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Optimization Model to Enhance the Petroleum Distribution Network in Sri Lanka

W.W.N. Sachini, W.M.S.K. Weerabahu, R. Wickramarchchi
Department of Industrial Management, University of Kelaniya, Sri Lanka
wijendranavodya@gmail.com

Petroleum is one of the industries that has a massive impact on living conditions of the population. Petroleum distribution network plays an increasingly important function in delivering value to the end user. The objective of this research is to study the current petroleum distribution network in Sri Lanka, identify the inefficiencies and causing critical factors and propose an optimization model to overcome these inefficiencies. A conceptual framework has been developed based on the findings observed from critical review of literature and further data was collected from Sri Lankan petroleum industry domain experts using in-depth interviews. It has been identified that Sri Lankan petroleum distribution network is not taken in to account for the optimization. Hence, it is performed by developing a mathematical model in this research. The proposed model is validated with complex and real data extracted from research findings. VBA (Visual Basic Application) is used to gain exact mathematical optimization. It is concluded from the study that distribution network overall cost can be minimized when causing critical factors are optimized. Thus, this study depicts an optimization model, with the purpose of minimizing the cost, based on inefficiencies and causing critical factors which are specific for Sri Lankan petroleum industry.

Key words: Petroleum Distribution Network, Inefficiencies, Cost, Optimization

1. Introduction

The study will consider the network optimization for petroleum distribution network in Sri Lanka. Petroleum distribution network is a part of Petroleum Supply Chain (PSC). The process flow of fuel deposit exploration to petroleum product end user customer, is called Petroleum Supply Chain (PSC). Petroleum industry contributes for transportation, power generation, agro chemicals, residential, commercial and industrial needs etc. Petroleum industry's complexity has grown as a result of tight competition, strict environmental regulations, high operational costs and low margin profits. The petroleum product demand fluctuation and the present scenario of high petroleum crude oil prices fluctuation demonstrate that industries and markets all over the world are impacted by the volatility and uncertainty of the petroleum industry. These reasons drive petroleum industry toward strategic planning and optimization with respective to the uncertainties and constraints in factors such as the source, raw materials availability, expected market demand, production costs and distribution costs. The ultimate objective of the work is to optimize the petroleum distribution network while minimizing the overall cost and maximizing the customer's level of service. Therefore it is important to have an optimized petroleum distribution network, since petroleum products cost a high amount. The cost of maintaining a well optimized distribution network is a considerable component of the total costs of petroleum products. By the using of well managed distribution execution it is expected to reduce the distribution cost and by that to reduce the total cost of the petroleum products. It is important that the products are delivered on time and efficiently with the required quality without tone down customer satisfaction. Optimization is the methodology for improving the quality and desirability of a product or product concept. It is the process of finding function extreme to solve problems and finding an alternative with the most cost effective or highest achievable performance under the given constraints, by maximizing desired factors and minimizing undesired factors.

The scope of the research is the intersection of three operational areas such as petroleum supply chain, distribution network and optimization. The research problem, "How to overcome the inefficiencies in petroleum distribution network in Sri Lanka" is justified based on two main pillars, "why we have to optimize the petroleum distribution network in Sri Lanka" and "Why there are inefficiencies in petroleum distribution network in Sri Lanka". Three main reasons for inefficiencies, were identified based on research findings. They are respectively petroleum industry demand uncertainty, petroleum industry supply uncertainty and petroleum supply chain's complex distribution network.

2. Literature Review

2.1. Petroleum Supply Chain

In 2017, a study explores what is typical petroleum supply chain. A typical petroleum supply chain involves oil exploration, oil production, oil transportation, crude oil storage (tanks are connected to the refinery by a network of pipelines), refinery operations, inventory of the finished products and distribution (via distribution centers). Strategic, tactical and operational decision making is required at all stages of the chain [hisain 2017]. According to Yasaman and joshep in 2015, the petroleum industry has one of the most complex and advanced supply chains around the world. It is vertically integrated, covering activities from exploration to transformation in refineries and product distribution with a large logistic network. It includes production, transportation, transformation into several refined products, and distribution to consumer markets. The whole supply chain is divided into upstream, midstream and downstream [Yasaman and joshep 2015]. Petroleum supply chains are global enterprises, engaged in managing activities across petroleum industry from crude oil production to refineries and petrochemical operations up to final product markets passing through all necessary logistics inclusive transportation, storages and distributions. To remain competitive in today's dynamic global marketplace they must optimize every aspect of their operations – supply, manufacturing and distribution – and integrate these different decisions levels leads to creating substantial value to process.

