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A lean thinking and simulation-based approach for the improvement of routing operations

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Received 22 September 2015
Revised 23 October 2015
27 November 2015
Accepted 16 December 2015

Abstract

Purpose – The improvement of routing operations performance has been of great concern for organisations. This has led to the development of alternative lean-based methods, however the literature research on the applications of lean thinking in the transportation sector is still considered rather limited. The purpose of this paper is to present a lean thinking and simulation-based approach to improve the efficiency of warehousing and routing operations.

Design/methodology/approach – The paper reviews the existing literature in the area of lean transportation and then presents and applies a novel approach to improve the vehicle routing operations of a Mexican firm. The proposed approach suggests the classification of wastes into those relevant to transport operations, their identification through a transportation value stream mapping study, and the use of the transportation overall vehicle effectiveness (TOVE) index for the measure of the overall performance of the transport operations.

Findings – The results obtained from the case study indicate that the proposed approach is an effective alternative for the improvement of vehicle routing operations as the number of routes decreased from 30 to 22 and the distance travelled by 32 per cent. Similarly, the average number of clients served by each route increased by 23 per cent as well as the TOVE index increased from 6.9 to 19.3 per cent. The TOVE component measures of vehicle performance and operating availability efficiencies also increased significantly while quality issues, in the form of number of customers not served per route, were reduced from six to zero.

Originality/value – The improvement of routing operations performance has been traditionally addressed through operations research and mathematical modelling approaches. This paper presents an alternative and novel lean thinking and simulation-based approach to improve the efficiency of routing operations.

Keywords Vehicle routing problem, Lean routing, Transportation efficiency, Transportation waste elimination, Value stream map

Paper type Research paper

1. Introduction

The improvement of routing operations performance has been of great concern since the mid 1900s. For instance, one of the first models to optimise the cost, distance and time of routing operations was developed by Dantzig and Ramser (1959). Due to both its practical relevance and considerable difficulty, the vehicle routing problem (VRP)

Industrial Management & Data Systems
Vol. 116 No. 5, 2016
pp. 903-925

0263-5577
DOI 10.1108/IMDS-09-2015-0385

has been one of the most studied combinatorial optimisation problems. In this context, several specific approaches (e.g. Boudia *et al.*, 2008; Chiu *et al.*, 2006; Ropke and Pisinger, 2006; Zhao *et al.*, 2003; Chung *et al.*, 2015) and surveys (Eksioglu *et al.*, 2009; Hasle and Kloster, 2007; Marvel and Standridge, 2009; Masson-Jones *et al.*, 2000; US Department of Transportation, 2009) of different algorithms to solve the VRP with various characteristics and assumptions have been developed and compiled. An important recent trend in VRP research is the movement of what has been called "rich VRP models". This movement has been fuelled by the need to solve real-life routing problems. A sample of contributions related to this movement are provided by Simmons *et al.* (2004), Sternberg *et al.* (2013), Irnich (2008), Bock (2010), Oppen *et al.* (2010) and Drexl and Prescott-Gagnon (2010). However, as pointed out by Berhan *et al.* (2014), both the classical and rich VRP models do not usually capture important aspects of real-life transportation and distribution-logistic problems. This is because several of the problem parameters such as demand, time, distance and others are stochastic in nature, but they are often oversimplified and treated as deterministic (Ak and Erera, 2007). In most of the cases, this is one of the main limitations when addressing the VRP through the traditional operations research and mathematical modelling approaches commonly followed by researchers (Sternberg *et al.*, 2013). As a result, a different movement to improve transport operations has emerged over the last decade.

This emergent movement is based on an extension and application of the lean approach to vehicle routing and transport operations. Thus, under this movement, improvement is achieved by identifying and eliminating wastes relevant to transport operations. Evidence suggests that lean methods and tools have helped organisations, from various sectors, to improve their operations and processes (Belekoukias *et al.*, 2014; Forrester *et al.*, 2010; Chan *et al.*, 2009). However, despite these positive results, the application of lean thinking to address vehicle routing and transportation challenges has been mainly confined to only three research streams. These streams include: definition of lean-based road transportation wastes (Sternberg *et al.*, 2013; Sutherland and Bennett, 2007; Guan *et al.*, 2003); development of lean-based performance measures to assess road transport operations (Villarreal, 2012; Taylor and Martichenko, 2006; Simmons *et al.*, 2004; Guan *et al.*, 2003); and proposal of lean-based methods to eliminate road transportation waste (Villarreal *et al.*, 2012; Villarreal, 2012; Hines and Taylor, 2000). Thus, the literature research on the applications of lean thinking in the transportation sector can still be considered rather limited (Villarreal *et al.*, 2009a). This is especially true when compared with the vast amount of research on lean's application in other industries such as services (Sternberg *et al.*, 2013), manufacturing (Taj, 2008), healthcare (Wang *et al.*, 2015) and processes (Lyons *et al.*, 2013). Therefore, this paper presents a lean thinking and simulation-based approach developed to improve the efficiency of the warehousing and routing operations, on a detailed level, of a Mexican firm. The application of simulation in resolving and improving operational effectiveness is well documented in literature (e.g. Gabriel *et al.*, 1991; Barceló *et al.*, 2007; Jovanoski *et al.*, 2013; Mostafa and Talaat, 2015; Wang *et al.*, 2015). The novelty of the proposed method consists of the combination of the previous works (i.e. schemes) of Villarreal (2012) and Sternberg *et al.* (2013). Through this combination, wastes are classified into those relevant to transport operations (Sternberg *et al.*, 2013) and identified using transportation value stream mapping (TVSM) (Villarreal, 2012), whereas the overall performance of the transport operations is measured by using the transportation overall vehicle effectiveness (TOVE) index (Villarreal, 2012).

The combinational approach of these schemes is complemented with the use of discrete-event simulation to take into account the variability inherent in vehicle routing and transport operations.

The rest of the paper is organised as follows: Section 2 provides a brief review of the previous work undertaken in the area of lean transportation; a description of the concepts and approach proposed in this paper to improve transport operations is outlined in Section 3; the application of such approach is then undertaken in Section 4; and Section 5 presents the conclusions.

