, we describe the real-life data.

4.1.1 Real-life scenario

Table 4.1 Customer profile (real-life scenario)

Customer type	No. of sites	No. of sites (pump required)
Petrol station	11	2
Industrial customer	17	17

Customer type	Avg. two-way distance from terminal (kilometers)	Weekly consumption (liters)
Petrol station	29.5	503,600
Industrial customer	40.6	61,500

Table 4.1 shows the number of customers, the number of customers requiring a vehicle equipped with a pump when unloading the product to storage tanks, average two-way distance from terminal, as well as the weekly consumption separated by customer type. As seen, although the number of the petrol stations is less than the number of industrial customers, if we look at the weekly consumption, approximately

89% of the demand is from the petrol stations. Regarding the average two-way distance from the terminal, the industrial customers are located farther comparing to the petrol stations.

Table 4.2 gives the number of petrol stations categorized by range of their daily consumption. Most of the petrol stations sell more than 3,000 liters a day considering all product types. There are 3 product types where the consumption rate for each product is completely different. As shown in Table 4.3, the product type 2 has the highest consumption (83% of the total consumption).

Table 4.2 Number of petrol stations categorized by range of daily consumption (real-life scenario)

Daily consumption (liters)	No. of sites
0-3,000	3
3,001-6,000	4
6,001-9,000	3
>9,000	1

Table 4.3 Percentage of demand consumption by product type (real-life scenario)

Product Type	Percentage (%)
1	6
2	83
3	11

Table 4.4 shows the tank capacity of all petrol stations categorized by range of tank size. Table 4.5 provides details of the vehicle profile. There are three vehicles in total; two of them are chartered as a contracted vehicle (one for each vehicle type), and one vehicle (type 2) is rented on a spot basis. The contracted vehicle involves the monthly fixed cost regardless of how many trips are used. For both contracted vehicle and spotted vehicle, if the vehicle is used, there are other charges including loading fee

and distance fee. Loading fee is charged based on the number of trips made by each vehicle, and the loading rate varies depending on the vehicle type, as well as the contract type. Distance fee is charged based on the total distance in kilometers. Similar to loading fee, the distance fee for each vehicle is different. Apparently, loading and distance fee for the spotted vehicle are much higher than those of the contracted vehicle as no fixed cost is paid.

Table 4.4 Number of petrol station's storage tanks categorized by range of tank size (real-life scenario)

Tank size (liters)	No. of tanks
0-6,000	1
6,001-15,000	15
15,001-30,000	11
>30,000	5

Table 4.5 Vehicle profile (real-life scenario)

Vehicle type	Total capacity (liters)	Max. loaded weight (Kg)	Pump equipped (Yes/No)
1	22,700	19,295	Yes
2	19,000	16,150	No

Vehicle type	No. of compartments	Capacities (liters)
1	3	11,400, 7,500, 3,800
2	3	7,600, 7,600, 3,800

To give more clarity on how the transportation cost is calculated, an example is provided below:

Example

Loading fee per trip	$50.00
Distance fee per kilometer	$4.00
Fixed cost per month	$3,000.00 ($100.00 per day)
Days	2
Total number of trips	10
Total kilometer travelled	500

The variable transportation cost = (50*10) + (4*500) = $2,500
The total transportation cost (incl. fixed cost) = 2,500 + (2*100) = $2,700

4.1.2 Randomly generated test instance

To come up with the larger test instance, we randomly generated conditions similar in nature as the real-life scenario. Table 4.6 shows the number of customers, the number of customers requiring the vehicle equipped with a pump when unloading the product to storage tanks, as well as the weekly consumption. In this test instance, we use only one customer type (petrol station) but with a larger scale. As seen, the number of petrol stations, as well as the weekly consumption is much higher than that of the real-life scenario (approximately 5 times). Regarding the average two-way distance from the terminal, these petrol stations are located considerably far from the terminal. Normally, the vehicle can run around 50-60 kilometers per hour depending on the road and traffic conditions, so it would take around 3-4 hours in average to drive to these customers and return to the fuel terminal.

Table 4.6 Customer profile (randomly generated case)

Customer type	No. of sites	No. of sites (pump required)
Petrol station	50	25

Customer type	Avg. two-way distance from terminal (kilometers)	Weekly consumption (liters)
Petrol station	204	3,077,306

Table 4.7 gives the number of petrol stations categorized by range of their daily consumption. Most of the petrol stations sell more than 6,000 liters a day considering all product types and the consumption rate for each product can be inferred from Table 4.3.

Table 4.7 Number of petrol stations categorized by range of daily consumption (randomly generated case)

Daily consumption (liters)	No. of sites
0-3,000	5
3,001-6,000	9
6,001-9,000	10
>9,000	26

Table 4.8 shows the tank capacity of all petrol stations categorized by tank size. In this test, there are only two tank sizes: 10,000 and 30,000 liters. We assume a 30,000 liter tank size for all tanks containing product type 2 due to the highest consumption.

Table 4.8 Number of petrol station's storage tanks by tank size
(randomly generated case)

Tank size (liters)	No. of tanks
10,000	100
30,000	50

Table 4.9 and 4.10 provide details of the physical vehicle profile as well as the vehicle cost profile. We based these physical vehicle profiles, vehicle cost profiles and configurations on the real-life scenario in one of the countries that is similar in terms of the characteristics. In this test, there are two vehicle types with six contracted vehicles in total (two type 1 vehicles and four type 2 vehicles).

Table 4.9 Vehicle profile (randomly generated case)

Vehicle type	Total capacity (liters)	Max. loaded weight (Kg)	Pump equipped (Yes/No)
1	24,000	20,000	No
2	18,000	15,000	Yes

Vehicle type	No. of compartments	Capacities (liters)
1	5	6,000, 4,000, 4,000, 4,000, 6,000
2	5	4,000, 4,000, 2,000, 4,000, 4,000

Table 4.10 Vehicle cost profile (randomly generated case)

Vehicle type	Monthly fixed cost ($)	Loading fee per trip ($)	Distance fee per kilometer ($)
1	8,333	33	0.7
2	6,667	30	0.5

Referring to the real-life scenario, the daily consumption of each product fluctuates from the estimated consumption demand. The average and standard deviation of the daily consumption variability for each product are shown in Table 12. As seen, the demand consumption for product type 2 is the most stable, followed by product type 3 and 1.

Table 4.11 Daily consumption variability (randomly generated case)

Product	Mean	S.D.
1	26.8%	49.9%
2	2.7%	14.2%
3	17.0%	44.8%

In this test, the fuel terminal is located at coordinates (32, 103), where the petrol stations coordinates are randomly generated between coordinate (0, 0) and (200, 200) as illustrated in Figure 4.1.

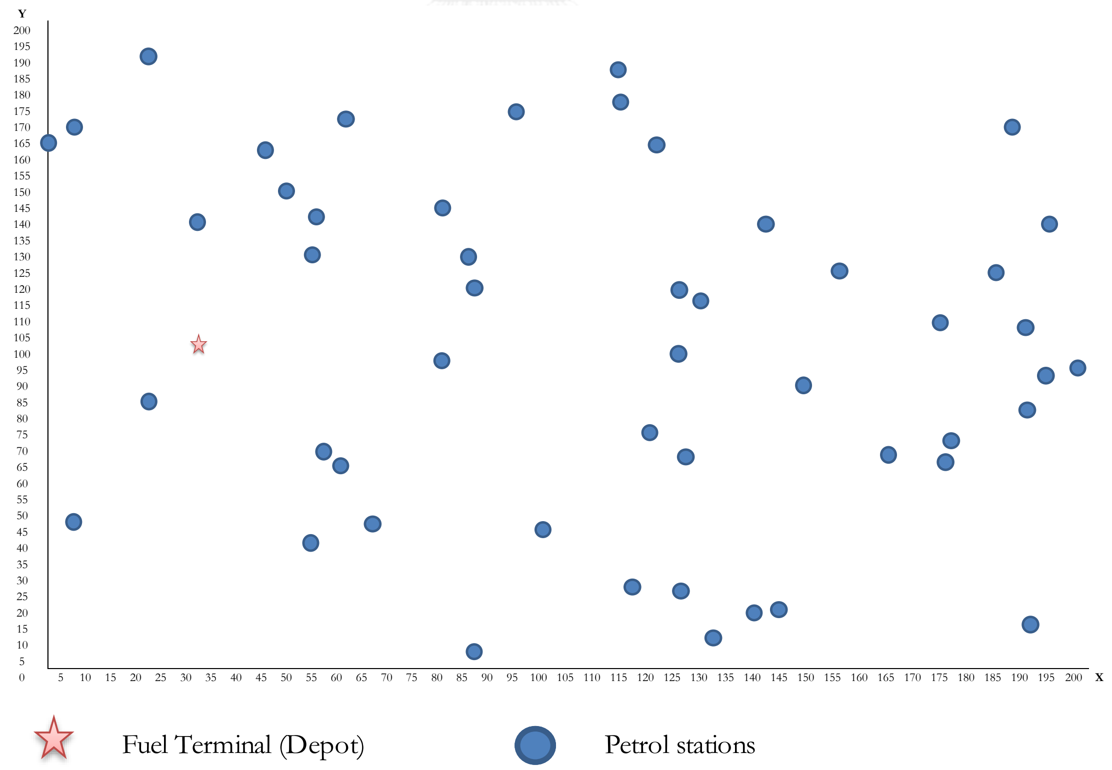

Figure 4.1 Fuel terminal and petrol stations network

4.2 Performance and Effectiveness of Proposed Algorithms

The model was implemented using the VB.NET programming language and the IBM ILOG CPLEX Version 12.6 where the data are kept in the MS Access database 2010. The model was run on an Intel Core i7 with 8GB of memory.

4.2.1 The Two-Phase Method (2PM)

As stated earlier, we tested this approach using real-life conditions. In this section, we provide the results of the 2PM run on several scenarios. Moreover, we compare the results against the replenishment plan created by experienced planners. Before describing the results, we explain how we obtain the coefficient (M).

Table 4.12 Results summary as a function of the coefficient (M) (2PM)

Coefficient (M)	Total loaded volume (liters)	Avg. loaded volume per trip (liters)	Transportation cost ($)*	Transportation unit cost ($/liter)
1	623,019	14,160	6090.8	0.0098
20	613,212	17,034	5394.8	0.0088
30	628,885	17,469	5283.4	0.0084
40	625,392	18,394	5119.8	0.0082
50	587,640	18,956	4845.9	0.0082
60	579,745	19,325	4729.6	0.0082
70	565,827	20,957	4541.6	0.0080
80	571,773	20,420	4615.2	0.0081

*including fixed cost component

We determined an appropriate coefficient (M) from the interactive method, solving the equations (1)-(13) in a single period with different coefficients (M). In this experiment, we tested this over a 9 day planning cycle. The coefficient (M) that gives the best result was selected to be used in the 2PM. Table 4.12 shows the operational results associated with each coefficient (M). In this case, we selected coefficient (M) = 70 as it gives the best result in terms of transportation unit cost. We also tested the sensitivity altering the coefficient (M) between 70 and 80 and found no difference, hence, we used coefficient (M) = 70 for all test scenarios.

The individual test scenarios are described as follows:

1. Consider 1 day planning horizon and solve the problem to optimality
2. Consider 2 days planning horizon and solve the problem to optimality
3. Consider 3 days planning horizon and solve the problem to optimality
4. Consider 4 days planning horizon and solve the problem to optimality
5. Consider 5 days planning horizon and solve the problem to optimality
6. Consider 1 day planning horizon and apply 2PM to solve the problem
7. Consider 2 days planning horizon and apply 2PM to solve the problem
8. Consider 3 days planning horizon and apply 2PM to solve the problem
9. Consider 4 days planning horizon and apply 2PM to solve the problem
10. Consider 5 days planning horizon and apply 2PM to solve the problem

Firstly, we solved all the above scenarios to optimality using the branch-and-bound technique. It was found that as the considered planning horizon was extended to 3 days, the exact method is no longer feasible due to the significant increase in the problem size. Hence, the scenarios 4 and 5 can be intuitively dropped.

In this context, 3 days planning horizon means: if today is period d, we look 3 days ahead (period d+1, d+2 and d+3) in order to come up with the replenishment plan for period d+1.

Table 4.13 and figure 4.2 show the growth in the number of rows, columns and non-zero elements when considering longer periods. These are the cumulative number of rows, columns and non-zero elements after 9 days planning cycle. The problem size grows exponentially as the number of considered planning horizon increases.