The purpose of optimized and planned petroleum supply chain is to minimize the production, operations, transportation, storage and distribution costs as well as top up the customer satisfaction while preserving market share, along with maximizing sales revenue. In 2004, Sergio and Pinto explores a general modeling framework for the operational planning of petroleum supply chains. They have implemented three mathematical models of each element of Processing, Tank and Pipeline. After that they formulated "Petroleum supply Chain Model" based on these three mathematical models [Sergio and Pinto 2004]. In 2008, the importance of four perspectives with respect to petroleum supply chain were introduced. They are in descending order of importance comes out as: customer, financial, internal business process, innovation and learning. Within these perspectives the following factors seem to be most important respectively: purity of product, market share, and steady supply of raw material and use of information technology [Siddharth et al. 2008]. The need for petroleum supply chain optimization is revealed in 2005. Sha and Che explored that an efficient and effective production and distribution strategy for supply chain networks plays a key factor in enhancing customer satisfaction. So effort must be made to integrate suppliers, manufactures, distributors and customers, so that they will collaborate effectively with each other in the entire network [Sha and Che 2005].

In 2008, distinguishing characteristics of the petroleum supply chain were studied. Petroleum has the several characteristics that justify a separate treatment of its supply chain. Some of these prominent features are listed below:

1. Process industry: petroleum is a result of the process industry, which is very different from discretely manufactured items like television sets or automobiles.

2. Inflammability: petroleum products are highly inflammable and so the risk in handling the product is much higher than in case of other products.

3. Contamination: petroleum products can be contaminated easily, e.g. by mixing kerosene with diesel. This is especially true for a country like India where subsidies provided by government on petroleum products like kerosene encourage mixing of petrol or diesel with kerosene by dealers.

4. Bulk volumes: petroleum products are produced and moved in bulk leading to high inventory carrying costs. There is no volume flexibility either in terms of production or distribution.

5. High transportation costs: transportation costs represent a much higher fraction of total costs than the in case of other products made by the discrete manufacturing.

Most research work has focused on discrete part manufacturing supply chains. Process industry supply chains deserve a different treatment due to their inherently different characteristics. Siddharth Varma and others have suggested a methodology that tries to include these characteristics and can help in comparing performance of supply chains of different petroleum companies [Siddharth Varma et al. 2008].

2.2. Distribution Network

The supply chain network design is one of the most comprehensive issues related to supply chain management, involving decisions on operational, tactical and strategic levels. This problem involves determining the number, location and capacity of the facilities, establish distribution channels and flows of materials and products that will be produced and sent to suppliers in each consumption layer [Gabriel and Denis 2016].

According to the Daniela and Maria (2005), while analyzing a distribution network, two factors can be distinguished as follows:

1. The optimization of the flows of goods: in this case it is considered an existing distribution network, and need to optimize the flows of goods through the network

2. The improvement of the existing network: in this case need to choose the best configuration of the facilities in the network in order to satisfy the goals of the company, while minimizing the overall costs

Distribution network design problems involve both kinds of analysis. More precisely, these problems consist of determining the best way to transfer goods from the supply to the demand points by choosing the structure of the network (layers, different kinds of facilities operating at different layers, their number and their location), while minimizing the overall costs [Daniela and Maria, 2005].

In 2006, a study was published about inbound logistic planning, where minimizing transportation and inventory cost was studied. This study considers the problem of selecting the appropriate distribution strategy for delivering a family of products from a set of suppliers to a set of plants so that the total transportation, pipeline inventory, and plant inventory costs are minimized [Berman and Wang, 2006].