2. Literature review

In the current globalised market, transportation and distribution are necessary activities to deliver goods to customers. In fact, although these are recognised as tertiary economic activities (Chase and Apte, 2007), Villarreal *et al.* (2009b) suggest that they can nowadays be considered as a differentiating factor that adds service value to customers. Despite this characteristic, lean thinking regards transportation and distribution as non-value added activities, for which they are categorised as waste that should be, if possible, eliminated (Womack and Jones, 2003). This has contributed to the development of research which has aimed at transferring the application of lean principles and tools to improve road transportation, particularly, through the three research streams on lean transportation previously mentioned in the introduction section. These research streams are briefly reviewed in the subsequent sub-sections.

2.1 Lean-based road transportation wastes

Due to the importance of waste elimination and its effect on increasing value for customers (e.g. Samaddar and Heiko, 1993; Dennis, 2002; Bicheno, 2004) and reducing cost (e.g. Ohno, 1988; Monden, 1998), Samaddar and Heiko (1993) concluded that its systematic and continuous identification and elimination should be used to increase efficiency, improve productivity and enhance competitiveness. In this context, various researchers (e.g. Sternberg *et al.*, 2013; Sutherland and Bennett, 2007; Guan *et al.*, 2003) have realised the potential of studying the Toyota's seven common forms of production wastes (Ohno, 1988) within the context of road transport operations. For example, Sternberg *et al.* (2013) proposed the identification and elimination of transport wastes departing from the seven wastes as defined by Toyota (Ohno, 1988). Table I presents these wastes within a transportation setting. A case study carried out through in-depth interviews with experts from the transportation and lean fields resulted in an adapted waste framework for motor carrier operations. The result of this study indicated that five out of the seven classical waste types can be applied in the motor carrier waste framework, but two are not adequate, namely: waste of excess inventory and conveyance. Instead, two new waste types were included: resource utilisation and uncovered assignments (see Table I).

Similarly, Sutherland and Bennett (2007) also defined seven lean-based transportation wastes, which according to them retain the management of supply chains from achieving their full business potential. They called these wastes the "Seven Deadly Wastes of Logistics", and listed them as activities that included overproduction, delay/wait, excess transport/conveyance, motion, inventory, space and errors. Finally, Guan *et al.* (2003) identified five lean-based transport wastes in road transport operations, these being: driver breaks, excess load time, fill losses, speed losses and quality delays.

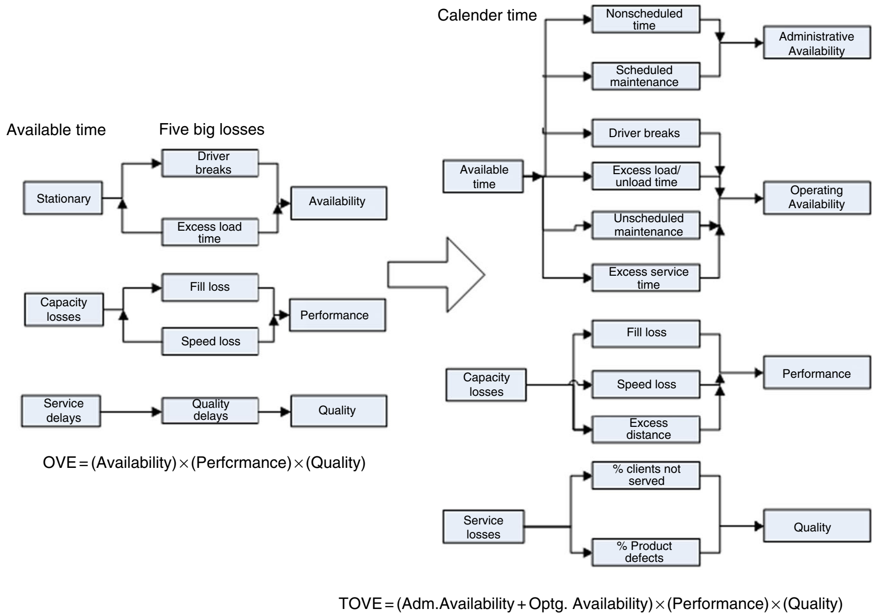
Waste	Description	Source
Overproduction	Producing reports no one reads or needs, making extra copies, e-mailing/faxing the same document/information multiple times, entering repetitive information on multiple documents and ineffective meetings	Definition by Tapping and Dunn (2006), confirmed in the empirical study
Waiting	Employees having to stand around waiting for the next process step, such as loading and unloading, or just having no work because of lack of orders, processing delays, equipment downtime and capacity bottlenecks	Definition from production (Liker, 2004), loading and unloading added as a common cause for waste of waiting noted from the empirical study
Incorrect processing	Consuming more resources for moving the goods than necessary due to inefficient routing or driving	Definition suggested based on the empirical study
Unnecessary movement	Any wasted motion employees have to perform during the course of their work, such as looking for information, reaching for, or stacking goods, equipment, papers, etc. Also, walking and extra movement created by sequencing errors is waste. This was found to be synonymous with conveyance	Definition by Tapping and Dunn (2006), movement due to sequencing errors added from the empirical study
Defects	Waste caused by repairs, redelivery, scrapping, etc., due to damages on the transported goods or the equipment	Damages to the equipment added to the production definition, in alignment with the empirical study
Resource utilisation (new)	Waste due to excessive equipment and bad resource planning	Definition suggested based on the empirical study
Uncovered assignments (new)	Carrying out unprofitable transport work due lack of information or planning	Definition suggested based on the empirical study
Excess inventory and Conveyance	Not applicable	Not reported in the empirical study

Source: Adapted from Sternberg *et al.* (2013)

Table I.
Description of seven wastes extended to transport operations

2.2 Lean-based performance measures to assess road transport operations

Measurement on a continuous basis is essential to improve supply chains and operations (Cabral *et al.*, 2012; Dey and Cheffi, 2013). For this reason, the application of lean thinking in the transportation sector needs to be supported by adequate metrics to measure the performance of lean systems as a basis for continuous improvement. In this line, Simmons *et al.* (2004) developed a metric called overall vehicle effectiveness (OVE) for measuring and improving the performance of truck transportations, see Figure 1. This is an extended version of the overall equipment effectiveness (OEE) (Nakajima, 1988) indicator employed in lean manufacturing to improve equipment effectiveness. Later, and to be able to reflect the efficiency of a route, Guan *et al.* (2003) modified OVE by dividing the performance factor into two components: route and time efficiencies. A modified version of the OVE measure was also proposed by Villarreal (2012). This is called TOVE, which considers total calendar time instead of loading time, see Figure 1. This is due to the fact that waste identification and elimination is related to the transportation vehicles utilised to move products. Since vehicles



Sources: Adapted from Simmons *et al.* (2004) and Villarreal (2012)

Figure 1.
OVE and TOVE structure and components

represent a high-capital investment for any organisation, it is of paramount importance to keep them in operation at all times. In summary, TOVE consists of four components to measure vehicle efficiency, namely: administrative or strategic availability; operating availability; performance; and quality. The measure is obtained from the product of these mutually exclusive components. In this case, the concept of vehicle administrative availability is important because it has a significant impact on the overall vehicle utilisation and efficiency. It is mainly the result of administrative policies and strategies related to capacity or maintenance decisions.