Table 4.13 Problem size of original problem (real-life scenario)

Planning horizon considered (days)	No. of rows	No. of columns	No. of non-zero
1	18,896	34,611	104,080
2	34,962	64,365	253,716
3	54,950	100,925	476,788
4	74,763	137,491	752,126
5	81,670	168,325	1,039,085

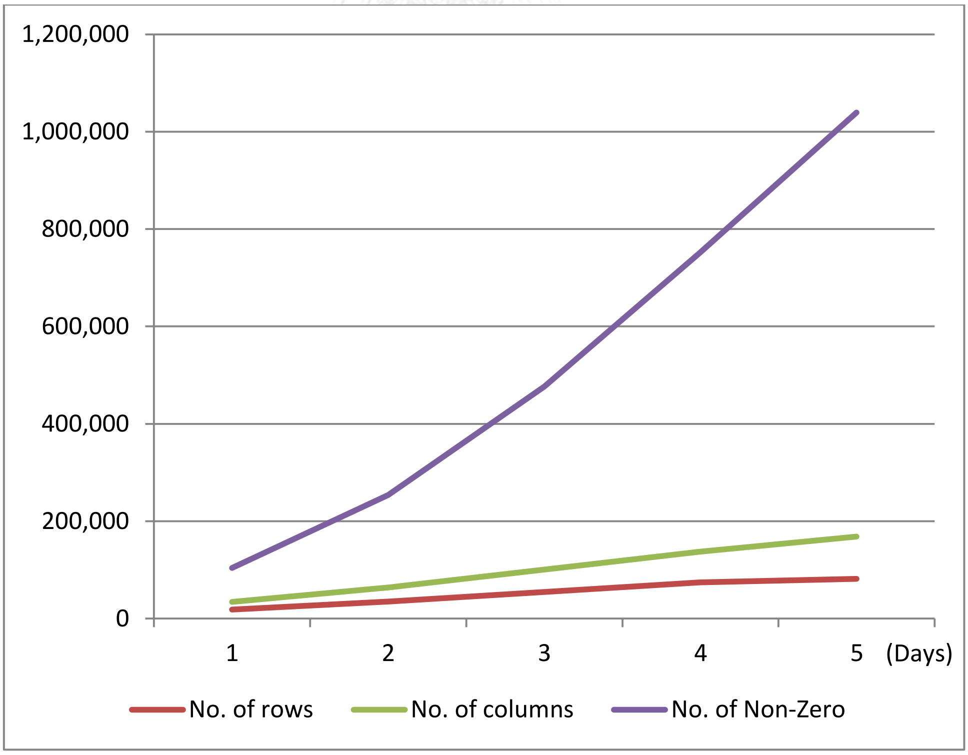

Figure 4.2 Problem size of original problem (real-life scenario)

As previously mentioned, the exact method is no longer practical when the considered planning horizon reaches 3 days, thus, we applied the 2PM for 3, 4 and 5 days planning horizon. Now, the problem size decreased significantly as shown in Table 4.14.

Table 4.14 Problem size after applying 2PM

Planning horizon considered (days)	No. of rows (2PM)	No. of columns (2PM)	No. of non-zero (2PM)
1	10,796	19,660	58,264
2	16,219	29,410	99,431
3	16,901	30,577	102,983
4	17,715	32,083	108,155
5	19,179	34,783	117,092

Next, we explain the results for each scenario. Table 4.15 shows the result of scenario 1 where we consider one day planning horizon and solve the problem to optimality. As seen, the average loaded volume per trip is outstanding, but the number of potential product run out is unacceptable. This is apparently due to the reason that scenario 1 is taking only one day into consideration, overlooking the inventory level for the petrol stations on the following day. For the transportation unit cost, this scenario gives 0.0079$/liter.

Table 4.15 Result of scenario 1 (real-life scenario)

Day	Total trips	No. of potential product run out	Total loaded volume (liters)	Avg. loaded volume per trip (liters)
1	2		45,420	22,710
2				
3	5	3	109,387	21,877
4	5	1	101,249	20,250
5	5	4	93,868	18,774
6	4	1	87,377	21,844
7	4	2	82,702	20,676
8	3	2	62,422	20,807
9				
10		5		
Total	28	18	582,424	20,801

Day	No. of rows	No. of columns	No. of non-zero	Solution times (sec)
1	950	1,716	4,662	0.6
2				
3	3317	6,116	19,540	7.0
4	3,243	5,897	20,452	7.0
5	3,076	5,645	17,502	2.8
6	3,878	7,172	21,001	18.2
7	3,072	5,599	14,953	2.6
8	1,360	2,466	5,970	0.9
9				
Total	18,896	34,611	104,080	39

Remark:

Fuel terminal operated 6:00 – 12:00 on Day 1 and 8

Fuel terminal operated 6:00 – 18:00 on Day 3 – 7

Fuel terminal closed on Day 2 and 9

Additionally, we also tested if consider only maximizing the replenished quantity in the objective function (1) can produce the replenishment plan with a lower transportation unit cost. Hence, we changed the objective function (1) to (40) and solve the equation (40) and equations (2)-(13) in a single period to optimality. In comparison with the result from scenario 1, Table 4.16 shows that it gives a better outcome in terms of operational performance but with a higher transportation unit cost. This particular scenario gives 0.0080$/liter.

Maximize $$\sum_{v\in V}\sum_{r\in R}\sum_{d\in D}\sum_{t\in T}\left[\sum_{k\in K}\sum_{i\in I}\sum_{j\in J} x_{ijdt}^{vkr}\right] \quad (40)$$

Similarly, we also tested if consider only minimizing the transportation cost in the objective function (1) can give a better result regarding the transportation unit cost. Therefore, similar to a previous exercise, we changed the objective function (1) to (41) and solve the equation (41) and equations (2)-(13) in a single period to optimality. In this test scenario, we were able to solve only the first two days planning cycle. The model could not find a feasible solution at day 4. This was because it sought for the replenishment plan that gives the lowest transportation unit cost while ignoring the importance of maximizing replenished quantity, causing the inventory level for each petrol station to be fairly low at day 4. Hence, the model was unable to find a feasible solution due to an insufficient vehicle at day 4.

Maximize $$\sum_{v\in V}\sum_{r\in R}\sum_{d\in D}\sum_{t\in T}[-Mc^{vr}z_{dt}^{vr}] \quad (41)$$

Based on the results from the above two additional exercises, we can conclude that the equations (1)-(13) suits our purpose of finding the fuel replenishment plan with the minimum transportation unit cost.

Table 4.16 Result of scenario 1.1 (real-life scenario)

Day	Total trips	No. of potential product run out	Total loaded volume (liters)	Avg. loaded volume per trip (liters)
1	2		45,420	22,710
2				
3	5	2	117,717	23,543
4	5	1	100,613	20,123
5	4	4	78,876	19,719
6	4		85,757	21,439
7	3	2	65,117	21,706
8	3	2	63,414	21,138
9				
10		5		
Total	26	16	556,914	21,420

Remark:

Fuel terminal operated 6:00 – 12:00 on Day 1 and 8

Fuel terminal operated 6:00 – 18:00 on Day 3 – 7

Fuel terminal closed on Day 2 and 9

Now, we continue with the next scenario (scenario 2). Table 4.17 describes the result of scenario 2 where we consider two days planning horizon and solve the problem to optimality. Comparing to scenario 1, the average loaded volume per trip is slightly smaller, but the number of potential product run out improved significantly (reduced by almost half). This is because scenario 2 is considering two days period when creating the replenishment plan each day. However, the number of potential product run out is still high on day 10 since it didn't consider day 10 while creating the replenishment on day 8. It used only day 8 and 9 in the model. Regarding the transportation unit cost, this scenario gives 0.0082$/liter which is higher than scenario 1.

Table 4.17 Result of scenario 2 (real-life scenario)

Day	Total trips	No. of potential product run out	Total loaded volume (liters)	Avg. loaded volume per trip (liters)
1	2		45,420	22,710
2				
3	4	2	86,624	21,656
4	5		100,514	20,103
5	5	2	101,128	20,226
6	4		87,456	21,864
7	5	1	101,249	20,250
8	2		34,065	17,033
9				
10		5		
Total	27	10	556,456	20,609

Day	No. of rows	No. of columns	No. of non-zero	Solution times (sec)
1	950	1,716	4,662	0.5
2				
3	6755	12,466	51,554	32.7
4	7,664	14,164	57,158	299.4
5	6,500	11,956	48,845	119.3
6	7,398	13,648	55,169	399.0
7	4,829	8,865	32,130	14.8
8	866	1,550	4,198	0.3
9				
Total	34,962	64,365	253,716	866

Remark:

Fuel terminal operated 6:00 – 12:00 on Day 1 and 8

Fuel terminal operated 6:00 – 18:00 on Day 3 – 7

Fuel terminal closed on Day 2 and 9

For scenario 3, as stated earlier, we were unable to solve the problem to optimality when we extended the number of days to 3 due to the significant increase in problem size. Thus, the test scenarios 3, 4 and 5 can be neglected.

In contrast with all the previous scenarios, the 2PM was applied to solve the scenarios 6-10. For scenario 6, only one day planning horizon is considered. Unfortunately, the model could not find a feasible solution at day 4 due to an insufficient vehicle. The following scenario (scenario 7), two days planning horizon is considered where the result is described in Table 4.18. The result shows that it gives a remarkable outcome. All the operational performance, as well as the transportation unit cost are better than the scenario 2 in which the problems were solved to optimality by the Branch-and-Bound technique. This scenario gives 0.0080$/liter in the transportation unit cost.

The result of the scenario 8 is shown in Table 4.19. According to the result, this scenario gives a similar operational performance to all the previous scenarios. However, this scenario gives the best result around the number of potential product run out. Nevertheless, the number of potential product run out at day 10 is still high. For the transportation unit cost, this scenario gives the same result as scenario 7. Next, Table 4.20 describes the result of scenario 9 where we consider 4 days planning horizon and solve the problem using 2PM. As seen, it shows a better outcome in comparison to all the scenarios described earlier, including the number of potential product run out on day 10. For the transportation unit cost, it gives the same result as scenarios 7 and 8.

Lastly, Table 4.21 shows the result of scenario 10 where we consider 5 days planning horizon and apply 2PM to solve the problem. Referring to the result, this scenario gives an outstanding outcome in all dimensions. It also gives the same transportation unit cost as scenario 1 (0.0079$/liter) which is the best among all scenarios.

Table 4.18 Result of scenario 7 (real-life scenario)

Day	Total trips	No. of potential product run out	Total loaded volume (liters)	Avg. loaded volume per trip (liters)
1	4		90,761	22,690
2				
3	4	1	90,685	22,671
4	5		89,894	17,979
5	4		79,107	19,777
6	5		105,382	21,076
7	3	1	58,963	19,654
8	3		64,319	21,440
9				
10		5		
Total	28	7	579,109	20,682

Day	No. of rows	No. of columns	No. of non-zero	Solution times (sec)
1	1,023	1,804	5,750	1.06
2				
3	2,545	4,630	15,920	6.77
4	2,311	4,157	13,816	10.81
5	3,735	6,870	23,394	136.13
6	3,315	6,044	20,326	35.02
7	2,816	5,121	17,730	8.18
8	474	784	2,495	0.42
9				
Total	16,219	29,410	99,431	198.39

Remark:

Fuel terminal operated 6:00 – 12:00 on Day 1 and 8

Fuel terminal operated 6:00 – 18:00 on Day 3 – 7

Fuel terminal closed on Day 2 and 9

Table 4.19 Result of scenario 8 (real-life scenario)

Day	Total trips	No. of potential product run out	Total loaded volume (liters)	Avg. loaded volume per trip (liters)
1	4		90,314	22,578
2				
3	4	1	90,628	22,657
4	5		89,258	17,852
5	3		66,843	22,281
6	5		106,078	21,216
7	3		58,281	19,427
8	4		81,824	20,456
9				
10		5		
Total	28	6	583,227	20,830

Day	No. of rows	No. of columns	No. of non-zero	Solution times (sec)
1	1,447	2,569	8,510	3.4
2				
3	2900	5,289	18,078	20.7
4	2,129	3,779	12,436	8.4
5	3,065	5,609	19,066	14.0
6	3,336	6,093	20,496	26.9
7	1,868	3,361	11,627	1.9
8	2,156	3,877	12,770	2.8
9				
Total	16,901	30,577	102,983	78

Remark:

Fuel Terminal operated 6:00 – 12:00 on Day 1 and 8

Fuel Terminal operated 6:00 – 18:00 on Day 3 – 7

Fuel Terminal closed on Day 2 and 9

Table 4.20 Result of scenario 9 (real-life scenario)

Day	Total trips	No. of potential product run out	Total loaded volume (liters)	Avg. loaded volume per trip (liters)
1	4		90,314	22,578
2				
3	4		90,628	22,657
4	5		89,258	17,852
5	3	1	66,843	22,281
6	5		107,543	21,509
7	4	1	81,646	20,412
8	3		60,340	20,113
9				
10		1		
Total	28	3	586,573	20,949

Day	No. of rows	No. of columns	No. of non-zero	Solution times (sec)
1	1,634	2,908	9,668	4.9
2				
3	2900	5,289	18,078	14.6
4	2,774	4,995	16,656	16.5
5	3,559	6,526	22,145	11.3
6	3,668	6,740	22,822	23.4
7	1,646	2,917	9,926	1.6
8	1,534	2,708	8,860	1.9
9				
Total	17,715	32,083	108,155	74

Remark:

Fuel Terminal operated 6:00 – 12:00 on Day 1 and 8

Fuel Terminal operated 6:00 – 18:00 on Day 3 – 7

Fuel Terminal closed on Day 2 and 9

Table 4.21 Result of scenario 10 (real-life scenario)

Day	Total trips	No. of potential product run out	Total loaded volume (liters)	Avg. loaded volume per trip (liters)
1	4		90,314	22,578
2				
3	4		90,628	22,657
4	5		96,828	19,366
5	3	1	60,560	20,187
6	5		99,583	19,917
7	5	1	105,412	21,082
8	3		56,041	18,680
9				
10				
Total	29	2	599,366	20,668

Day	No. of rows	No. of columns	No. of non-zero	Solution times (sec)
1	1,634	2,908	9,668	4.2
2				
3	2405	4,362	14,979	14.3
4	3,582	6,537	21,984	22.1
5	3,112	5,691	19,266	11.2
6	3,076	5,592	18,831	28.9
7	2,403	4,338	14,616	6.5
8	1,145	1,980	6,699	1.4
9				
Total	17,357	31,408	106,043	89

Remark:

Fuel Terminal operated 6:00 – 12:00 on Day 1 and 8

Fuel Terminal operated 6:00 – 18:00 on Day 3 – 7

Fuel Terminal closed on Day 2 and 9

We have summarized all the results in Table 4.22, showing the results for each scenario in three aspects: operational performance, transportation cost and solution times. According to these results, it is clear that scenario 10 (considering 5 days planning horizon and apply 2PM) is the best despite giving the same transportation unit cost as scenario 1. Scenario 10 is most effective in preventing product run out due to the fact that it explores 5 days ahead as opposed to scenario 1 that takes only one single period into account. Moreover, it can be seen that the longer period of considered planning horizon, the less number of potential product run out. Regarding the solution time, scenario 10 is slightly higher than scenario 1 but it is certainly acceptable, taking only 66 seconds to solve 9 days planning cycle where it takes approximately 50,400 seconds if performed by experienced planners. We also found that it is possible to visit customers more than once a day, ranging between 3–9% out of total number of customer visits.