Past literature reviews reveal that distribution network plays a major role in supply chains. Petroleum distribution network also plays a major part in PSC since there is a huge distance from crude oil exploration to petroleum product end user customer and petroleum distribution network cost is higher than the other commercial good distribution networks.

2.3. Distribution Network of Petroleum Supply Chain

The petroleum distribution network is a channel that is used to get petroleum products from the manufacturer to the end user customer. The shape of this petroleum distribution network is complicated and broad.

In 2004, critical areas of petroleum distribution network were discussed by Jean Paul Rodrigue. The transportation of petroleum represents one of the most strategically important circulations of resources in the global economy. Its role cannot be overstated. Yet, petroleum has become a “strategically invisible” commodity as its flow has been continuous with limited, but eye-opening, disruptions [Rodrigue 2004]. In 2009, an optimal network design and storage management in petroleum distribution network were studied respective to under uncertainty. It was difficult to describe the topology of this network precisely. In this paper they consider the petroleum distribution network under uncertainty which can be captured with fuzzy concepts. The design of such networks is dependent on the restriction on location of facilities including manufacturing plants, distribution centers, warehouses etc. [Ghatee and Hashemi 2009].

The importance of optimal distribution network in petroleum industry has been highlighted by many researchers. Contesse et al. (2005) worked on petroleum supply chain involving producers, transportation companies and local distribution companies. Sergio and Pinto (2004) studied the planning and scheduling of several subsystems of the petroleum supply chain. Schulz et al. (2005) designed supply chain model for a petrochemical complex system. Grossmann (2005) also recommended some ways for value preservation and value growth in petroleum industry. In 2001, Iakovou investigated the petroleum distribution network in a different perspective. Therefore Potential environmental pollution created by petroleum distribution, was discussed. With the rapid growth of countries, demand for the petroleum industry has been increased over the past years and environmental pollution also got increased. Iakovou introduced strategic multi objective network flow model, allowing for risk analysis and routing, with multiple commodities, modalities and origin-destination pairs [Iakovou, 2001].

2.4. Optimization Methods

As Chandrasekaran & Gabriel described (2010), Optimization is the methodology for improving the quality and desirability of an existing product or product concept. Several approaches can be found in the literature, which provide models to coordinate at least two stages of the supply chain and which can detect new opportunities that may exist for improving the efficiency of the supply chain and profitability of the organization. Recently there has been a growing interest in research in supply chain network optimization problems. This may be due to increasing competitiveness introduced by rapid globalization, such that firms want to reduce costs and maintain profit margins as observed by Altiparmak et al. (2006).

In 2011, a paper on multisite planning under demand and transportation time uncertainty, related to robust optimization and conditional value-at-risk frameworks was developed. The operational planning of a multisite production and distribution network entails determining the daily production and shipment profiles for the supply chain under consideration. The generated profiles should provide a tight upper bound on the true production capacity of the supply chain to ensure the maximization of customer satisfaction along with the minimization of resource misallocation. With a specific operational planning time horizon, it is also imperative to take into account pertinent parameter uncertainty, so that the production and shipment profiles are not only a tight upper bound on the supply chain's production capacity but also immune to the different forms of system uncertainty, such as demand due date, demand amount, and transportation time uncertainty [Verderame and Floudas, 2011]. According to the Josefa et al. (2010) the most widely used modeling approach is mixed integer linear programming, where the use of heuristic algorithms and meta heuristics to solve the approach stands out and the purpose of the vast majority of the models proposed is the minimization of the total supply chain costs and, to a lesser extent, the maximization of revenues. Recently many researchers have considered multi-objective optimization of multi-echelon supply chain network problems [Cheng-Liang and Wen-Cheng, 2004].