Finally, within this research stream, Taylor and Martichenko (2006) proposed the laws of transportation performance, transportation strategy, daily event management and transportation waste. These four laws describe where and how transportation processes may be sub-optimal and how the application of lean in transportation can positively impact efficiency and overall organisational performance.

2.3 Lean-based methods to eliminate road transportation waste

Unlike the VRP, which is normally addressed by focusing on the optimisation of resource utilisation, routes, cost, time and distance (e.g. Zhong *et al.*, 2007; Boudia *et al.*, 2008; Jemai *et al.*, 2013; Chiu *et al.*, 2006), the lean transportation approach focuses on the elimination of waste from the actual road transportation operations to improve efficiency. Although according to Fugate *et al.* (2009) this approach to gain efficiency has rarely been studied, the literature shows some limited evidence of its application. For example, since road transportation has traditionally been stated as inefficient in Europe (McKinnon *et al.*, 1999; Swedish Association of Road Haulage Companies, 2008), USA (Belman *et al.*, 2005; US Department of Transportation, 2009) and Mexico (Instituto Mexicano para la

Competitividad, 2004), the US Department of Transportation conducted a study to identify inefficiencies in motor carrier operations. The study identified inefficiencies belonging to five different categories: equipment/asset utilisation, fuel economy and fuel waste, loss and theft, safety losses (e.g. crashes), and administrative waste (e.g. data and information processing) (US Department of Transportation, 2009).

One of the initial works regarding the improvement of transport efficiency through waste elimination was that of McKinnon *et al.* (1999). According to these authors, eliminating unnecessary transportation can also be achieved by increasing transport efficiency, in addition to a change of transport mode or the relocation of facilities. On the other hand, Hines and Taylor (2000) proposed a methodology, consisting of four stages, to eliminate waste in transportation processes. Villarreal *et al.* (2009a) applied this methodology to the distribution of frozen goods by a Mexican company. This resulted in an improved availability and capacity utilisation of vehicles, helping this company to save about $12.3 million Mexican pesos (approximately £0.55 million) in future budgeted investment. Similarly, Villarreal *et al.* (2012) integrated, through a comprehensive scheme, the just-in-time approach of milk runs to identify and reduce waste with the traditional operations research approach of developing algorithms to achieve an optimal solution to the VRP. Lastly, Villarreal (2012) adapted value stream mapping (VSM) approach, which he called TVSM, to support efficiency improvement programmes in transport operations.

3. Methodology

As indicated earlier in the previous sections, researchers have mainly attempted to improve transport operations using operations research and mathematical modelling methods. Similarly, some researchers have also explored the implementation of lean thinking to address vehicle routing and transportation challenges. However, there is limited evidence of such application in this area, and as a result this research aims to address this research gap by following a lean and simulation-based approach. Hines and Taylor (2000) suggested a scheme to implement lean improvement initiatives that was later modified by Villarreal *et al.* (2009a, b) to eliminate transportation waste. Later, Villarreal (2012) further modified this original scheme proposed by Hines and Taylor (2000) to adapt it to a specific environment of transport operations, considering efficiency wastes in the procedure. This scheme is now modified in this work to consider the variability inherited in routing operations, see Figure 2. A complete review of schemes for VSM considering variability was recently suggested by Roessler *et al.* (2014).

The first step (Stage I) of the proposed approach consists of the detail description of the transportation activities, complemented by the estimation of the TOVE index. This is achieved by elaborating a TVSM (Villarreal, 2012). The structure of the TVSM map can be divided into two parts. The first part is intended to gather information to explain the macro context of the transportation activities – i.e. general context of the operations and the values of all the efficiency factors described on the right of the

Figure 2.
General structure of transportation waste reduction approach proposed

TOVE measure in Figure 1. This stage also considers an analysis of the degree of variability of customer demand and operation times. The second part is used to facilitate the micro analysis phase. Here, all the relevant wastes associated with the efficiency factors, described on the left of the TOVE measure in Figure 1, and their causes are identified (Stage II). The TVSM has been slightly modified to include information relevant to explain the existence of variability in operations in the form of range, variance, and type of distribution, as presented in the studies of McDonald *et al.* (2002), Braglia *et al.* (2009) and Marvel and Standridge (2009). After identifying the most relevant wastes, a strategy for their elimination is devised in Stage III. This should include all the initiatives designed to reduce waste, and therefore, improve the levels of customer service.

The feasibility and impact of the improvement initiatives should be assessed and validated before being implemented. This task is realised with the use of simulation in Stage IV. Simulation has been used as a viable option to design routes considering variability (e.g. El-Gharably *et al.*, 2013; Wang and Lin, 2013; Angel *et al.*, 2009, 2013; Faulin *et al.*, 2008). The use of simulation as the tool to handle the stochastic nature of the problem was decided by the authors based on the numerous advantages encountered by researchers (e.g. Cigolini *et al.*, 2015; Parthanadee and Buddhakulsomsiri, 2014; Wainer, 2009; Law, 2006; Banks, 1998). For our case, the flexibility of the tool to assess the feasibility of different distribution scenarios, and to communicate and explain company managers the results was the most important advantage obtained from its use. In our case, this was specifically done by using ProModel, which is an object-oriented discrete-event simulation software suite used to develop, model, visualise and monitor the dynamic flow of process activities and entire systems (Harrell *et al.*, 2011; Lu and Wong, 2007), see Figure 3. The focus of the simulation model is on the routing activities; transporting and customer serving.

The initial step of Stage IV consists of building the model of the initial routing operations. Figure 4 presents an excerpt of the variable and processing description of the model built for our case. This model considered that customer demand was known in advance since all clients placed their orders on the day previous to when they needed them. Routing and serving client times were variable.