Lastly, we implemented the 2PM on scenario 10 over a 16 day planning cycle and compared it against the actual results of the replenishment plans made by the experienced planners (more than 10 years of experience) over the same planning cycle. The results comparison is shown in Table 4.23. The results obtained from 2PM are much better than those created by the experienced planners in all dimensions: operational performance, transportation cost and the solving times. Moreover, the cost of human resources can also be saved due to the reduction in fuel replenishment planning time.

Based on the estimation applying 2PM to the real-life scenario for 12 months period, it could generate approximately 40,000$ saving from the reduction in the transportation cost (6,000$) and human resources (34,000$). Additionally, it could efficiently prevent product run out at the petrol stations, leading to higher sales volume.

Table 4.22 Results summary of 2PM (real-life scenario)

Scenario	Total trips	Total no. of customer visits	No. of times that customers are visited more than once/day
1	28	56	4
2	27	53	2
3 - 6	*Unable to solve - Out of memory or no solution exists*		
7	28	55	3
8	28	53	3
9	28	55	3
10	29	57	5

Scenario	No. of potential product run out	Total loaded volume (liters)	Avg. loaded volume per trip (liters)
1	18	582,424	20,801
2	10	556,456	20,609
3 - 6	*Unable to solve - Out of memory or no solution exists*		
7	7	579,109	20,682
8	6	583,227	20,830
9	3	586,573	20,949
10	2	604,188	20,834

Scenario	Transportation cost ($)*	Transportation unit cost ($/liter)	Solution times (sec)
1	4,599.6	0.0079	39
2	4,563.9	0.0082	866
3 - 6	*Unable to solve - Out of memory or no solution exists*		
7	4,661.0	0.0080	65
8	4,675.1	0.0080	78
9	4,684.7	0.0080	74
10	4,766.1	0.0079	66

*including fixed cost component

Table 4.23 Results comparison between 2PM and experienced planner

Scenario	Total trips	Total no. of customer visits	No. of times that customers are visited more than once/day
0**	58	92	1
10	55	106	7

Scenario	No. of potential product run out	Total loaded volume (liters)	Avg. loaded volume per trip (liters)
0**	6	1,119,792	19,307
10	4	1,122,642	20,412

Scenario	Transportation cost ($)*	Transportation unit cost ($/liter)	Solution times (sec)
0**	8,986.0	0.0080	93,600
10	8,779.7	0.0078	173

*including fixed cost component

**replenishment plan created by an experienced planner

4.2.2 The Three-Phase Method (3PM)

The 2PM approach is very effective and efficient in solving the problem of multi-period fuel replenishment, however, it has a limitation in the problem size. If the problem size is huge, the 2PM will become unpractical and unable to solve the problem. We tested this assumption by applying the 2PM to solve a larger test instance, considering only one day planning horizon. The 2PM was unable to solve the problem due to insufficient memory. Therefore, we introduced the 3PM which offers a similar approach but has an ability to solve a larger problem. We tested this approach with the randomly generated test instance described in Chapter 4.1.2.

Similar to the 2PM, we determined an appropriate coefficient (M) from the interactive method over a 1 day planning cycle. Table 4.24 shows that coefficient (M) = 60 gives the lowest transportation unit cost, thus, we use this for all test scenarios.

Table 4.24 Results summary as a function of the coefficient M (3PM)

Coefficient (M)	Total loaded volume (liters)	Avg. loaded volume per trip (liters)	Transportation cost ($)*	Transportation unit cost ($/liter)
1	478,578	19,941	4,848.8	0.0101
10	474,477	19,770	5,047.2	0.0106
20	478,452	19,936	4,915.9	0.0103
30	479,307	19,971	4,874.6	0.0102
40	476,209	19,842	4,788.5	0.0101
50	480,000	20,000	4,842.0	0.0101
60	479,246	19,969	4,776.9	0.0100
70	475,960	19,832	4,793.9	0.0101
80	476,446	19,852	4,789.0	0.0101

*including fixed cost component

The individual test scenarios are described as follows:

1. Consider 1 day planning horizon and apply 3PM
2. Consider 2 days planning horizon and apply 3PM
3. Consider 3 days planning horizon and apply 3PM
4. Consider 4 days planning horizon and apply 3PM
5. Consider 5 days planning horizon and apply 3PM

Table 4.25 and Figure 4.3, Table 4.26 and Figure 4.4, and Table 4.27 and Figure 4.5 show the number of rows, columns and non-zero elements respectively at each stage of the 3PM approach for all test scenarios. These are the cumulative number of rows, columns and non-zero elements for a 7 day planning cycle. As seen, the problem size grows exponentially as the number of days increases, especially the non-zero element. Before applying the 3PM approach, it went beyond 60 million when we extended the planning horizon to 5 days. This cannot be solved to optimality with an exact algorithm nor the 2PM. Hence, decomposing such a problem in 3 phases, the problem size reduces significantly, and the problem is now solvable in a polynomial time.

Table 4.25 Comparison of the number of rows in each step of 3PM

Planning horizon considered (days)	No. of rows (Original)	No. of rows (Phase I)
1	905,352	66,584
2	1,810,697	133,168
3	2,716,051	199,752
4	3,621,401	266,336
5	4,526,751	332,920
Planning horizon considered (days)	**No. of rows (Phase II)**	**No. of rows (Phase III)**
1	51,136	6,455
2	65,210	6,381
3	62,110	6,295
4	76,865	6,235
5	77,005	6,597

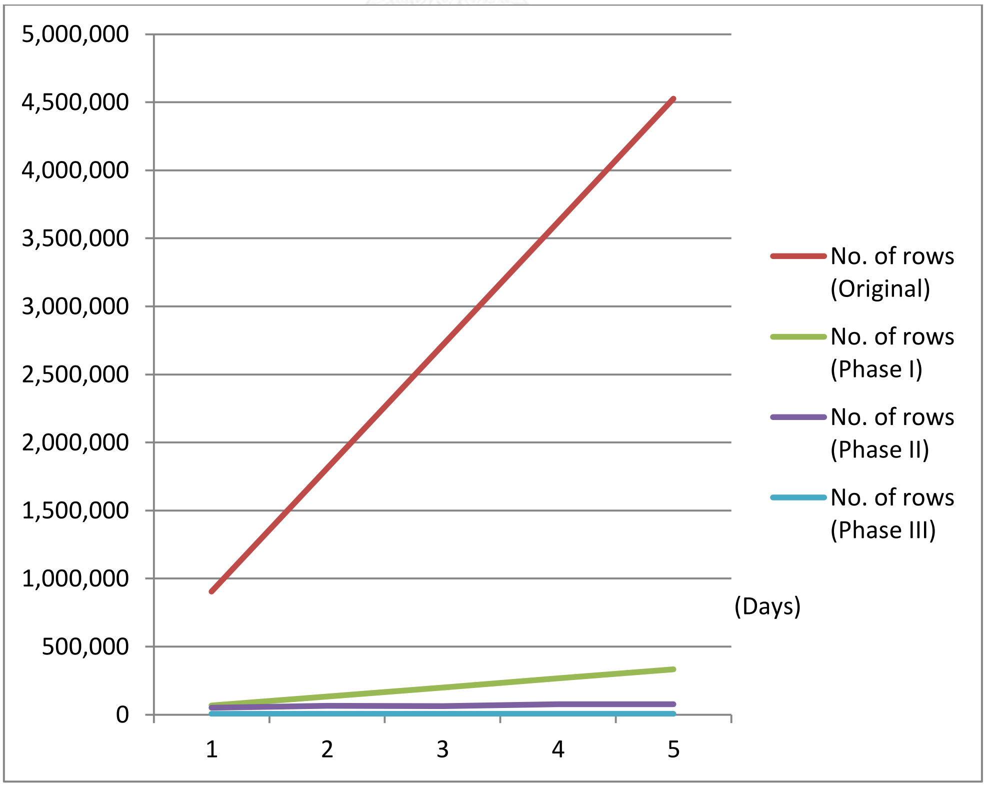

Figure 4.3 Comparison of the number of rows in each step of 3PM

Table 4.26 Comparison of the number of columns in each step of 3PM

Planning horizon considered (days)	No. of columns (Original)	No. of columns (Phase I)
1	1,767,864	122,696
2	3,535,728	245,392
3	5,303,592	368,088
4	7,071,456	490,784
5	8,839,320	613,480
Planning horizon considered (days)	**No. of columns (Phase II)**	**No. of columns (Phase III)**
1	93,280	9,450
2	118,910	9,300
3	113,080	9,150
4	141,180	9,060
5	141,470	9,660

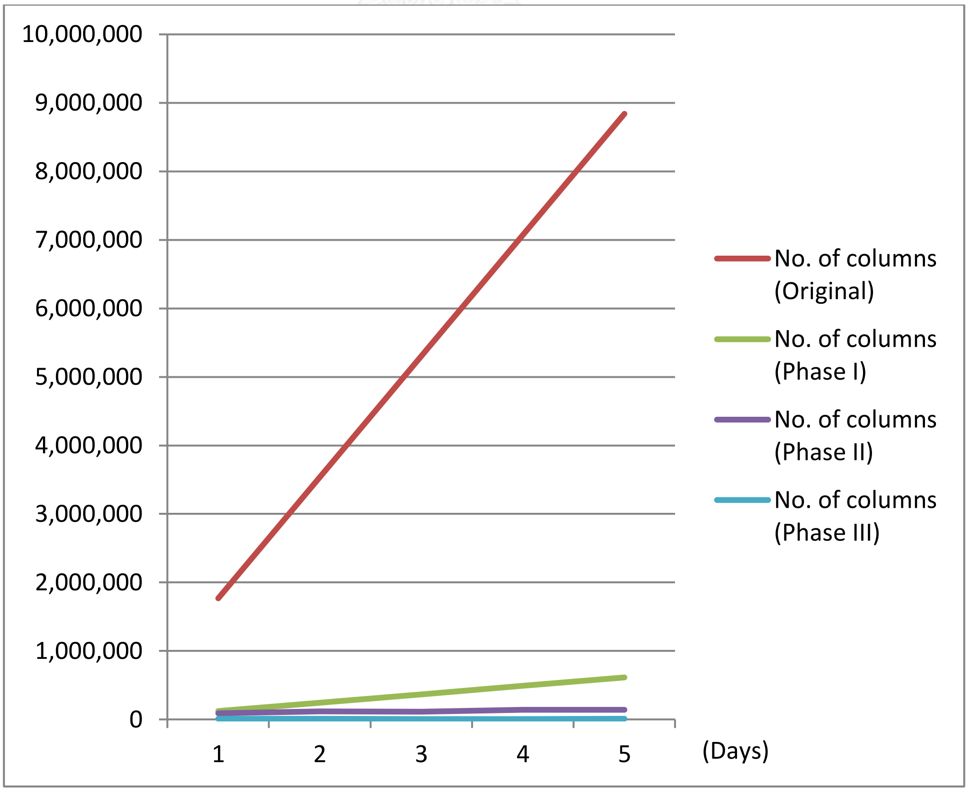

Figure 4.4 Comparison of the number of columns in each step of 3PM

Table 4.27 Comparison of the number of Non-Zero in each step of 3PM

Planning horizon considered (days)	No. of Non-Zero (Original)	No. of Non-Zero (Phase I)
1	5,705,028	364,588
2	14,880,936	960,568
3	27,837,945	1,787,940
4	44,322,734	2,846,704
5	64,410,260	4,136,860
Planning horizon considered (days)	**No. of Non-Zero (Phase II)**	**No. of Non-Zero (Phase III)**
1	276,864	19,560
2	380,720	19,500
3	361,960	19,170
4	452,550	18,870
5	453,500	20,025