Most of the studies have focused to develop a mathematical model for a distribution network in a three echelon supply chain that minimizes the system-wide costs and delays on delivery of products. The mathematical model is designed as a multi-objective optimization problem taking into account the two conflicting objective functions [Nelson and Yaw 2014]. In 2007, Amodeo et al. optimized a supply chain as a multi-objective optimization using genetic algorithms and simulation model. Objectives considered were: minimizing inventory cost and maximizing service level [Amodeo et al., 2007]. Moreover, last decade, researchers have focused to develop a hybrid optimization approach to address the Supply Chain Configuration Design problem. The new approach combines simulation, mixed integer programming and genetic algorithm. Simulation is used to evaluate performance of each supply chain configuration with non-linear, complex relationships and under more realistic assumptions [Truong et al., 2003].

2.5. Systematic review of the optimization methods

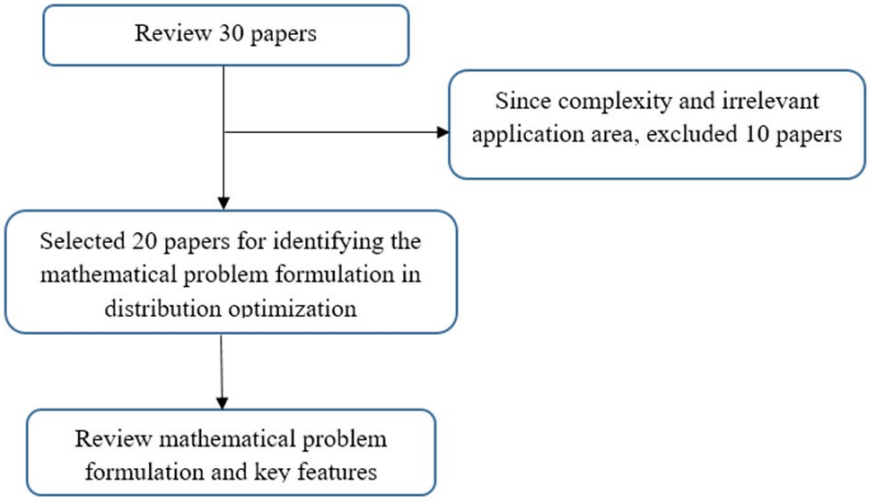


Figure 1. Systematic Review Process

3. Materials & Methods

This study was conducted in order to address the knowledge gap in distribution optimization of petroleum distribution network in Sri Lanka. An optimization enables obtaining the most efficient solution for inefficiencies in petroleum distribution network in Sri Lanka. A methodical review of literature is conducted underlying three area i.e. petroleum supply chain, distribution network and optimization methods. The research is a study for optimizing the petroleum distribution network. The research is designed to address research questions, which are developed based on objectives.

3.1. Research Objectives

RO1: To study the current Sri Lankan petroleum distribution network and identify the issues and inefficiencies.

RO2: To study the current "Distribution Network Problem" related solving approaches for petroleum supply chain.

RO3: To develop a model to optimize the petroleum distribution network in Sri Lanka

3.2. Research Questions

RQ1 - What are the characteristics of Sri Lankan petroleum industry?

RQ1 – I. What are the major features of Sri Lankan petroleum industry?

RQ1 – II. What are the main processes in Sri Lankan petroleum distribution network?

RQ2 - What are the main inefficiencies in petroleum distribution network?

RQ2 – I. What are the factors causing inefficient petroleum distribution network?

RQ2 – II. What are the most critical areas that should be addressed in research?

RQ3 - What are the most applicable methods that can be used for optimization?

RQ4 - How to develop a model to optimize the petroleum distribution network in Sri Lanka?