As part of the model built for our case, goodness of fit testing was used to identify the probability density functions (pdf) for serving each client of each route, and of the time taken between each pair of clients for each route. All the work developed to determine the best fitted pdf was carried out with the Stat:Fit tool of ProModel. Stat:Fit is a utility tool used to fit probability distributions to empirical data. It performs goodness of fit tests using χ^2, Kolmorogov-Smirnov and Anderson-Darling procedures. The tool contains an automatic fitting feature that yields, in accordance with the results of the previously mentioned tests, the best fitted distributions ranked from the best to those rejected, see Figure 5. The time data required to carry out the previous task was collected with the help of an information truck tracking system that was updated by the hand held tools carried by each driver.

Garza-Reyes *et al.* (2012) comment that reliability and accuracy of any simulation model must be verified and validated to ensure that it performs as a true representation of the replicated system. To do this, Kleijnen (1995) suggests the comparison of datasets from the real system and simulated model, and then using statistical tests such as Schruben-Turing and *t*-tests to validate the model. For our case, modelling the current situation was determined valid after reviewing the simulation's logic and the closeness of the results of the variables; in-transit time and the number of customers

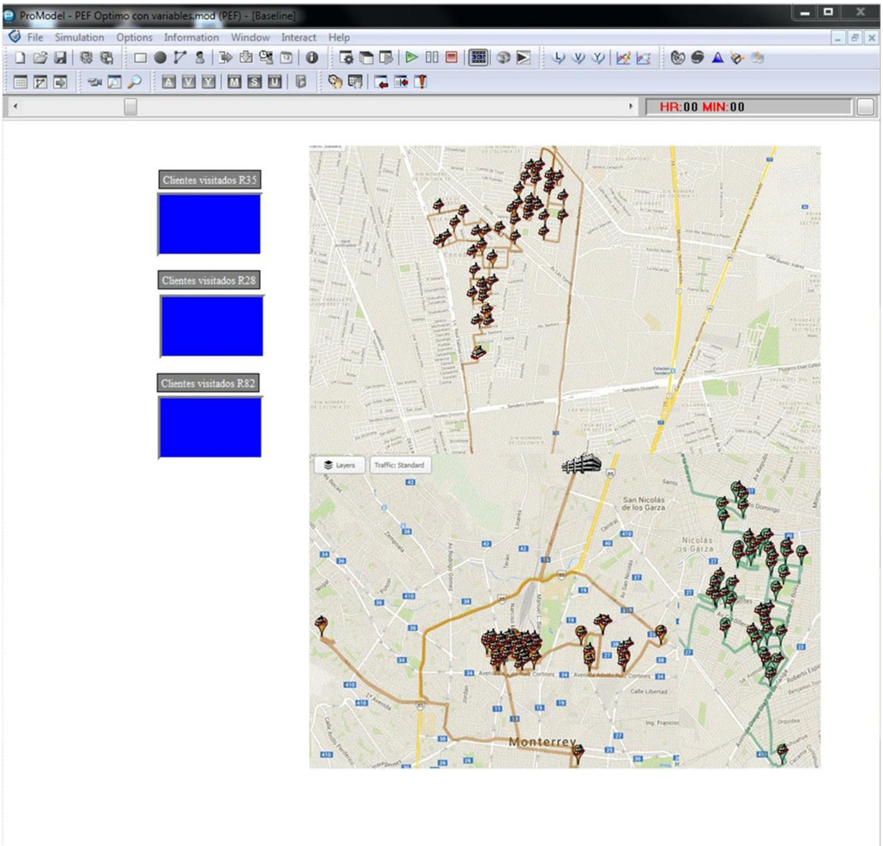


Figure 3.
Illustration of ProModel simulation model

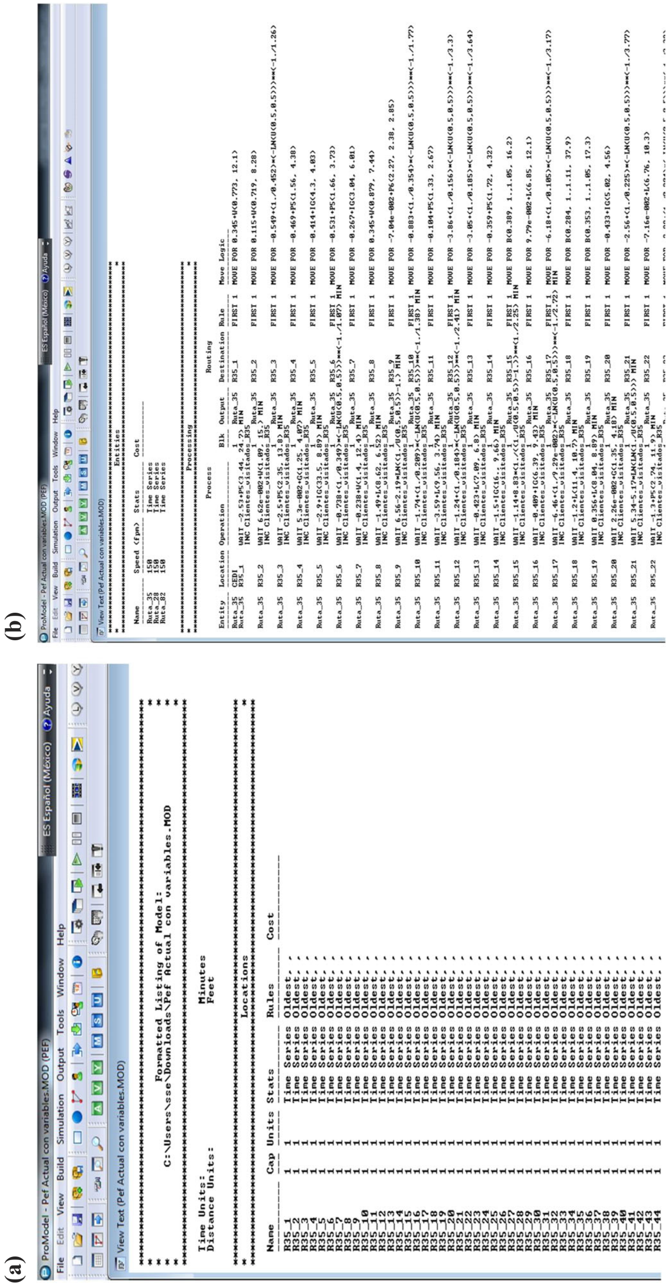
per route not served. Hypothesis testing of the differences of means for these variables, under the simulation model and reality, is also suggested for a desired confidence level.