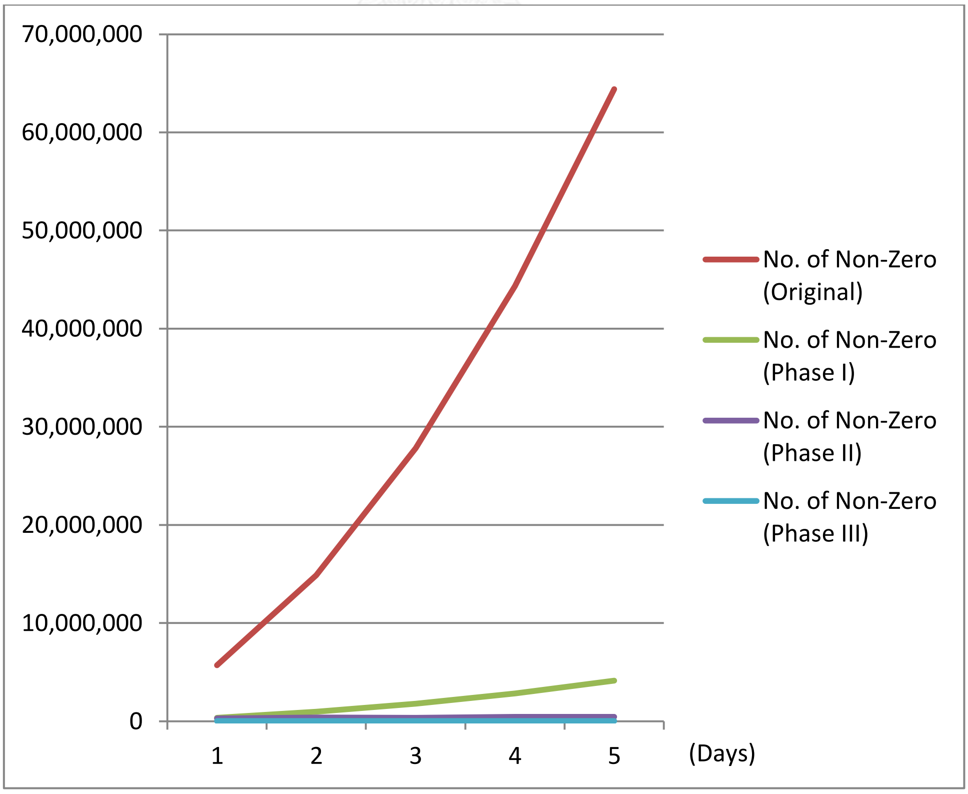

Figure 4.5 Comparison of the number of Non-Zero in each step of 3PM

We tested the above scenarios over a 7 day planning cycle. In this case, we solved phase I and III to optimality but limited the solution time in phase II to 600 seconds as we found phase II typically takes time due to the problem size and containing integer variables.

Table 4.28, Table 4.29, Table 4.30, Table 4.31 and Table 4.32 show the daily results of scenario 1, 2, 3, 4 and 5 respectively. As seen, all scenarios give a similar outcome regarding the operational performance. The only difference is the number of potential product run out: 1 for scenario 1, and 0 for other scenarios. Although there is one potential product run out in scenario 1, it proves that the 3PM can handle the problem effectively.

In this case, the number of product run out seems to be very low even the case that we considered only one day planning horizon (single-period). This is because the fuel terminal is operating every day, so the customers having a low inventory level can be replenished on a timely fashion.

Table 4.28 Result of scenario 1 (randomly generated case)

Day	Total trips	No. of potential product run out	Total loaded volume (liters)	Avg. loaded volume per trip (liters)
1	24		473,893	19,746
2	22		412,685	18,758
3	22		407,906	18,541
4	24		461,120	19,213
5	24		468,535	19,522
6	24	1	469,353	19,556
7	24		467,317	19,472
Total	164	1	3,160,809	19,273

Remark: Fuel Terminal operates every day

Table 4.29 Result of scenario 2 (randomly generated case)

Day	Total trips	No. of potential product run out	Total loaded volume (liters)	Avg. loaded volume per trip (liters)
1	24		471,713	19,655
2	22		418,134	19,006
3	23		429,762	18,685
4	23		441,880	19,212
5	24		472,677	19,695
6	24		470,446	19,602
7	24		469,732	19,572
Total	164	0	3,174,344	19,356

Remark: Fuel Terminal operates every day

Table 4.30 Result of scenario 3 (randomly generated case)

Day	Total trips	No. of potential product run out	Total loaded volume (liters)	Avg. loaded volume per trip (liters)
1	24		464,727	19,364
2	23		430,953	18,737
3	22		405,892	18,450
4	23		445,179	19,356
5	24		467,640	19,485
6	24		472,652	19,694
7	24		470,945	19,623
Total	164	0	3,157,988	19,256

Remark: Fuel Terminal operates every day

Table 4.31 Result of scenario 4 (randomly generated case)

Day	Total trips	No. of potential product run out	Total loaded volume (liters)	Avg. loaded volume per trip (liters)
1	24		475,603	19,817
2	21		383,541	18,264
3	23		416,330	18,101
4	24		468,317	19,513
5	24		463,714	19,321
6	24		465,761	19,407
7	24		468,509	19,521
Total	164	0	3,141,775	19,157

Remark: Fuel Terminal operates every day

Table 4.32 Result of scenario 5 (randomly generated case)

Day	Total trips	No. of potential product run out	Total loaded volume (liters)	Avg. loaded volume per trip (liters)
1	24		475,072	19,795
2	22		397,790	18,081
3	22		422,416	19,201
4	24		469,522	19,563
5	24		473,506	19,729
6	24		467,542	19,481
7	24		470,324	19,597
Total	164	0	3,176,172	19,367

Remark: Fuel Terminal operates every day

We have summarized all the results in Table 4.33, showing the operational performance, transportation unit cost and solution times for each test scenario. The test result proves that the 3PM can give an outstanding performance within a reasonable solving time. The average loaded volume per trip is considerably high. In terms of the vehicle capacity utilization, it was higher than 95% for all test scenarios. The number of potential run out is also very impressive. Moreover, with the same problem size, it normally requires 4 hours to complete each day planning cycle, even when performed by an experienced planner, thus, for a 7 day planning cycle, it would take approximately 28 hours or 100,800 seconds. In this case, we found approximately 14–18% of customers are visited more than once a day.

By comparing the results among all test scenarios, it is obvious that scenario 5 (considering 5 days planning horizon and apply 3PM) gives the best result in all aspects. This is a similar finding as the 2PM results where we achieve a better result when the number of considered planning horizon increases.

Table 4.33 Results summary of 3PM

Planning horizon considered (days)	Total trips	Total no. of customer visits	No. of times that customers are visited more than once/day
1	164	315	47
2	164	310	54
3	164	305	48
4	164	302	44
5	164	322	52

Planning horizon considered (days)	No. of potential product run out	Total loaded volume (liters)	Avg. loaded volume per trip (liters)
1	1	3,160,809	19,273
2	0	3,174,344	19,356
3	0	3,157,988	19,256
4	0	3,141,775	19,157
5	0	3,176,172	19,367

Planning horizon considered (days)	Transportation cost ($)*	Transportation unit cost ($/liter)	Solution times (sec)
1	35,052.5	0.0111	982
2	35,712.0	0.0113	1842
3	35,302.8	0.0112	1958
4	35,221.5	0.0112	1686
5	35,342.4	0.0111	1994

*including fixed cost component

CHAPTER 5

CONCLUSION

The fuel replenishment planning, from the fuel terminal to petrol stations and industrial customers, is exceptionally complicated. One has to determine the set of routes, approximate delivery time (trip), vehicles to be used for delivering petroleum products for those routes, quantity of the product to be loaded on each vehicle compartment and specify how and when to discharge to each customer's storage tank following the safety guidelines and country regulations. Moreover, there are several constraints (as described in Chapter 1) that must be honored when devising the fuel replenishment plan. Further complication arises when the number of customers increase, consequently leading to a higher number of vehicles, storage tanks, routes, trips, etc. Despite in a small problem, we often find that it requires many planners and lead time to complete the fuel replenishment plan. Another challenge is that planners need to submit a completed fuel replenishment plan to the transport company by the agreed timeline. Due to the time constraints, it is challenging for planners to devise a fuel replenishment plan that minimizes transportation costs while satisfying all the constraints and requirements.

To minimize the transportation cost, considering fuel replenishment in a single period does not necessarily guarantee the minimum cost in the long term. It may provide the best solution for the first day, but it could potentially give a poor solution on the following day because it is a sequential decision. The solution is to holistically consider multiple periods when planning for the fuel replenishment.

According to the past studies, we found many previous studies have considered the fuel replenishment problem with multiple periods. However, we found none of them have proved that solving the model considering multiple periods outperforms those with a single period. Also, to the best of the author' knowledge, none of these studies allow customers to be visited more than once per day, which does not reflect the real-life situation where high demand customers could be served several times per day.

To solve such problems, we observed that most of the past studies proposed heuristic approaches to solve the fuel replenishment problem because the exact method might not be an appropriate approach to solve large scale problems.

With the above background, in this study, the author purposes two heuristic approaches, the 2PM and 3PM, to solve the multi-period fuel replenishment planning problem. The 2PM is primarily designed for solving small problems, whereas the 3PM adopts a similar approach but has the ability to solve a larger problem. We used real-life data and randomly generated test instance to test the 2PM and 3PM, respectively.

According to the results, both approaches prove that the solution obtained from the multi-period model is superior to single-period in many aspects: lower transportation unit cost, less time for devising the replenishment plan, lower the product run out, etc. This is because the multi-period model explores several days ahead as opposed to the single-period model that takes only one single period into account. The only disadvantage for the multi-period model is the problem-solving time. Despite the fact that, it requires longer solving time in comparison to the single-period model because of a larger in the problem size, the solving time is still acceptable and much faster comparing to the current practice where the replenishment plan is devised by the experienced planners.

In addition, the proposed solution (2PM) outperforms the solution constructed by the planners who possess more than 10 years of fuel replenishment planning experience. Based on the estimation applying 2PM to the real-life scenario for 12 months period, it could generate approximately 40,000$ saving and efficiently prevent product run out at the petrol stations, leading to higher sales volume.

In case that the fuel terminal is operating on a 24/7 basis, we also found that considering only one day planning horizon (single-period) gives an acceptable outcome, and the model can be solved much faster in comparison to the multi-period model.

Furthermore, it is possible for customers to be visited more than once a day, which reflects the real-life situation where high demand customers could potentially be served several times per day. Additionally, by allowing customers to be visited more than once a day, it can give a better outcome in terms of vehicle utilization as there is more opportunity for delivery to other customers in the same route, maximizing the vehicle compartment usage.

Future studies could consider incorporating inventory holding cost and opportunity cost in the model in case a product runs out, better reflecting the real-life situation. The author is also interested in finding new solution approaches that are able to solve a very large scale problem given that the replenishment plan must be constructed within a reasonable time frame. It would also be of interest is to find a solution approach that can recommend replenishment plan adjustment, which happens in real-time due to an uncertainty in fuel consumption at each customer site, as well as other unexpected issues such as vehicle breakdown, product outage at fuel terminal etc., while maintaining a low transportation unit cost. As fuel consumption is stochastic in nature and the fuel consumption forecast is the most crucial factor for fuel replenishment planning, investigation of a statistical model and new forecasting method that accurately predicts fuel consumption at each customer site would also be beneficial.