Research design methodology is visualized in the following figure 1,

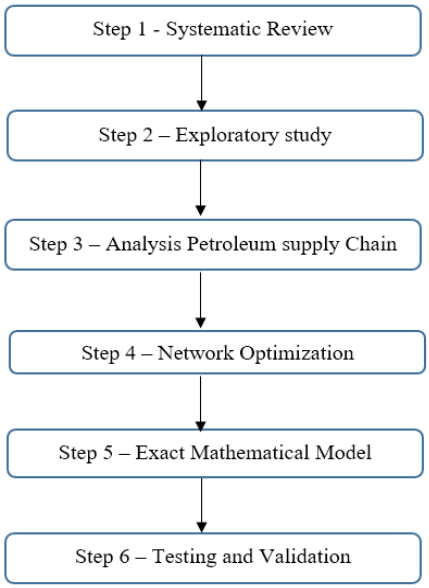


Figure 2. Design Methodology

3.3. Research Techniques and Tools

Step 1 - Systematic Review

The research was started with a literature survey to find out the approaches, gaps and applicability of existing available literature related to distribution network optimization on petroleum supply chain. Systematic review of the literature is the first step of the research that was conducted to identify the studies that have been already done related to petroleum supply chain. The commencement is via literature review of the research area that will be conducted to identify the fundamental characteristics in petroleum supply chain. Then results of the literature survey to business context and research questions was formulated. The objective of this phase is to create consensus on data, constraints, requirements, assumptions, and modeling approach for developing the model.

Step 2 - Exploratory Study

An exploratory study was carried out by interviewing an expert on the Sri Lankan petroleum distribution network. That was caused to identify inefficiencies in the petroleum distribution network and how it will help to improve optimize the distribution network. Thorough knowledge can be gained by interviewing the experts on that particular area. Therefore, this questionnaires was created to get inputs in the experts' perspective of the current issues and inefficiencies of Sri Lankan petroleum distribution network.

Step 3 – Analysis Petroleum supply Chain

The objective is to create consensus on data, constraints, requirements and assumptions on which the network design will be based, storage and distribution related data, operational constraints, future trends and business requirements.

Step 4 – Network Optimization

An overall distribution network that is efficient, meeting all requirements, minimizing cost, minimizing structurally cost based issues and supports any other management constraints and satisfying constraints is developed, via an optimization model.

Step 5 – Exact Mathematical Model

Mathematical model is a scientific approach in a decision-making process to find an optimal, or the absolutely most efficient, way to achieve an objective while simultaneously satisfying all constraints associated with achieving the objective. Typically, the objective is maximization or minimization of an analytical mathematical expression with a large amount of variables. Quite often, the objective function is a mathematical expression of the revenue or cost function. The optimization can be simplified in to a mathematic subject, based on causing critical factors in petroleum distribution network. The distribution network problem is one of the most comprehensive strategic decision issues that need to be optimized for the long term efficient operation of whole supply chain. VBA (Visual Basic Application) is used to gain exact mathematical optimization focused on petroleum distribution network.

Step 6 – Testing and Validation

Testing the data using the model will be done, and it will also be validated and verified using appropriate techniques. The final optimization is ensured to be giving an accurate output under a wide variety of conditions.

4. Data Acquisition

An exploratory study was carried out by interviewing an expert on the Sri Lankan petroleum industry. The expert interviews was conducted to acquire the needed data to conduct the research. The use of interviews can help to gather valid and reliable data that are relevant to the research questions and objectives. Interviews were carried out by two stages. The first stage interviews were conducted to explore in depth a general area in which authors are interested by using unstructured in-depth interviews.

It was helpful to understand the general petroleum distribution in Sri Lanka and get clear idea about the aspects that authors want to explore. Unstructured in-depth interviews gave an opportunity to talk freely about the research

purpose. The second stage interview was formalized and structured, using interview questions for each research participant. Interview responses were recorded and written by the author. The nature of the questions and the ensuing discussion that data is recorded by audio-recording the conversation and note taking. The interview questionnaire was used as a data acquisition tool. This is the major method of data acquisition.

Subsequently, identified the full variety of secondary data that are available with Sri Lankan petroleum industry. Data that have already been collected for some other purpose, perhaps processed and subsequently stored, are termed secondary data. Secondary data can provide a useful source from which to answer, or partially to answer the research question mentioned in chapter 1. Secondary data include both raw data and published summaries. Sri Lankan petroleum industry collects and stores a variety of data to support their operations: for example accounts of sales and distributions, accounts of finance and including reports about daily refined products, distributed products, petroleum product demand all over the country etc. These archival records and documents was gathered in order to acquire the required data.