The final step in Stage IV is to use the validated simulation model to assess new proposed improved scenarios resulting from the recommended initiatives. The purpose of our particular study was to determine its impact on customer service (the number of clients not served).

Finally, those accepted initiatives are implemented in the final phase (Stage V).

4. Implementation and results

An application of the proposed approach is illustrated in this section through a case study of an international company based in Mexico. The studied organisation is the leading firm in the production and distribution of frozen and refrigerated food in the Mexican market. Its annual sales in Mexico were estimated to be around 4 billion USD in 2013. Its annual turnover in 2013 was estimated to be about 9.8 billion USD. The company has extended its operations to the USA, Central America and Peru. The company has a primary distribution network in Mexico that sends product from plants to central distribution centres (CDCs), and from these to regional distribution centres (RDCs). It also includes a secondary network that takes the goods from the RDCs to the retailing points or stores.



Notes: (a) Variable list of ProModel model; (b) processing instructions of ProModel model

Figure 4.
Partial view

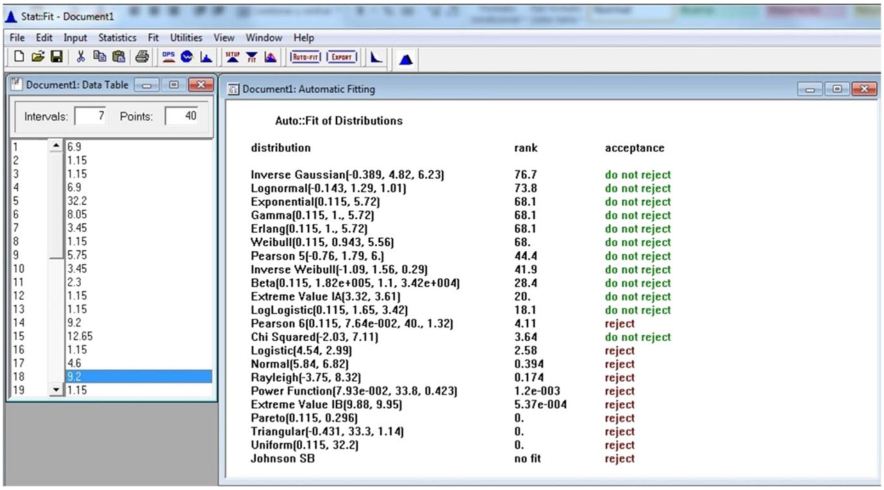


Figure 5.
Example of goodness of fit with Stat:Fit

The primary network includes thirteen plants, five CDCs and seventy four RDCs located across Mexico. It is divided into five geographical regions. This paper is concerned with the application of the project on the Northeastern geographical region. This zone satisfies 15 per cent of the total national demand with sixteen RDCs. The studied firm started an effort to reduce distribution cost in its primary distribution network in 2009. A summary of the initiative applied on the Northeastern part of the network with the objective of eliminating waste to diminish transportation cost is described in Villarreal *et al.* (2009a). This case focuses on increasing customer service level in the secondary distribution network, and in particular, the routing operations from the Escobedo distribution centre (DC) to its customers.

The detailed stages of the improvement project following the lean thinking and simulation-based approach proposed are described in the following sub-sections.

4.1 Mapping the transportation process

The first step of the proposed approach is to map the current state of the transportation processes of interest, which in this case corresponded to the vehicle routing distribution from the Escobedo DC to convenience stores. The current TVSM for the routing operation studied is shown in Figure 6. This includes information regarding the level of variability identified in the operations (Roessler *et al.*, 2014; McDonald *et al.*, 2002; Braglia *et al.*, 2009; Marvel and Standridge, 2009).

4.2 Identify relevant wastes at macro level

As previously stated in Section 3, waste identification at this level emphasises the overall context of the routing process chosen to study. This is the second stage of the proposed approach. As illustrated by the TVSM (Figure 6), the average journey time for the distribution of goods from the Escobedo DC to its corresponding retailing stores was 11.8 hr. All the activities included in the process, from preparing the routes, serving the stores until closing every route were executed during the journey, i.e. all are internal. Internal not-in-transit (NIT) activities took 1.95 hr, on average about 17 per cent of the journey time. Total-in-transit time had an average of 9.9 hr and a standard