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APPENDIX

Appendix A Real-life Data

No.	Customer Name	One way distance from fuel terminal to location (km)
1	IC1	3.2
2	IC2	19.3
3	IC3	11.3
4	IC4	20.9
5	IC5	20.9
6	IC6	32.2
7	IC7	38.6
8	IC8	22.5
9	IC9	35.4
10	IC10	8.1
11	IC11	16.1
12	IC12	6.4
13	IC13	27.4
14	IC14	27.4
15	IC15	27.4
16	IC16	3.2
17	PS1	22.5
18	PS2	27.4
19	PS3	6.4
20	PS4	19.3
21	PS5	12.9
22	PS6	14.5
23	PS7	20.9
24	PS8	6.4
25	PS9	4.3

No.	Customer Name	One way distance from fuel terminal to location (km)
26	PS10	17.7
27	PS11	9.7

ID	Product Type	Tank No.	Physical tank size (liters)	Tank capacity (liters)	Tank safety stock level (liters)
PS1	1	3	3675	3308	958
PS1	3	1	14830	13347	2248
PS1	3	2	14830	13347	2248
PS2	2	2	14455	13009	1491
PS2	1	3	14455	13009	1491
PS2	3	1	22320	20088	2256
PS3	2	3	18058	16252	1843
PS3	1	2	17816	16034	1518
PS3	3	1	36654	32989	3285
PS4	2	2	23225	20902	3558
PS4	1	3	14584	13125	2044
PS4	3	1	36101	32491	3880
PS5	2	2	29633	26669	2873
PS5	1	3	14830	13347	2248
PS5	3	1	35942	32348	3618
PS6	2	2	22699	20429	3475
PS6	3	1	22619	20357	3550
PS7	2	2	15163	13646	1911
PS7	3	3	7566	6810	1207
PS7	3	1	14769	13292	2051
PS8	2	2	17861	16075	1802

ID	Product Type	Tank No.	Physical tank size (liters)	Tank capacity (liters)	Tank safety stock level (liters)
PS8	1	3	18395	16556	1862
PS8	3	1	36756	33081	3974
PS9	2	2	8986	8087	1302
PS9	1	3	8986	8087	1302
PS9	3	1	23164	20848	2203
PS10	2	3	11355	10220	2271
PS10	3	2	11279	10151	2256
PS10	3	1	22566	20310	4512
PS11	2	2	14830	13347	2195
PS11	1	3	14830	13347	2248
PS11	3	1	36696	33026	3827

ID	Product Type	Tank No.	Fuel consumption (liters)	Day	ID	Product Type	Tank No.	Fuel consumption (liters)	Day
PS1	1	3	34	1	PS6	3	1	3425	1
PS1	1	3	0	2	PS6	3	1	2415	2
PS1	1	3	170	3	PS6	3	1	4319	3
PS1	1	3	64	4	PS6	3	1	3815	4
PS1	1	3	19	5	PS6	3	1	4099	5
PS1	1	3	57	6	PS6	3	1	3819	6
PS1	1	3	68	7	PS6	3	1	4088	7
PS1	1	3	4	8	PS6	3	1	3157	8
PS1	1	3	4	9	PS6	3	1	3592	9
PS1	1	3	15	10	PS6	3	1	3482	10
PS1	1	3	57	11	PS6	3	1	4243	11
PS1	1	3	98	12	PS6	3	1	3902	12
PS1	1	3	34	13	PS6	3	1	4962	13
PS1	1	3	0	14	PS6	3	1	4186	14
PS1	1	3	38	15	PS6	3	1	3142	15
PS1	3	1	2320	1	PS7	2	2	174	1
PS1	3	1	2112	2	PS7	2	2	182	2
PS1	3	1	2782	3	PS7	2	2	307	3

ID	Product Type	Tank No.	Fuel consumption (liters)	Day	ID	Product Type	Tank No.	Fuel consumption (liters)	Day
PS1	3	1	1741	4	PS7	2	2	189	4
PS1	3	1	2487	5	PS7	2	2	189	5
PS1	3	1	2127	6	PS7	2	2	163	6
PS1	3	1	2381	7	PS7	2	2	643	7
PS1	3	1	2797	8	PS7	2	2	379	8
PS1	3	1	1919	9	PS7	2	2	140	9
PS1	3	1	3176	10	PS7	2	2	15	10
PS1	3	1	2385	11	PS7	2	2	265	11
PS1	3	1	2210	12	PS7	2	2	144	12
PS1	3	1	2093	13	PS7	2	2	310	13
PS1	3	1	2226	14	PS7	2	2	242	14
PS1	3	1	1760	15	PS7	2	2	318	15
PS1	3	2	1344	1	PS7	3	1	3785	1
PS1	3	2	1207	2	PS7	3	1	3085	2
PS1	3	2	1120	3	PS7	3	1	4375	3
PS1	3	2	1412	4	PS7	3	1	3463	4
PS1	3	2	1404	5	PS7	3	1	6431	5
PS1	3	2	1480	6	PS7	3	1	3952	6
PS1	3	2	1798	7	PS7	3	1	7180	7
PS1	3	2	920	8	PS7	3	1	3785	8
PS1	3	2	1567	9	PS7	3	1	3278	9
PS1	3	2	1052	10	PS7	3	1	6056	10
PS1	3	2	1370	11	PS7	3	1	3944	11
PS1	3	2	1987	12	PS7	3	1	3346	12
PS1	3	2	1688	13	PS7	3	1	4444	13
PS1	3	2	1321	14	PS7	3	1	4538	14
PS1	3	2	1862	15	PS7	3	1	3456	15
PS2	2	2	462	1	PS7	3	3	1067	1
PS2	2	2	170	2	PS7	3	3	1741	2
PS2	2	2	140	3	PS7	3	3	1983	3
PS2	2	2	68	4	PS7	3	3	1927	4
PS2	2	2	72	5	PS7	3	3	1893	5
PS2	2	2	238	6	PS7	3	3	2430	6
PS2	2	2	68	7	PS7	3	3	1980	7
PS2	2	2	185	8	PS7	3	3	1382	8
PS2	2	2	91	9	PS7	3	3	1949	9

ID	Product Type	Tank No.	Fuel consumption (liters)	Day	ID	Product Type	Tank No.	Fuel consumption (liters)	Day
PS2	2	2	121	10	PS7	3	3	1329	10
PS2	2	2	76	11	PS7	3	3	1688	11
PS2	2	2	431	12	PS7	3	3	1911	12
PS2	2	2	64	13	PS7	3	3	2082	13
PS2	2	2	473	14	PS7	3	3	1639	14
PS2	2	2	129	15	PS7	3	3	1995	15
PS2	1	3	49	1	PS8	2	2	348	1
PS2	1	3	26	2	PS8	2	2	326	2
PS2	1	3	68	3	PS8	2	2	715	3
PS2	1	3	38	4	PS8	2	2	749	4
PS2	1	3	390	5	PS8	2	2	496	5
PS2	1	3	140	6	PS8	2	2	908	6
PS2	1	3	64	7	PS8	2	2	651	7
PS2	1	3	34	8	PS8	2	2	360	8
PS2	1	3	68	9	PS8	2	2	337	9
PS2	1	3	72	10	PS8	2	2	776	10
PS2	1	3	238	11	PS8	2	2	431	11
PS2	1	3	64	12	PS8	2	2	295	12
PS2	1	3	185	13	PS8	2	2	651	13
PS2	1	3	144	14	PS8	2	2	920	14
PS2	1	3	95	15	PS8	2	2	500	15
PS2	3	1	2445	1	PS8	1	3	2260	1
PS2	3	1	2279	2	PS8	1	3	1631	2
PS2	3	1	2983	3	PS8	1	3	742	3
PS2	3	1	2434	4	PS8	1	3	2914	4
PS2	3	1	2623	5	PS8	1	3	1980	5
PS2	3	1	2790	6	PS8	1	3	1893	6
PS2	3	1	2922	7	PS8	1	3	2570	7
PS2	3	1	1945	8	PS8	1	3	2332	8
PS2	3	1	2362	9	PS8	1	3	1639	9
PS2	3	1	2491	10	PS8	1	3	3020	10
PS2	3	1	2290	11	PS8	1	3	1586	11
PS2	3	1	2562	12	PS8	1	3	2169	12
PS2	3	1	2229	13	PS8	1	3	1927	13
PS2	3	1	2725	14	PS8	1	3	2846	14
PS2	3	1	2070	15	PS8	1	3	1563	15

ID	Product Type	Tank No.	Fuel consumption (liters)	Day	ID	Product Type	Tank No.	Fuel consumption (liters)	Day
PS3	2	3	507	1	PS8	3	1	9379	1
PS3	2	3	628	2	PS8	3	1	8811	2
PS3	2	3	882	3	PS8	3	1	11313	3
PS3	2	3	2759	4	PS8	3	1	10167	4
PS3	2	3	1162	5	PS8	3	1	12714	5
PS3	2	3	439	6	PS8	3	1	11124	6
PS3	2	3	1052	7	PS8	3	1	11283	7
PS3	2	3	1306	8	PS8	3	1	9099	8
PS3	2	3	776	9	PS8	3	1	9375	9
PS3	2	3	916	10	PS8	3	1	11029	10
PS3	2	3	1037	11	PS8	3	1	10443	11
PS3	2	3	848	12	PS8	3	1	8887	12
PS3	2	3	1162	13	PS8	3	1	11128	13
PS3	2	3	500	14	PS8	3	1	11166	14
PS3	2	3	795	15	PS8	3	1	8444	15
PS3	1	2	511	1	PS9	2	2	114	1
PS3	1	2	121	2	PS9	2	2	185	2
PS3	1	2	250	3	PS9	2	2	227	3
PS3	1	2	98	4	PS9	2	2	95	4
PS3	1	2	189	5	PS9	2	2	121	5
PS3	1	2	322	6	PS9	2	2	125	6
PS3	1	2	356	7	PS9	2	2	129	7
PS3	1	2	553	8	PS9	2	2	185	8
PS3	1	2	148	9	PS9	2	2	57	9
PS3	1	2	242	10	PS9	2	2	140	10
PS3	1	2	269	11	PS9	2	2	182	11
PS3	1	2	201	12	PS9	2	2	132	12
PS3	1	2	42	13	PS9	2	2	87	13
PS3	1	2	1052	14	PS9	2	2	117	14
PS3	1	2	163	15	PS9	2	2	49	15
PS3	3	1	7657	1	PS9	1	3	182	1
PS3	3	1	4182	2	PS9	1	3	49	2
PS3	3	1	7930	3	PS9	1	3	212	3
PS3	3	1	7790	4	PS9	1	3	178	4
PS3	3	1	5178	5	PS9	1	3	261	5
PS3	3	1	6892	6	PS9	1	3	170	6

ID	Product Type	Tank No.	Fuel consumption (liters)	Day	ID	Product Type	Tank No.	Fuel consumption (liters)	Day
PS3	3	1	7438	7	PS9	1	3	329	7
PS3	3	1	6673	8	PS9	1	3	204	8
PS3	3	1	5829	9	PS9	1	3	19	9
PS3	3	1	6317	10	PS9	1	3	326	10
PS3	3	1	6620	11	PS9	1	3	363	11
PS3	3	1	5965	12	PS9	1	3	257	12
PS3	3	1	6177	13	PS9	1	3	159	13
PS3	3	1	6870	14	PS9	1	3	0	14
PS3	3	1	5670	15	PS9	1	3	53	15
PS4	2	2	284	1	PS9	3	1	2017	1
PS4	2	2	261	2	PS9	3	1	1885	2
PS4	2	2	307	3	PS9	3	1	2305	3
PS4	2	2	269	4	PS9	3	1	2316	4
PS4	2	2	431	5	PS9	3	1	3005	5
PS4	2	2	299	6	PS9	3	1	2937	6
PS4	2	2	337	7	PS9	3	1	3039	7
PS4	2	2	238	8	PS9	3	1	2074	8
PS4	2	2	273	9	PS9	3	1	1980	9
PS4	2	2	299	10	PS9	3	1	3316	10
PS4	2	2	363	11	PS9	3	1	2123	11
PS4	2	2	273	12	PS9	3	1	2131	12
PS4	2	2	148	13	PS9	3	1	2192	13
PS4	2	2	390	14	PS9	3	1	2786	14
PS4	2	2	295	15	PS9	3	1	2286	15
PS4	1	3	34	1	PS10	2	3	284	1
PS4	1	3	167	2	PS10	2	3	189	2
PS4	1	3	1223	3	PS10	2	3	167	3
PS4	1	3	1730	4	PS10	2	3	299	4
PS4	1	3	761	5	PS10	2	3	235	5
PS4	1	3	969	6	PS10	2	3	238	6
PS4	1	3	401	7	PS10	2	3	254	7
PS4	1	3	23	8	PS10	2	3	208	8
PS4	1	3	420	9	PS10	2	3	360	9
PS4	1	3	712	10	PS10	2	3	242	10
PS4	1	3	825	11	PS10	2	3	310	11
PS4	1	3	655	12	PS10	2	3	379	12