4.1. Data Analysis Methods

Qualitative Analysis

Qualitative data refers to all non-numeric data or data that have not been quantified and can be a product of all research strategies. Qualitative data analysis method is used when there is complex and real data which are extracted from unstructured data acquisition methods. To be useful these data need to be analyzed and the meanings understood. In this research, authors have used the unstructured in-depth interviews in the first stage of exploratory study. Therefore qualitative analysis method was used to analyze the data that are extracted from in-depth interviews with petroleum industry domain experts. There are three main common qualitative analysis approaches, summarizing (condensation) of meanings, categorization (grouping) of meanings and structuring (ordering) of meanings using narrative. All of these can be used on their own, or in combination, to support interpretation of the acquired data. Subsequently, descriptive analysis is used as a qualitative analysis method.

Quantitative Analysis

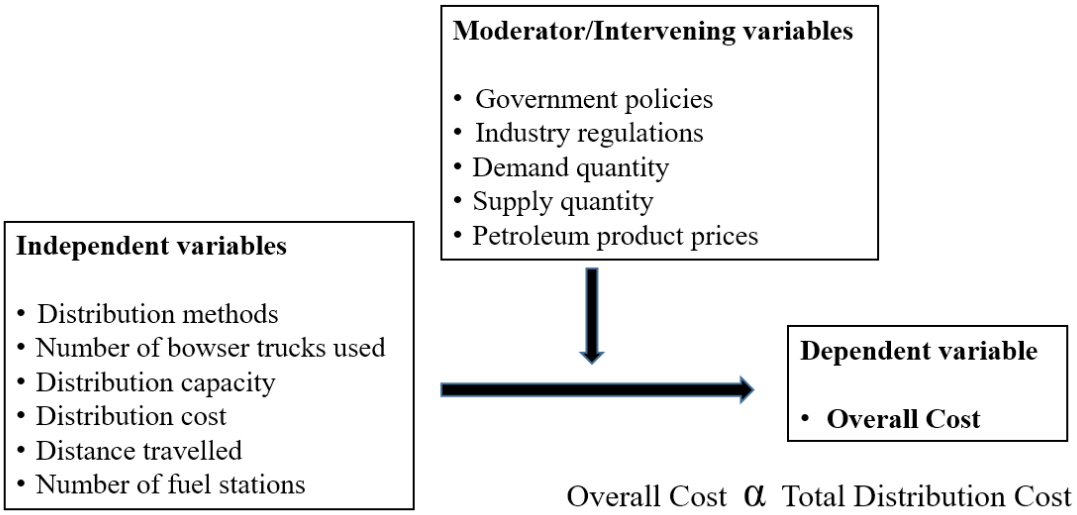
Quantitative data refers to all numeric data or data that have been quantified. Quantitative data in a raw form, that is, before these data have been processed and analyzed, convey very little meaning. These data, therefore, need to be processed to make them useful, that is, to turn them into information. In this research, authors have used the structured interview in the second stage of exploratory study. As structured interviews are used to collect quantifiable data they are also referred to as 'quantitative research interviews'. Therefore quantitative analysis method was used to analyze the data that are extracted from structured interviews with petroleum industry domain experts. Quantitative analysis techniques such as graphs, charts and statistics allow to do this; helping to explore, present, describe and examine relationships and trends within the acquired data.

4.2. Data Reliability and Validity

Reducing the possibility of getting the wrong outcomes means that attention has to be paid to two particular emphases on research design that are reliability and validity. Reliability refers to the extent to which the data collection techniques or analysis procedures will yield consistent findings. Validity is concerned with whether the findings are really about what they appear to be about. The reliability and validity of the acquired data, are functions of the method by which the data were collected and the source. In this research, the proposed model is validated with complex and real data that was collected from Sri Lankan petroleum industry.