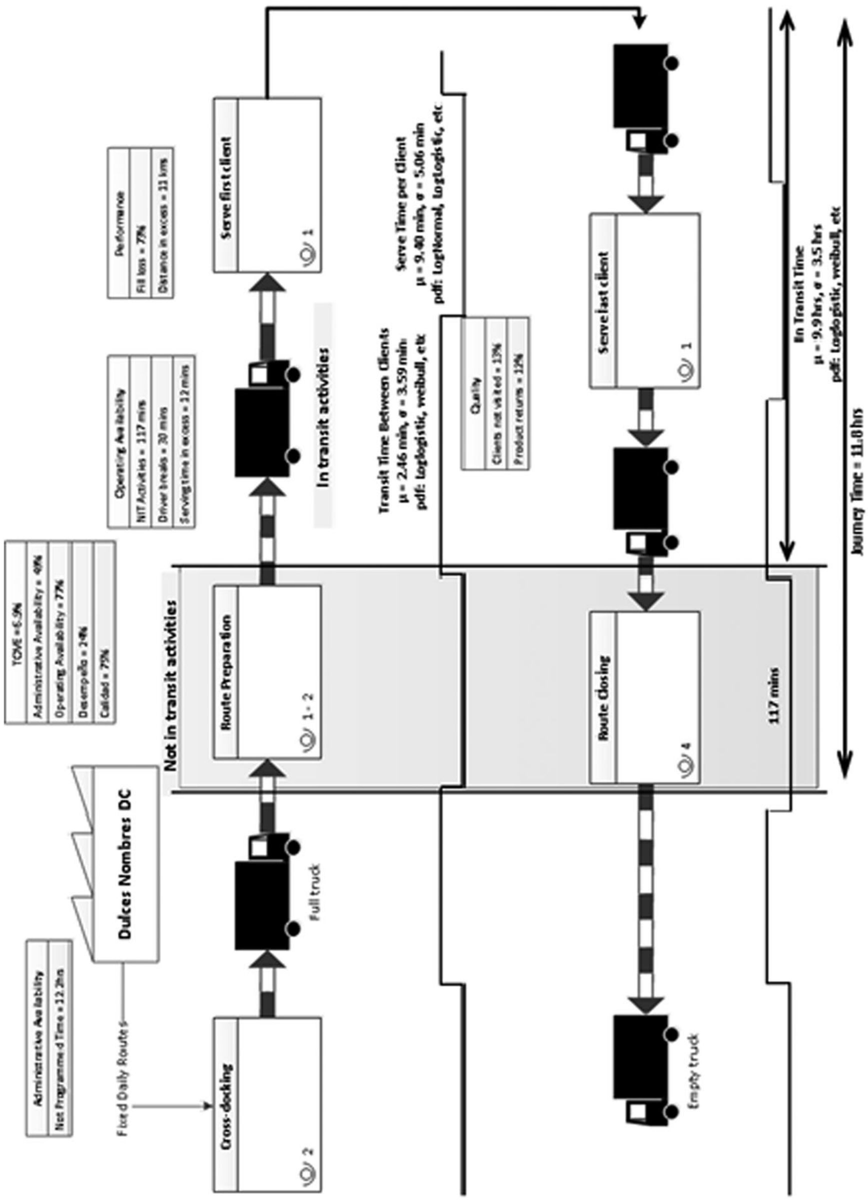


Figure 6.
Current TVSM

deviation of 3.5 hr. The average number of stores served by a route was 45. TOVE index was estimated at 6.9 per cent. The factors with greatest areas for improvement were performance efficiency with 24 per cent and administrative availability with 49 per cent. Operating availability and quality efficiencies were estimated as 77 and 75 per cent, respectively. An alternative description of the efficiency factors and the associated main wastes identified is given in Figure 7.

An additional feature included in the TVSM study referred to the description of the probability distribution functions (pdf) related to the transport times between customers and the times to serve customers in every route. As shown in Figure 8, the best fitted pdfs for transport times between customers were LogLogistic in 40 per cent of the cases, inverse Gaussian with 21 per cent, inverse Weibull with 19 per cent and Pearson with 13 per cent. Similarly, the best fitted pdfs for customer service times were LogLogistic with 29 per cent of the cases, inverse Gaussian with 23 per cent and Weibull with 19 per cent. All the previous pdfs have in common that they are bounded from below on a positive value. All of them are usually used to model time probability functions.

4.3 Identifying key wastes at micro level

As shown in Figures 6 and 7, the first factor to consider was the performance efficiency. The main wastes that drive the level of this efficiency factor down were fill loss with 73 per cent and a distance travelled in excess of 11 km. Distance travelled in excess was the result of an inefficient route design. This process consisted of assigning customers to a truck and defining the sequence for visiting them. This process was carried out by

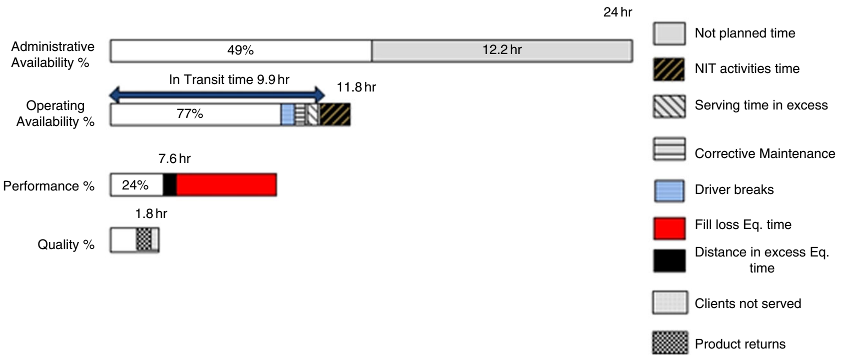


Figure 7.
Efficiency factors and main waste description

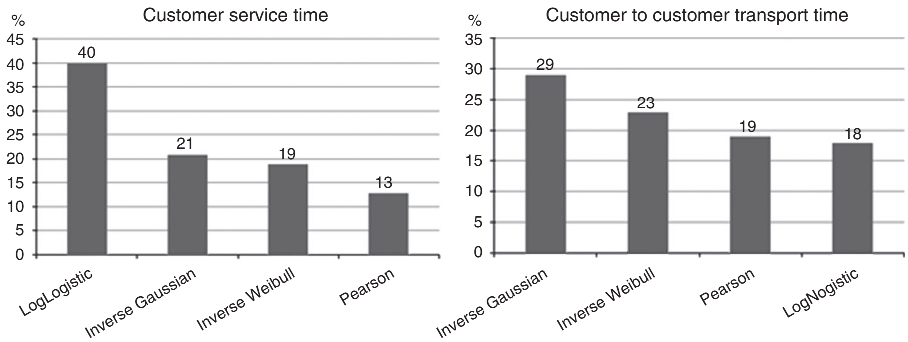


Figure 8.
Percentage of occurrence of most common pdf for customer service and in-transit times

each driver. There was no effort to seek cost reductions and customer time windows were disregarded. In summary, driver's experience and criterion were used to design daily routes. Fill losses were the result of basket and truck capacity under-utilisation. Low customer order demand was not enough to fill completely each customer basket used to carry the order. Truck capacity could not be fully filled because the number of customers visited in each route was insufficient. This quantity was limited by the journey's time. The only way to increase it was by reducing customer serving time. This would allow each route to increase the number of customers visited.

The next efficiency factor to analyse was the operating availability efficiency. The main wastes that determine the level of this factor were NIT activities, serving time in excess and driver breaks. NIT activities included route preparation and closing, totalling 1.95 hr per route on average. This represented about 17 per cent of total journey time. These activities should be improved and executed off the journey time by the warehousing personnel. If done properly, the driving crew would utilise its working journey time in-transit activities and be able to serve more customers. Customer service time included the time taken to perform unloading product, inspecting and verifying with the store leader if the order is complete and getting and loading product returns. There was also the need to consider the time taken to obtain the payment of the order from the customer.

Finally, the quality efficiency was also important for this case. The two important wastes identified were product returns because of obsolescence and the percentage of customers not being satisfied. Expired or perished food was due to the frequency of customer visits, which was two times per week. The demand not satisfied occurred because six customers per route were not visited on average. This was due to either missing time windows or not having the time to visit them.