ID	Product Type	Tank No.	Fuel consumption (liters)	Day	ID	Product Type	Tank No.	Fuel consumption (liters)	Day
PS4	1	3	481	13	PS10	2	3	276	13
PS4	1	3	254	14	PS10	2	3	341	14
PS4	1	3	212	15	PS10	2	3	227	15
PS4	3	1	5201	1	PS10	3	1	6953	1
PS4	3	1	3721	2	PS10	3	1	5723	2
PS4	3	1	5117	3	PS10	3	1	5178	3
PS4	3	1	4656	4	PS10	3	1	4637	4
PS4	3	1	5867	5	PS10	3	1	4451	5
PS4	3	1	5216	6	PS10	3	1	7244	6
PS4	3	1	5852	7	PS10	3	1	4304	7
PS4	3	1	4357	8	PS10	3	1	6487	8
PS4	3	1	3634	9	PS10	3	1	5204	9
PS4	3	1	5984	10	PS10	3	1	5405	10
PS4	3	1	5280	11	PS10	3	1	4860	11
PS4	3	1	3123	12	PS10	3	1	4921	12
PS4	3	1	4667	13	PS10	3	1	5783	13
PS4	3	1	6745	14	PS10	3	1	5284	14
PS4	3	1	4985	15	PS10	3	1	6684	15
PS5	2	2	428	1	PS10	3	2	0	1
PS5	2	2	416	2	PS10	3	2	4	2
PS5	2	2	242	3	PS10	3	2	0	3
PS5	2	2	276	4	PS10	3	2	0	4
PS5	2	2	310	5	PS10	3	2	4	5
PS5	2	2	201	6	PS10	3	2	4	6
PS5	2	2	265	7	PS10	3	2	0	7
PS5	2	2	390	8	PS10	3	2	0	8
PS5	2	2	276	9	PS10	3	2	4	9
PS5	2	2	140	10	PS10	3	2	0	10
PS5	2	2	238	11	PS10	3	2	0	11
PS5	2	2	201	12	PS10	3	2	0	12
PS5	2	2	246	13	PS10	3	2	0	13
PS5	2	2	284	14	PS10	3	2	0	14
PS5	2	2	500	15	PS10	3	2	0	15
PS5	1	3	905	1	PS11	2	2	57	1
PS5	1	3	1056	2	PS11	2	2	140	2
PS5	1	3	3225	3	PS11	2	2	0	3

ID	Product Type	Tank No.	Fuel consumption (liters)	Day	ID	Product Type	Tank No.	Fuel consumption (liters)	Day
PS5	1	3	1075	4	PS11	2	2	53	4
PS5	1	3	700	5	PS11	2	2	72	5
PS5	1	3	1798	6	PS11	2	2	42	6
PS5	1	3	1597	7	PS11	2	2	163	7
PS5	1	3	1435	8	PS11	2	2	64	8
PS5	1	3	1400	9	PS11	2	2	117	9
PS5	1	3	958	10	PS11	2	2	72	10
PS5	1	3	795	11	PS11	2	2	42	11
PS5	1	3	1404	12	PS11	2	2	15	12
PS5	1	3	204	13	PS11	2	2	34	13
PS5	1	3	1794	14	PS11	2	2	64	14
PS5	1	3	500	15	PS11	2	2	30	15
PS5	3	1	5034	1	PS11	1	3	15	1
PS5	3	1	4500	2	PS11	1	3	170	2
PS5	3	1	5602	3	PS11	1	3	314	3
PS5	3	1	6518	4	PS11	1	3	469	4
PS5	3	1	4985	5	PS11	1	3	242	5
PS5	3	1	6828	6	PS11	1	3	254	6
PS5	3	1	6283	7	PS11	1	3	575	7
PS5	3	1	5220	8	PS11	1	3	0	8
PS5	3	1	4962	9	PS11	1	3	64	9
PS5	3	1	5617	10	PS11	1	3	394	10
PS5	3	1	6067	11	PS11	1	3	45	11
PS5	3	1	6075	12	PS11	1	3	553	12
PS5	3	1	5836	13	PS11	1	3	231	13
PS5	3	1	6135	14	PS11	1	3	276	14
PS5	3	1	4845	15	PS11	1	3	30	15
PS6	2	2	136	1	PS11	3	1	1628	1
PS6	2	2	57	2	PS11	3	1	2188	2
PS6	2	2	132	3	PS11	3	1	1893	3
PS6	2	2	238	4	PS11	3	1	1325	4
PS6	2	2	246	5	PS11	3	1	1351	5
PS6	2	2	254	6	PS11	3	1	1241	6
PS6	2	2	390	7	PS11	3	1	1514	7
PS6	2	2	53	8	PS11	3	1	1291	8
PS6	2	2	235	9	PS11	3	1	1143	9

ID	Product Type	Tank No.	Fuel consumption (liters)	Day	ID	Product Type	Tank No.	Fuel consumption (liters)	Day
PS6	2	2	125	10	PS11	3	1	1556	10
PS6	2	2	185	11	PS11	3	1	1344	11
PS6	2	2	83	12	PS11	3	1	1987	12
PS6	2	2	246	13	PS11	3	1	1347	13
PS6	2	2	299	14	PS11	3	1	1817	14
PS6	2	2	144	15	PS11	3	1	1612	15

Appendix B Randomly Generated Test Instance

Customer	Coordinate		Pump required	Distance from fuel terminal	Weekly sales volume (liters)
	x	Y			
Fuel terminal	32	103			
1	191	171	Y	173	88904
2	194	93		162	22184
3	139	21	Y	135	63379
4	7	171		72	50293
5	133	12	Y	136	12332
6	82	97	Y	50	15828
7	59	65		47	85314
8	156	125	Y	126	31946
9	127	27	Y	122	95880
10	44	163		61	76631
11	127	119	Y	96	94176
12	126	99	Y	94	87944
13	131	118	Y	100	93373
14	79	145		63	37867
15	23	192		89	58686
16	199	94		167	97596
17	117	21		118	55979
18	88	8	Y	110	77756
19	185	124		154	83541
20	62	172	Y	75	49207
21	178	72		149	42734
22	1	165	Y	69	66526
23	94	174		94	30599
24	66	47	Y	66	15107
25	189	82	Y	158	13320
26	120	74	Y	93	31168
27	122	165		109	61883
28	100	46		89	94788

Customer	Coordinate		Pump required	Distance from fuel terminal	Weekly sales volume (liters)
	x	y			
29	127	68		101	57499
30	175	66		148	87388
31	51	149		50	86669
32	56	131		37	79729
33	146	21	Y	140	20970
34	151	89	Y	120	57525
35	56	143	Y	47	31521
36	55	42		65	36063
37	142	140	Y	116	79154
38	194	140		166	37533
39	164	67	Y	137	78526
40	58	69		43	91290
41	86	128	Y	60	68569
42	115	187		118	83658
43	175	109		143	60051
44	7	47	Y	61	59591
45	193	16		183	74414
46	32	140	Y	37	32669
47	114	178		111	70763
48	87	120	Y	58	92462
49	27	85	Y	19	72080
50	189	107		157	84241

Customer	Product 1 - Avg. sales volume/day (liters)			Product 2 - Avg. sales volume/day (liters)			Product 3 - Avg. sales volume/day (liters)		
	Wkday	Sat	Sun	Wkday	Sat	Sun	Wkday	Sat	Sun
1	1029	892	814	683	592	540	11641	10091	9211
2	257	223	203	170	148	135	2905	2518	2298
3	733	636	580	487	422	385	8299	7194	6567
4	582	505	461	386	335	306	6585	5709	5211
5	143	124	113	95	82	75	1615	1400	1278
6	183	159	145	122	105	96	2072	1797	1640
7	987	856	781	655	568	519	11171	9684	8839
8	370	321	293	245	213	194	4183	3626	3310
9	1110	962	878	736	638	583	12554	10883	9934
10	887	769	702	589	510	466	10034	8698	7940
11	1090	945	862	723	627	572	12331	10690	9758
12	1018	882	805	675	586	535	11515	9983	9112
13	1081	937	855	717	622	568	12226	10599	9674
14	438	380	347	291	252	230	4958	4298	3923
15	679	589	537	451	391	357	7684	6661	6080
16	1129	979	894	750	650	593	12779	11078	10112
17	648	562	513	430	373	340	7330	6354	5800
18	900	780	712	597	518	473	10181	8826	8056
19	967	838	765	642	556	508	10939	9483	8656
20	569	494	451	378	328	299	6443	5585	5098
21	495	429	391	328	285	260	5595	4851	4428
22	770	667	609	511	443	404	8711	7551	6893
23	354	307	280	235	204	186	4007	3473	3170
24	175	152	138	116	101	92	1978	1715	1565
25	154	134	122	102	89	81	1744	1512	1380
26	361	313	285	239	208	189	4081	3538	3229
27	716	621	567	475	412	376	8103	7024	6412

Customer	Product 1 - Avg. sales volume/day (liters)			Product 2 - Avg. sales volume/day (liters)			Product 3 - Avg. sales volume/day (liters)		
	Wkday	Sat	Sun	Wkday	Sat	Sun	Wkday	Sat	Sun
28	1097	951	868	728	631	576	12411	10759	9821
29	665	577	527	442	383	349	7529	6527	5957
30	1011	877	800	671	582	531	11442	9919	9054
31	1003	870	794	666	577	527	11348	9838	8980
32	923	800	730	612	531	485	10439	9050	8261
33	243	210	192	161	140	127	2746	2380	2173
34	666	577	527	442	383	350	7532	6530	5960
35	365	316	289	242	210	192	4127	3578	3266
36	417	362	330	277	240	219	4722	4094	3736
37	916	794	725	608	527	481	10364	8985	8201
38	434	377	344	288	250	228	4914	4260	3889
39	909	788	719	603	523	477	10282	8913	8136
40	1056	916	836	701	608	555	11953	10362	9459
41	794	688	628	527	457	417	8978	7783	7104
42	968	839	766	643	557	508	10954	9496	8668
43	695	602	550	461	400	365	7863	6816	6222
44	690	598	546	458	397	362	7803	6764	6174
45	861	747	681	572	495	452	9744	8447	7710
46	378	328	299	251	218	199	4278	3708	3385
47	819	710	648	544	471	430	9265	8032	7332
48	1070	928	847	710	616	562	12107	10495	9580
49	834	723	660	554	480	438	9438	8182	7468
50	975	845	771	647	561	512	11030	9562	8728

ID	Product Type	Tank No.	Fuel consumption (liters)	Day	ID	Product Type	Tank No.	Fuel consumption (liters)	Day
1	1	3	842	1	26	1	3	285	1
1	1	3	516	2	26	1	3	368	2
1	1	3	1468	3	26	1	3	778	3
1	1	3	1275	4	26	1	3	106	4
1	1	3	1705	5	26	1	3	639	5
1	1	3	1026	6	26	1	3	248	6
1	1	3	1285	7	26	1	3	722	7
1	2	1	1128	1	26	2	1	312	1
1	2	1	480	2	26	2	1	247	2
1	2	1	739	3	26	2	1	366	3
1	2	1	1122	4	26	2	1	289	4
1	2	1	444	5	26	2	1	281	5
1	2	1	931	6	26	2	1	334	6
1	2	1	1324	7	26	2	1	152	7
1	3	2	8508	1	26	3	2	4179	1
1	3	2	8818	2	26	3	2	3156	2
1	3	2	10931	3	26	3	2	3950	3
1	3	2	10294	4	26	3	2	4169	4
1	3	2	12391	5	26	3	2	3542	5
1	3	2	10315	6	26	3	2	4673	6
1	3	2	11288	7	26	3	2	4632	7
2	1	3	281	1	27	1	3	263	1
2	1	3	25	2	27	1	3	1089	2
2	1	3	225	3	27	1	3	861	3
2	1	3	364	4	27	1	3	725	4
2	1	3	386	5	27	1	3	0	5
2	1	3	419	6	27	1	3	468	6
2	1	3	78	7	27	1	3	973	7
2	2	1	167	1	27	2	1	554	1
2	2	1	226	2	27	2	1	406	2
2	2	1	236	3	27	2	1	328	3
2	2	1	115	4	27	2	1	695	4
2	2	1	140	5	27	2	1	693	5
2	2	1	68	6	27	2	1	135	6
2	2	1	280	7	27	2	1	486	7
2	3	2	2667	1	27	3	2	4594	1

ID	Product Type	Tank No.	Fuel consumption (liters)	Day	ID	Product Type	Tank No.	Fuel consumption (liters)	Day
2	3	2	2077	2	27	3	2	4631	2
2	3	2	2855	3	27	3	2	8922	3
2	3	2	3449	4	27	3	2	8797	4
2	3	2	2829	5	27	3	2	7641	5
2	3	2	3182	6	27	3	2	9616	6
2	3	2	3388	7	27	3	2	8063	7
3	1	3	864	1	28	1	3	476	1
3	1	3	968	2	28	1	3	1584	2
3	1	3	1519	3	28	1	3	1601	3
3	1	3	922	4	28	1	3	1577	4
3	1	3	530	5	28	1	3	806	5
3	1	3	531	6	28	1	3	1612	6
3	1	3	294	7	28	1	3	284	7
3	2	1	474	1	28	2	1	1027	1
3	2	1	170	2	28	2	1	1087	2
3	2	1	454	3	28	2	1	1011	3
3	2	1	453	4	28	2	1	480	4
3	2	1	340	5	28	2	1	1888	5
3	2	1	914	6	28	2	1	448	6
3	2	1	219	7	28	2	1	666	7
3	3	2	6967	1	28	3	2	9259	1
3	3	2	7301	2	28	3	2	10447	2
3	3	2	8744	3	28	3	2	12863	3
3	3	2	9343	4	28	3	2	14612	4
3	3	2	8639	5	28	3	2	14742	5
3	3	2	5978	6	28	3	2	15174	6
3	3	2	6587	7	28	3	2	13539	7
4	1	3	583	1	29	1	3	475	1
4	1	3	511	2	29	1	3	1042	2
4	1	3	520	3	29	1	3	138	3
4	1	3	217	4	29	1	3	826	4
4	1	3	1079	5	29	1	3	1482	5
4	1	3	980	6	29	1	3	840	6
4	1	3	323	7	29	1	3	969	7
4	2	1	446	1	29	2	1	409	1
4	2	1	354	2	29	2	1	390	2