5. Findings & Results

A conceptual framework has been developed based on the research findings,



Overall Cost α Total Distribution Cost

Overall Cost = Total distribution Cost via CPSTL trucks, hired trucks and railway + Inventory Cost

A mathematical model has been developed based on the research findings,

$$Z = \sum_{s} P_s \left(\sum_{i,j,k} \left(XT_{i,j,k,s} \times CT_{i,j,k} + XH_{i,j,k,s} \times CH_{i,j,k} + XR_{i,j,k,s} \times CR_{i,j,k} \right) + \sum_{i,k} \left(XI_{i,k,s} \times IC_{i,k} \right) \right)$$

Indices

i , j – Nodes

i - Distribution center

j - Fuel station

t - Distribution type

k - Product

s - Scenarios

Parameters & Variables

- $XT_{i,j,k,s}$ - Volume of product k carrying by truck between nodes in a scenario
- $XH_{i,j,k,s}$ - Volume of product k carrying by hired truck between nodes in a scenario

- $XR_{i,j,k,s}$ - Volume of product k carrying by railway between nodes in a scenario
- $XI_{i,k,s}$ - The initial volume of product k at a distribution center in a scenario
- $XF_{i,k,s}$ - The final volume of product k at a distribution center in a scenario

- $D_{i,j,t}$ - Distance between nodes for a distribution type
- $IC_{i,k}$ - Inventory cost of product k at distribution center
- $UT_{i,j,k}$ - Unit cost for CPSTL bowser truck distribution
- $UR_{i,j,k}$ - Unit cost for railway distribution
- $CH_{i,j,k}$ - Hiring cost for the hired bowser trucks from private sector
- $CT_{i,j,k}$ - Distribution cost for CPSTL truck

$$CT_{i,j,k} = UT_{i,j,k} * D_{i,j,t}$$

- $CR_{i,j,k}$ - Distribution cost for railway

$$CR_{i,j,k} = UR_{i,j,k} * D_{i,j,t}$$

6. Conclusion

In this research, the proposed model is validated with complex and real data that was collected from Sri Lankan petroleum industry (CPSTL, Kolonnawa). VBA is used to gain exact mathematical optimization. The qualitative and quantitative analysis of data has been done to evaluate the research findings. It is concluded from the study that the overall cost of the petroleum distribution network can be minimized by optimizing the causing critical factors. Thus, this study depicts a distribution network optimization model, with the purpose of minimizing the cost, based on inefficiencies and causing critical factors which are specific for Sri Lankan petroleum industry. As a result, the developed optimization model would enable the Sri Lankan petroleum industry to achieve higher performance leading to competitive advantage.

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Biographies

W.W.N. Sachini is an university undergraduate, following B.Sc (Hons) in Management & Information Technology degree programme (Specialized in Business System Engineering) in the Department of Industrial Management, Faculty of Science, University of Kelaniya, Sri Lanka. She has completed computer science degree programme in SLIIT (Sri Lanka Institute of Information Technology). She is currently following CGMA (Charted Global Management Accountant). Her research interests include Simulation, Optimization, and Supply Chains.

W.M.S.K. Weerabahu is currently a fulltime lecturer in Department of Industrial Management, University of Kelaniya, Sri Lanka. She obtained her MBA in Management of Technology from University of Moratuwa in 2016.Her first degree was in Management and Information Technology, graduating with first class honors from University of Kelaniya in 2013. After finishing her first degree she worked in the industry for about four years as a SAP functional consultant for Camso GIT (PVT) Ltd, Associated Motorways (PVT) Ltd and Printcare PLC. She has gained expertise in material management, SAP workflow and Plant maintenance modules. She is also a visiting lecturer to other institutions in Sri Lanka. Her research interests include, Business Process Management, Process automation with Enterprise Resource Planning systems, Management of technology and supply chain management.

R. Wickramarachchi is a Senior lecturer at the Department of Industrial Management, University of Kelaniya, Sri Lanka. He holds BSc in Industrial Management from the University of Kelaniya and MPhil in Management studies (specialized in Information systems) from the University of Cambridge, United Kingdom. He received his PhD in distributed simulation from the Sheffield Hallam University, United Kingdom.