4.4 Defining the waste elimination strategy

The strategy established to decrease the main wastes identified was originally aimed at significantly improving both the operating availability and performance factors. This consisted of the initiatives presented in Table II.

Process	Description	Initiative	Efficiency waste
Serving customers Returning spoiled products Closing routes	Procedures for serving customers, preparing and closing routes have non-value activities	Eliminating waste in procedures	Serving customer time in excess Waiting time to close routes
Transporting product to customers	Sub-optimal routes defined by drivers Sub-optimal client sequencing Customers are visited several times per route Baskets for product larger than necessary	Semi-dynamic route optimisation Redesign of basket size Replace for smaller trucks	Truck fill loss Distance in excess % of clients not visited
Transporting product to customers	Truck capacity over sized Basket for product larger than necessary		Truck fill loss
Transporting product to customers	Customers not satisfied		% of product returns
Serving clients	Product in customer premises gets spoiled	Increase customer visit frequency	% of clients not covered

Table II. Description of improvement strategy

This paper focused on the implementation of the semi-dynamic route design and the improvement of procedures. Increasing customer frequency, redesigning basket size and using smaller trucks were initiatives that would be defined, evaluated and implemented in the future.

4.4.1 Semi-dynamic routing design. This initiative started with the definition of a new route redesign review period. At the time of the development of the project no review period was determined. Four years had passed since 2009 and the market had changed significantly in terms of the quantity, location and demand of the clients. After analysing market demand growth, it was decided that the company would carry out a weekly route redesign when additional new clients appeared. The company had the option of using the Roadnet Transportation Suite Routing and Scheduling Systems (UPS Logistic Group, 2004), which they already owned, and MapInfo (MapInfo Corporation, 2015). MapInfo software, in particular, could be used to perform a geocode and map analysis while Roadnet Transportation Suite would enable the company to create optimised routes and load plans (Alagöz and Kocasoy, 2008).

4.4.2 Simplifying procedures. The simplification of procedure involved three stages of the routing operations undertaken during: route preparation before trucks left for distribution; serving clients; and at closing routes. Route preparation before leaving to distribute product took too long. Driving crews were idle at least 50 per cent of the time doing nothing. For this reason, they could have about 30 additional minutes for routing and distributing product. Serving clients consisted of unloading and inspecting each customer order. Then, they would put the product in the customer's freezer and obtain their payment. Finally, product returns were identified, counted and packed to be transported back to the company's DC. The last stage requiring procedure simplification is closing routes at the DC. This stage includes the activities of settling customer payments and product returns. Here long queues occurred because of the inefficient work of two cashiers. Each cashier performed different activities in series, being idle 36 per cent of the time. A new procedure in which both cashiers performed all the tasks was designed. This reduced idle time to 15 per cent and decreased total time required for this activity by about 22 per cent.

4.5 Strategy validation (with simulation) and implementation

The implementation of the strategy included an initial pilot test. The two initiatives that required careful attention were the cashier's new procedure and the semi-dynamic route redesign. Both were previously validated with simulation. This paper only describes the work done for the route redesign initiative. This stage consisted of validating the feasibility of the improvement strategy.

As part of the model building, goodness of fit testing was used to identify the pdfs for serving each client of each route, and of the time taken between each pair of clients for each route. As mentioned in Section 3, this task was realised with the help of the Stat:Fit tool. The pdfs most commonly obtained were LogLogistics, inverse Gaussian and Weibull. As recommended by Garza-Reyes *et al.* (2012), the simulation model was validated. In this case, modelling the current situation was determined valid after reviewing the simulation logic and the closeness of the results of the variables; "in-transit time" and the number of customers per route not served. Hypothesis testing of the differences of means was performed for a confidence level of 99 per cent. The time simulated per route was 15 days. The null hypothesis that the differences of means for both variables are the same was accepted. Therefore, it was concluded that the model could be used to represent the real system studied.

4.5.1 Redesign of routes. The next step consisted of redesigning routes. A sample of 30 per cent of the routes was re-defined; see Figure 9 for an example of a re-designed route. This task was carried out by using the route planning and optimisation software VIAMENTE (Viamente, 2015). Here, both the assignment of clients and the sequence of visiting them were modified.

4.5.2 Pilot testing and new time gathering. Due to the route changes suggested by VIAMENTE, it was decided to do a pilot test with ten routes during two weeks. This had the purpose of building confidence, and gathering the new transport times between customers and the new service times. This new data were used to simulate the new routes and their future potential performance. The results from the pilot run showed a significant reduction on the average number of clients not being served per route from six to zero. In addition, a simulation of the improved scenario was carried out to consider the variability of the operations. The purpose of this study was to determine if this would impact the number of clients not served. Again, the results obtained showed that the customer service level was improved significantly reinforcing the pilot test results. The simulated average number of customers not served per route was 0.9 compared to none during the pilot run. The null hypothesis that the differences of means for this variable are the same was accepted. Thus, confirming the result that the simulation model represented the pilot run scenario.

4.5.3 Final implementation of initiatives. The implementation of the previously described strategy is currently under way in the company. This has been divided into two fronts: The first front is concentrated on improving warehousing (NIT) activities considering their impact on transport efficiency. The main initiative consists of improving the tasks performed by the cashiers. The second front is concerned with the

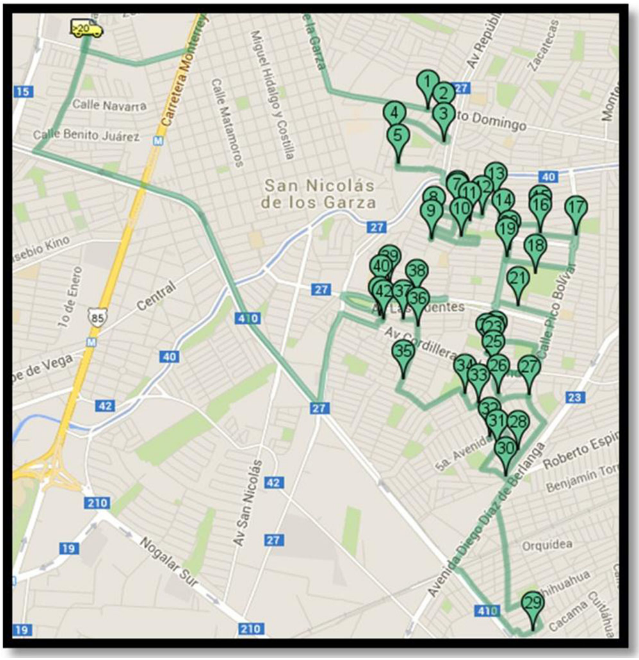


Figure 9.
Example of route re-designed

route design. The initial step in this front consisted of the pilot test explained previously. The second step was the redesigning of 30 routes. As required by the methodology, the simulation model was used to evaluate the new re-designed routing operation. As shown in Table III, after applying the optimisation software and running the simulation model, the number of routes was reduced to 22 without compromising the customer service level. The average number of clients to be served by each route increased by 23 per cent (i.e. from 45 to 55 clients) and the distance travelled decreased to 32 per cent (from 1,770 to 1,203 km). TOVE Index increased to 19.3 per cent and performance and operating availability efficiencies were also improved significantly, see Table III.