ID	Product Type	Tank No.	Fuel consumption (liters)	Day	ID	Product Type	Tank No.	Fuel consumption (liters)	Day
4	2	1	547	3	29	2	1	487	3
4	2	1	569	4	29	2	1	718	4
4	2	1	544	5	29	2	1	735	5
4	2	1	634	6	29	2	1	967	6
4	2	1	301	7	29	2	1	677	7
4	3	2	5307	1	29	3	2	6218	1
4	3	2	6433	2	29	3	2	5211	2
4	3	2	6244	3	29	3	2	7790	3
4	3	2	7444	4	29	3	2	5589	4
4	3	2	8205	5	29	3	2	8425	5
4	3	2	6720	6	29	3	2	7600	6
4	3	2	6510	7	29	3	2	6526	7
5	1	3	209	1	30	1	3	1869	1
5	1	3	158	2	30	1	3	1547	2
5	1	3	103	3	30	1	3	1261	3
5	1	3	155	4	30	1	3	2126	4
5	1	3	161	5	30	1	3	2479	5
5	1	3	200	6	30	1	3	1391	6
5	1	3	184	7	30	1	3	1267	7
5	2	1	169	1	30	2	1	525	1
5	2	1	165	2	30	2	1	811	2
5	2	1	185	3	30	2	1	1206	3
5	2	1	40	4	30	2	1	647	4
5	2	1	206	5	30	2	1	714	5
5	2	1	185	6	30	2	1	1183	6
5	2	1	131	7	30	2	1	453	7
5	3	2	1575	1	30	3	2	9237	1
5	3	2	1356	2	30	3	2	9582	2
5	3	2	1719	3	30	3	2	11325	3
5	3	2	1230	4	30	3	2	15274	4
5	3	2	1555	5	30	3	2	10208	5
5	3	2	2043	6	30	3	2	11957	6
5	3	2	1654	7	30	3	2	11888	7
6	1	3	87	1	31	1	3	1375	1
6	1	3	50	2	31	1	3	459	2
6	1	3	369	3	31	1	3	2011	3

ID	Product Type	Tank No.	Fuel consumption (liters)	Day	ID	Product Type	Tank No.	Fuel consumption (liters)	Day
6	1	3	139	4	31	1	3	1114	4
6	1	3	191	5	31	1	3	568	5
6	1	3	327	6	31	1	3	1564	6
6	1	3	190	7	31	1	3	815	7
6	2	1	65	1	31	2	1	650	1
6	2	1	78	2	31	2	1	339	2
6	2	1	179	3	31	2	1	551	3
6	2	1	133	4	31	2	1	1383	4
6	2	1	82	5	31	2	1	720	5
6	2	1	148	6	31	2	1	432	6
6	2	1	117	7	31	2	1	558	7
6	3	2	2021	1	31	3	2	9055	1
6	3	2	1856	2	31	3	2	9718	2
6	3	2	2102	3	31	3	2	10603	3
6	3	2	2222	4	31	3	2	8688	4
6	3	2	1941	5	31	3	2	8659	5
6	3	2	2011	6	31	3	2	10639	6
6	3	2	2170	7	31	3	2	11981	7
7	1	3	1409	1	32	1	3	1886	1
7	1	3	1326	2	32	1	3	890	2
7	1	3	932	3	32	1	3	165	3
7	1	3	370	4	32	1	3	1714	4
7	1	3	844	5	32	1	3	1037	5
7	1	3	709	6	32	1	3	1093	6
7	1	3	1016	7	32	1	3	1236	7
7	2	1	435	1	32	2	1	1012	1
7	2	1	1023	2	32	2	1	642	2
7	2	1	489	3	32	2	1	950	3
7	2	1	1097	4	32	2	1	562	4
7	2	1	870	5	32	2	1	1224	5
7	2	1	1012	6	32	2	1	930	6
7	2	1	1169	7	32	2	1	1188	7
7	3	2	13554	1	32	3	2	8468	1
7	3	2	9571	2	32	3	2	8490	2
7	3	2	10405	3	32	3	2	10792	3
7	3	2	10252	4	32	3	2	10384	4

ID	Product Type	Tank No.	Fuel consumption (liters)	Day	ID	Product Type	Tank No.	Fuel consumption (liters)	Day
7	3	2	12784	5	32	3	2	9608	5
7	3	2	15977	6	32	3	2	10959	6
7	3	2	11823	7	32	3	2	9317	7
8	1	3	72	1	33	1	3	162	1
8	1	3	220	2	33	1	3	203	2
8	1	3	631	3	33	1	3	354	3
8	1	3	757	4	33	1	3	202	4
8	1	3	290	5	33	1	3	337	5
8	1	3	742	6	33	1	3	333	6
8	1	3	442	7	33	1	3	434	7
8	2	1	449	1	33	2	1	225	1
8	2	1	339	2	33	2	1	55	2
8	2	1	288	3	33	2	1	154	3
8	2	1	531	4	33	2	1	79	4
8	2	1	180	5	33	2	1	172	5
8	2	1	70	6	33	2	1	207	6
8	2	1	468	7	33	2	1	206	7
8	3	2	3678	1	33	3	2	2034	1
8	3	2	3405	2	33	3	2	1474	2
8	3	2	4625	3	33	3	2	3347	3
8	3	2	4645	4	33	3	2	2536	4
8	3	2	3673	5	33	3	2	2612	5
8	3	2	3636	6	33	3	2	2929	6
8	3	2	4375	7	33	3	2	2565	7
9	1	3	949	1	34	1	3	431	1
9	1	3	1448	2	34	1	3	519	2
9	1	3	1596	3	34	1	3	448	3
9	1	3	975	4	34	1	3	241	4
9	1	3	1997	5	34	1	3	601	5
9	1	3	1713	6	34	1	3	670	6
9	1	3	2038	7	34	1	3	883	7
9	2	1	851	1	34	2	1	365	1
9	2	1	851	2	34	2	1	754	2
9	2	1	909	3	34	2	1	698	3
9	2	1	159	4	34	2	1	917	4
9	2	1	1156	5	34	2	1	641	5

ID	Product Type	Tank No.	Fuel consumption (liters)	Day	ID	Product Type	Tank No.	Fuel consumption (liters)	Day
9	2	1	823	6	34	2	1	724	6
9	2	1	902	7	34	2	1	628	7
9	3	2	8402	1	34	3	2	5849	1
9	3	2	9727	2	34	3	2	6901	2
9	3	2	13926	3	34	3	2	9334	3
9	3	2	14949	4	34	3	2	8150	4
9	3	2	8736	5	34	3	2	8929	5
9	3	2	12336	6	34	3	2	9375	6
9	3	2	13105	7	34	3	2	8075	7
10	1	3	1313	1	35	1	3	126	1
10	1	3	701	2	35	1	3	351	2
10	1	3	963	3	35	1	3	547	3
10	1	3	1777	4	35	1	3	199	4
10	1	3	913	5	35	1	3	711	5
10	1	3	742	6	35	1	3	543	6
10	1	3	745	7	35	1	3	556	7
10	2	1	230	1	35	2	1	293	1
10	2	1	345	2	35	2	1	317	2
10	2	1	521	3	35	2	1	119	3
10	2	1	179	4	35	2	1	500	4
10	2	1	1063	5	35	2	1	133	5
10	2	1	471	6	35	2	1	182	6
10	2	1	1007	7	35	2	1	315	7
10	3	2	9802	1	35	3	2	3032	1
10	3	2	8754	2	35	3	2	2575	2
10	3	2	8706	3	35	3	2	3875	3
10	3	2	8243	4	35	3	2	3921	4
10	3	2	10144	5	35	3	2	3541	5
10	3	2	7987	6	35	3	2	4374	6
10	3	2	9164	7	35	3	2	3730	7
11	1	3	1193	1	36	1	3	463	1
11	1	3	1222	2	36	1	3	341	2
11	1	3	817	3	36	1	3	985	3
11	1	3	909	4	36	1	3	765	4
11	1	3	1522	5	36	1	3	590	5
11	1	3	1199	6	36	1	3	570	6

ID	Product Type	Tank No.	Fuel consumption (liters)	Day	ID	Product Type	Tank No.	Fuel consumption (liters)	Day
11	1	3	882	7	36	1	3	168	7
11	2	1	628	1	36	2	1	378	1
11	2	1	988	2	36	2	1	311	2
11	2	1	915	3	36	2	1	309	3
11	2	1	570	4	36	2	1	249	4
11	2	1	854	5	36	2	1	244	5
11	2	1	823	6	36	2	1	456	6
11	2	1	881	7	36	2	1	357	7
11	3	2	12860	1	36	3	2	3064	1
11	3	2	8464	2	36	3	2	3534	2
11	3	2	13979	3	36	3	2	6098	3
11	3	2	13090	4	36	3	2	4473	4
11	3	2	13454	5	36	3	2	4716	5
11	3	2	11008	6	36	3	2	5055	6
11	3	2	10559	7	36	3	2	5843	7
12	1	3	903	1	37	1	3	901	1
12	1	3	1584	2	37	1	3	1271	2
12	1	3	1869	3	37	1	3	1468	3
12	1	3	812	4	37	1	3	1131	4
12	1	3	1890	5	37	1	3	1237	5
12	1	3	1170	6	37	1	3	1412	6
12	1	3	2180	7	37	1	3	986	7
12	2	1	1160	1	37	2	1	1051	1
12	2	1	293	2	37	2	1	775	2
12	2	1	800	3	37	2	1	830	3
12	2	1	781	4	37	2	1	700	4
12	2	1	868	5	37	2	1	812	5
12	2	1	733	6	37	2	1	1006	6
12	2	1	1203	7	37	2	1	830	7
12	3	2	9218	1	37	3	2	10692	1
12	3	2	8765	2	37	3	2	10090	2
12	3	2	11482	3	37	3	2	13296	3
12	3	2	12961	4	37	3	2	10211	4
12	3	2	10688	5	37	3	2	9206	5
12	3	2	11347	6	37	3	2	9518	6
12	3	2	12228	7	37	3	2	11519	7

ID	Product Type	Tank No.	Fuel consumption (liters)	Day	ID	Product Type	Tank No.	Fuel consumption (liters)	Day
13	1	3	1253	1	38	1	3	507	1
13	1	3	802	2	38	1	3	316	2
13	1	3	2517	3	38	1	3	634	3
13	1	3	1092	4	38	1	3	369	4
13	1	3	1637	5	38	1	3	726	5
13	1	3	1631	6	38	1	3	393	6
13	1	3	1610	7	38	1	3	359	7
13	2	1	746	1	38	2	1	159	1
13	2	1	623	2	38	2	1	206	2
13	2	1	1188	3	38	2	1	267	3
13	2	1	770	4	38	2	1	105	4
13	2	1	764	5	38	2	1	136	5
13	2	1	1827	6	38	2	1	330	6
13	2	1	1545	7	38	2	1	493	7
13	3	2	11999	1	38	3	2	4884	1
13	3	2	8150	2	38	3	2	3989	2
13	3	2	12297	3	38	3	2	4263	3
13	3	2	13534	4	38	3	2	5439	4
13	3	2	11788	5	38	3	2	4676	5
13	3	2	13667	6	38	3	2	4708	6
13	3	2	11908	7	38	3	2	5487	7
14	1	3	688	1	39	1	3	468	1
14	1	3	534	2	39	1	3	763	2
14	1	3	288	3	39	1	3	488	3
14	1	3	591	4	39	1	3	978	4
14	1	3	858	5	39	1	3	1128	5
14	1	3	304	6	39	1	3	1018	6
14	1	3	486	7	39	1	3	1129	7
14	2	1	305	1	39	2	1	910	1
14	2	1	106	2	39	2	1	471	2
14	2	1	284	3	39	2	1	100	3
14	2	1	442	4	39	2	1	685	4
14	2	1	470	5	39	2	1	617	5
14	2	1	252	6	39	2	1	281	6
14	2	1	361	7	39	2	1	541	7
14	3	2	5211	1	39	3	2	9180	1

ID	Product Type	Tank No.	Fuel consumption (liters)	Day	ID	Product Type	Tank No.	Fuel consumption (liters)	Day
14	3	2	4068	2	39	3	2	7011	2
14	3	2	5743	3	39	3	2	8576	3
14	3	2	5302	4	39	3	2	8937	4
14	3	2	6450	5	39	3	2	10707	5
14	3	2	5382	6	39	3	2	10890	6
14	3	2	4698	7	39	3	2	12283	7
15	1	3	499	1	40	1	3	587	1
15	1	3	1136	2	40	1	3	1227	2
15	1	3	448	3	40	1	3	2149	3
15	1	3	1034	4	40	1	3	1586	4
15	1	3	1066	5	40	1	3	989	5
15	1	3	764	6	40	1	3	1397	6
15	1	3	282	7	40	1	3	1712	7
15	2	1	391	1	40	2	1	503	1
15	2	1	221	2	40	2	1	792	2
15	2	1	402	3	40	2	1	1032	3
15	2	1	580	4	40	2	1	624	4
15	2	1	555	5	40	2	1	1294	5
15	2	1	772	6	40	2	1	1105	6
15	2	1	487	7	40	2	1	691	7
15	3	2	5063	1	40	3	2	13042	1
15	3	2	7811	2	40	3	2	10702	2
15	3	2	10008	3	40	3	2	10505	3
15	3	2	8008	4	40	3	2	12942	4
15	3	2	7707	5	40	3	2	10972	5
15	3	2	8893	6	40	3	2	11734	6
15	3	2	6161	7	40	3	2	12323	7
16	1	3	1024	1	41	1	3	797	1
16	1	3	1318	2	41	1	3	1370	2
16	1	3	2568	3	41	1	3	1046	3
16	1	3	1439	4	41	1	3	947	4
16	1	3	1741	5	41	1	3	1640	5
16	1	3	83	6	41	1	3	777	6
16	1	3	1836	7	41	1	3	938	7
16	2	1	694	1	41	2	1	545	1
16	2	1	879	2	41	2	1	460	2

ID	Product Type	Tank No.	Fuel consumption (liters)	Day	ID	Product Type	Tank No.	Fuel consumption (liters)	Day
16	2	1	1083	3	41	2	1	685	3
16	2	1	1260	4	41	2	1	658	4
16	2	1	516	5	41	2	1	647	5
16	2	1	471	6	41	2	1	626	6
16	2	1	1103	7	41	2	1	806	7
16	3	2	10667	1	41	3	2	6511	1
16	3	2	10098	2	41	3	2	5362	2
16	3	2	13315	3	41	3	2	8522	3
16	3	2	11388	4	41	3	2	7211	4
16	3	2	12961	5	41	3	2	10591	5
16	3	2	14032	6	41	3	2	10365	6
16	3	2	12063	7	41	3	2	8289	7
17	1	3	567	1	42	1	3	1496	1
17	1	3	437	2	42	1	3	1154	2
17	1	3	495	3	42	1	3	923	3
17	1	3	1246	4	42	1	3	1546	4
17	1	3	831	5	42	1	3	1346	5
17	1	3	975	6	42	1	3	653	6
17	1	3	593	7	42	1	3	1045	7
17	2	1	294	1	42	2	1	330	1
17	2	1	74	2	42	2	1	903	2
17	2	1	612	3	42	2	1	831	3
17	2	1	665	4	42	2	1	536	4
17	2	1	772	5	42	2	1	465	5
17	2	1	750	6	42	2	1	43	6
17	2	1	560	7	42	2	1	648	7
17	3	2	6049	1	42	3	2	9650	1
17	3	2	5206	2	42	3	2	9658	2
17	3	2	9278	3	42	3	2	13812	3
17	3	2	8043	4	42	3	2	7945	4
17	3	2	8047	5	42	3	2	12572	5
17	3	2	8689	6	42	3	2	11943	6
17	3	2	3903	7	42	3	2	11118	7
18	1	3	1193	1	43	1	3	1050	1
18	1	3	1179	2	43	1	3	767	2
18	1	3	1241	3	43	1	3	443	3

ID	Product Type	Tank No.	Fuel consumption (liters)	Day	ID	Product Type	Tank No.	Fuel consumption (liters)	Day
18	1	3	703	4	43	1	3	601	4
18	1	3	1788	5	43	1	3	1138	5
18	1	3	365	6	43	1	3	928	6
18	1	3	1470	7	43	1	3	546	7
18	2	1	772	1	43	2	1	377	1
18	2	1	718	2	43	2	1	165	2
18	2	1	728	3	43	2	1	643	3
18	2	1	876	4	43	2	1	506	4
18	2	1	865	5	43	2	1	875	5
18	2	1	743	6	43	2	1	403	6
18	2	1	979	7	43	2	1	428	7
18	3	2	7739	1	43	3	2	8618	1
18	3	2	7588	2	43	3	2	6251	2
18	3	2	12111	3	43	3	2	8811	3
18	3	2	9498	4	43	3	2	7597	4
18	3	2	13005	5	43	3	2	6363	5
18	3	2	12327	6	43	3	2	7483	6
18	3	2	10625	7	43	3	2	6927	7
19	1	3	852	1	44	1	3	605	1
19	1	3	1225	2	44	1	3	724	2
19	1	3	1336	3	44	1	3	1408	3
19	1	3	736	4	44	1	3	998	4
19	1	3	383	5	44	1	3	1150	5
19	1	3	612	6	44	1	3	615	6
19	1	3	1100	7	44	1	3	1424	7
19	2	1	928	1	44	2	1	457	1
19	2	1	811	2	44	2	1	213	2
19	2	1	969	3	44	2	1	870	3
19	2	1	409	4	44	2	1	1006	4
19	2	1	586	5	44	2	1	461	5
19	2	1	1019	6	44	2	1	786	6
19	2	1	884	7	44	2	1	415	7
19	3	2	9311	1	44	3	2	6995	1
19	3	2	8274	2	44	3	2	5962	2
19	3	2	9455	3	44	3	2	7260	3
19	3	2	7577	4	44	3	2	7472	4

ID	Product Type	Tank No.	Fuel consumption (liters)	Day	ID	Product Type	Tank No.	Fuel consumption (liters)	Day
19	3	2	12186	5	44	3	2	7195	5
19	3	2	11651	6	44	3	2	8632	6
19	3	2	11511	7	44	3	2	7734	7
20	1	3	44	1	45	1	3	521	1
20	1	3	384	2	45	1	3	577	2
20	1	3	430	3	45	1	3	1070	3
20	1	3	580	4	45	1	3	515	4
20	1	3	1052	5	45	1	3	804	5
20	1	3	829	6	45	1	3	1253	6
20	1	3	774	7	45	1	3	1487	7
20	2	1	600	1	45	2	1	844	1
20	2	1	726	2	45	2	1	949	2
20	2	1	307	3	45	2	1	40	3
20	2	1	363	4	45	2	1	678	4
20	2	1	386	5	45	2	1	1210	5
20	2	1	570	6	45	2	1	689	6
20	2	1	534	7	45	2	1	806	7
20	3	2	7076	1	45	3	2	10458	1
20	3	2	5205	2	45	3	2	8090	2
20	3	2	7758	3	45	3	2	10319	3
20	3	2	6830	4	45	3	2	9519	4
20	3	2	6776	5	45	3	2	9718	5
20	3	2	7471	6	45	3	2	10922	6
20	3	2	6883	7	45	3	2	10253	7
21	1	3	809	1	46	1	3	348	1
21	1	3	440	2	46	1	3	309	2
21	1	3	356	3	46	1	3	413	3
21	1	3	543	4	46	1	3	399	4
21	1	3	507	5	46	1	3	423	5
21	1	3	608	6	46	1	3	426	6
21	1	3	719	7	46	1	3	547	7
21	2	1	511	1	46	2	1	354	1
21	2	1	231	2	46	2	1	311	2
21	2	1	496	3	46	2	1	446	3
21	2	1	216	4	46	2	1	438	4
21	2	1	283	5	46	2	1	261	5

ID	Product Type	Tank No.	Fuel consumption (liters)	Day	ID	Product Type	Tank No.	Fuel consumption (liters)	Day
21	2	1	470	6	46	2	1	296	6
21	2	1	685	7	46	2	1	171	7
21	3	2	4696	1	46	3	2	2762	1
21	3	2	5160	2	46	3	2	3283	2
21	3	2	6445	3	46	3	2	5033	3
21	3	2	4902	4	46	3	2	4886	4
21	3	2	5235	5	46	3	2	4192	5
21	3	2	6752	6	46	3	2	4549	6
21	3	2	6096	7	46	3	2	4817	7
22	1	3	655	1	47	1	3	1324	1
22	1	3	1094	2	47	1	3	588	2
22	1	3	1179	3	47	1	3	596	3
22	1	3	926	4	47	1	3	1175	4
22	1	3	1227	5	47	1	3	494	5
22	1	3	1052	6	47	1	3	483	6
22	1	3	1176	7	47	1	3	748	7
22	2	1	450	1	47	2	1	811	1
22	2	1	407	2	47	2	1	405	2
22	2	1	613	3	47	2	1	177	3
22	2	1	153	4	47	2	1	579	4
22	2	1	664	5	47	2	1	416	5
22	2	1	225	6	47	2	1	233	6
22	2	1	927	7	47	2	1	960	7
22	3	2	8837	1	47	3	2	8300	1
22	3	2	7882	2	47	3	2	5327	2
22	3	2	8663	3	47	3	2	9774	3
22	3	2	7312	4	47	3	2	9701	4
22	3	2	10391	5	47	3	2	8473	5
22	3	2	7658	6	47	3	2	8702	6
22	3	2	8852	7	47	3	2	10305	7
23	1	3	553	1	48	1	3	1431	1
23	1	3	259	2	48	1	3	887	2
23	1	3	707	3	48	1	3	643	3
23	1	3	570	4	48	1	3	1596	4
23	1	3	360	5	48	1	3	1396	5
23	1	3	261	6	48	1	3	1269	6

ID	Product Type	Tank No.	Fuel consumption (liters)	Day	ID	Product Type	Tank No.	Fuel consumption (liters)	Day
23	1	3	248	7	48	1	3	1897	7
23	2	1	112	1	48	2	1	1020	1
23	2	1	154	2	48	2	1	855	2
23	2	1	347	3	48	2	1	1091	3
23	2	1	199	4	48	2	1	423	4
23	2	1	139	5	48	2	1	1090	5
23	2	1	36	6	48	2	1	460	6
23	2	1	98	7	48	2	1	779	7
23	3	2	3478	1	48	3	2	10978	1
23	3	2	3151	2	48	3	2	9742	2
23	3	2	3997	3	48	3	2	12330	3
23	3	2	5044	4	48	3	2	12462	4
23	3	2	4251	5	48	3	2	11636	5
23	3	2	4619	6	48	3	2	12131	6
23	3	2	4351	7	48	3	2	14451	7
24	1	3	160	1	49	1	3	1269	1
24	1	3	165	2	49	1	3	1110	2
24	1	3	121	3	49	1	3	472	3
24	1	3	240	4	49	1	3	825	4
24	1	3	324	5	49	1	3	1113	5
24	1	3	190	6	49	1	3	251	6
24	1	3	165	7	49	1	3	1022	7
24	2	1	99	1	49	2	1	635	1
24	2	1	94	2	49	2	1	576	2
24	2	1	184	3	49	2	1	689	3
24	2	1	74	4	49	2	1	129	4
24	2	1	249	5	49	2	1	773	5
24	2	1	121	6	49	2	1	905	6
24	2	1	53	7	49	2	1	439	7
24	3	2	1913	1	49	3	2	7892	1
24	3	2	1241	2	49	3	2	6570	2
24	3	2	1620	3	49	3	2	12719	3
24	3	2	2643	4	49	3	2	10394	4
24	3	2	2110	5	49	3	2	9510	5
24	3	2	1820	6	49	3	2	10352	6
24	3	2	2318	7	49	3	2	11545	7

ID	Product Type	Tank No.	Fuel consumption (liters)	Day	ID	Product Type	Tank No.	Fuel consumption (liters)	Day
25	1	3	256	1	50	1	3	1527	1
25	1	3	119	2	50	1	3	676	2
25	1	3	164	3	50	1	3	848	3
25	1	3	172	4	50	1	3	1888	4
25	1	3	191	5	50	1	3	1603	5
25	1	3	96	6	50	1	3	967	6
25	1	3	266	7	50	1	3	891	7
25	2	1	121	1	50	2	1	888	1
25	2	1	90	2	50	2	1	478	2
25	2	1	112	3	50	2	1	942	3
25	2	1	84	4	50	2	1	316	4
25	2	1	68	5	50	2	1	1019	5
25	2	1	135	6	50	2	1	1357	6
25	2	1	220	7	50	2	1	150	7
25	3	2	1278	1	50	3	2	8495	1
25	3	2	1496	2	50	3	2	6301	2
25	3	2	1988	3	50	3	2	14148	3
25	3	2	1550	4	50	3	2	13032	4
25	3	2	1775	5	50	3	2	14714	5
25	3	2	1917	6	50	3	2	10598	6
25	3	2	1988	7	50	3	2	9535	7

VITA

Mr. Narongkorn Charusakwong was born in Bangkok, October 17, 1983 as the third son of Mr. Chettapong and Mrs. Nattawan Charusakwong. He married to Mrs. Raweewan Charusakwong and currently has 2 sons, Mr. Charuthas and Mr. Thassapong Charusakwong. He finished 2 years intensive high school program from Saint Gabriel's College. He obtained his Bachelor and Master degrees in Civil Engineering from Thammasat and Chulalongkorn University respectively. He continued his further study in the Doctor of Philosophy Program in Logistics Management at Chulalongkorn University in 2010. For his work experience, he has worked as a consultant and a research assistant during the beginning of his professional career, and joined one of the major oil and gas industries later. Presently, he is still working in this oil and gas industry with more than 8 years of services.