5. Conclusions

This paper presents an application of the lean methodology to the field of transportation, and in particular, to routing operations. It contributes by combining the previous works of Sternberg *et al.* (2013) and Villarreal (2012) to propose an alternative approach, based on lean thinking and simulation, to improve the efficiency of warehousing and routing operations.

The proposed approach was employed to improve the operations and customer service level of a Mexican firm that produces and distributes frozen and refrigerated food. Originally, about six clients per route were not satisfied on average. The firm had identified an important degree of variability in transport and service times, which were thought to be a cause for the deficient customer service level. Based on the proposed approach, this work describes the design of a strategy based on the elimination of waste to increase efficiency in the distribution operations of the company. As previously described, the company's distribution network had a primary distribution network that sends product from plants to CDCs, and from these to RDCs. It also included a secondary network that takes the goods from the RDCs to the retailing points or stores. The purpose of this study was to describe the efforts to increase customer service level in the secondary distribution network, and in particular, the routing operations from the Escobedo DC to its customers. The first step of the approach consists of obtaining the current TVSM for the routing operation and modified to include information regarding the level of variability identified in the operations. In this case, the focus was on service and transportation times. The factors with the greatest areas for improvement were performance efficiency with 24 per cent and administrative availability with 49 per cent. Operating availability and quality efficiencies were estimated to be 78 and 75 per cent, respectively.

The quality efficiency was very important for this case. The demand could not be satisfied because six customers per route were not visited on average. This was due to

Table III.
Summary of real and projected results after implementation

Concept	Initial situation	Projected situation
TOVE index (%)	6.9	19.3
Performance efficiency (%)	24.0	47.0
Operating availability efficiency (%)	77.0	84.0
Number of customers not served/route	6	0
Number of routes	30	22
Average number of clients per route	45	55
Total distance travelled (kms)	1,770	1,203

either missing time windows or not having the time to visit them. This level of customer service was improved by re-assigning time spent on waste activities associated to the performance and operating availability efficiencies. The most important wastes identified within these factors were distance travelled in excess (due to an inefficient route design) and NIT activities (that include preparing and closing routes) and represented about 17 per cent of total journey time. The two initiatives designed to reduce both were the cashier's new procedure and the semi-dynamic route redesign. Both were validated with simulation modelling to ensure their technical feasibility and successful implementation. After implementing both initiatives, the company was confident that customer service level could achieve a level of excellence. In addition, the number of routes could also be reduced by 27 per cent without compromising the customer service level, and the distance travelled would decrease by 32 per cent.

The work described in this study represents an extension of the scheme for reducing transportation waste developed by Villarreal (2012) to consider the identification and impact of the variability inherent in routing operations. To our knowledge, this is the first waste reduction scheme of this type, suggested for the area of transportation. Therefore providing an important contribution by extending the existing knowledge and understanding of this area. The use of simulation, in this case, provided more confidence to the firm's management for the successful implementation of the improvement initiatives.

6. Discussion and future research

The most important impact of this research on society is on the improvement of the competitiveness of the transportation sector and on environmental issues. Freight transportation by road has become an important element of international trade and supply chains performance (Demir *et al.*, 2014). For example, the US Department of Transportation (2009) concluded that 68 per cent of the total tonnage moved in the USA in 2010 was done by road, whereas 29 per cent of the ton-km of this country's trade with Mexico and Canada was also moved under this mode of transportation. Similarly, the Mexican Transportation Secretary informed that in 2013 nearly 75 per cent of total ton-km was distributed by road (Subsecretaría de Transporte, 2013). In the same line, the European Commission reported in 2008 that the European Union moved 27 per cent of its ton-km by road. However, road transportation has traditionally been stated as inefficient, in European countries (McKinnon *et al.*, 1999; Swedish Association of Road Haulage Companies, 2008), North America (Belman *et al.*, 2005; US Department of Transportation, 2009) and in Mexico (Instituto Mexicano para la Competitividad, 2004).

Additionally, according to Demir *et al.* (2014) and Dekker *et al.* (2012), the transportation sector is becoming increasingly linked to environmental problems. With a technology relying heavily on the combustion of hydrocarbons, notably with the internal combustion engine, the negative effects of transportation, especially road freight transportation, on environmental systems has increased (Demir *et al.*, 2014). This has reached to the point where road transportation activities are a major factor behind the emission of harmful pollutants including nitrogen oxides, particulate matter and carbon dioxide (CO_2). In particular, greenhouse gases are dominated by CO_2 emissions from burning fossil fuels, which generate climate disruptions and atmospheric changes posing health risks and are harmful to the natural and built environments. Therefore, the potential of adapting and using a waste elimination approach, such as the one proposed in this paper, to improve competitiveness and the environmental impact of truck transport operations appears to be high.

Further research in this area should consider the incorporation of demand and operation time variabilities as additional wastes. The direction of this research is aligned with the future research direction suggested by Zammori *et al.* (2011). In their work, the authors proposed the use of a stochastic OEE index to take into account the variability concept. Thus, our future study will involve developing a suggested stochastic TOVE. Woodside (2010) and Cameron and Price (2009) consider a single detailed case study, such as the one conducted in this paper, as a valid research methodology. However, it might still be considered as a limited research method to prove the effectiveness of the proposed approach. Nevertheless, if it is replicated again in this and/or different industrial context, a generalisation and validation of findings can be achieved (Garza-Reyes *et al.*, 2014; Yin, 2012). Thus, it would also fall into a future research agenda to test the lean thinking and simulation-based approach for the improvement of routing and warehousing operations proposed in this paper through the use of multiple cases studies in different settings.

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