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LEAN DISTRIBUTION ASSESSMENT USING AN INTEGRATED MODEL OF VALUE STREAM MAPPING AND SIMULATION

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ABSTRACT

Distribution is a critical component that maintains the efficiency, flexibility, and reliability of any supply chain. Given the limited financial and physical resources of today's businesses, distribution enterprises have begun to embrace the far-reaching value of lean paradigm. Value Stream Mapping (VSM) is prescribed as a part of the lean implementation portfolio of tools. It is applied to map material and information flows seeking to identify company's waste and non-value added activities. Integrating simulation with VSM introduces a whole new dimension for lean implementation and assessment processes. This paper show a dynamic value stream mapping model using discrete event simulation to assess two basic lean practices, pull replenishment and class-based policy, of a tire distribution company.

1 INTRODUCTION

Distribution Centres (DCs) often perform more than a single function in supply chain networks including make-bulk/break-bulk consolidation centre, cross docking centre, product fulfilment centre and depot for return goods (Higginson and Bookbinder, 2005). In addition, they offer a customer support by scheduling services such as product installation or offering space for retail sales to end-consumers (i.e. factory-outlet store) (Berman, 1996). However, DCs face many challenges in an environment characterised by increasing globalisation, competitiveness and consolidation. The quest to offer high level of service to customers while keeping a worthwhile profit margin under these challenges urge DC managers to think of applying the lean management thinking to manage and improve their activities.

Lean philosophy is defined as a multidimensional concept that effectively eliminates or at least mitigates systems' waste (Womack and Jones 2003). Extending lean philosophy beyond manufacturing into distribution centres provides supply chains a competitive advantage by increasing the efficiency and responsiveness to customer demands with the minimum cost (Reichhart and Holweg, 2007). In order to successfully implement lean philosophy there is a need to track system's improvement through a quantitative lean index. To date most of lean assessment models are based on subjective methods of assessment which ultimately create difficulties in assessing or benchmarking the leanness of distribution companies consistently (Ray *et al.* 2006).

Hence, this papers aims to present a quantitative lean assessment framework that integrates VSM with simulation approach in order to dynamically assess the leanness level of a tire distribution company. A current state model of the studied company and two lean practices – pull replenishment and class-based storage policies– are evaluated against a set of lean performance indicators. By employing the proposed VSM-based simulation model, the company's managers can figure out the lean transformation impact before the actual lean implementation.

2 VSM-BASED SIMULATION

Value stream mapping (VSM) is an important tool that supports lean assessment efforts through a visual comparison of the systems' current and future states (Tapping and Shuker 2003; Hung-Da, Chen and Rivera 2007). The tool was employed in several applications due to its simplicity and effectiveness (Duggan, 2002, Tapping and Shuker, 2003). It was carried out in distribution environments aiming to map firms activities, assess firms supplier relationships, and identify their improvement opportunities (Hines et al. 1998). Although its efficiency, several criticisms against VSM have been addressed. Standridge and Marvel (2006) stated that VSM is unable to effectively handle systems variability and complexity due to its static nature. Wan and Chen (2008) also concluded that applying VSM on its own could not provide an effective evaluation for systems' leanness levels.

Various publications highlighted the necessity of integrating VSM with simulation. Sullivan et al. (2002) indicated that simulation supports VSM by handling the complexity and variability of the system. In addition it has the ability to concurrently evaluate various performance metrics regarding their nature or measurement units (Mahfouz, Hassan and Arisha 2010). This kind of in-depth analysis enables simulation to model systems' future state showing the ideal performance that is pursued over time. Combining VSM with simulation leads to two main advantages, (1) an accurate analysis of system's current and future states and (2) an efficient quantitative assessment for the lean practices and policies (Donatelli 2008).

VSM-based simulation has been applied to a wide variety of applications including manufacturing and non-manufacturing systems. Simulation was integrated with VSM in order to support the lean implementation in a steel mill and textile industry (Abdulmalek and Rajgopal, 2007). In other study, two simulation models are developed for the VSM evaluating two scenarios of push and pull manufacturing systems (Lian and Van Landeghem, 2002). In 2007, both authors have discussed the application of VSM-based simulation in a low-volume and high-variety component production job shop. McDonald et al. (2002) presented an application of VSM and simulation to a dedicated product line in an engineer to order motion-control products manufacturing plant. A new approach known as the "simulation-aided Value Stream Mapping" (saVSM) was introduced by Narasimhan et al. (2007) and applied at a global engine manufacturer's test environment. In the service industry, Dennis et al. (2000) has demonstrated the application of VSM with simulation in the British Telecommunication company.

3 TIRE DISTRIBUTION INDUSTRY

In this paper, a tire distribution company is employed as a case study. The company supplies tires for a wide variety of customers ranging from large scale companies to individual buyers. The main objective of the company is to respond speedily to the customers demand in an accurate manner with the least possible cost. Monthly forecasting plans are generated for all company's products and are used as a basic component for operations management. These plans are based on extensive analysis for markets conditions, competitors positions and SKU consumption rates. Two main concerns face the forecasting process in the studied company; (1) generating forecasting plans for more than 200 different SKUs consumes a considerable time and effort and (2) forecasting inaccuracy due to the high fluctuation of customers demand. 'Pull replenishment' is suggested to replace the current push replenishment strategy (i.e. forecasting based strategy) in order to compromise the trade-off between the company's flexibility to customers demand and the total cost. However, under pull replenishment strategy a robust relationship with company's suppliers has to be established in order to mitigate the risk of item stock-out and reduce items lead time.

The company also faces a challenge with the currently applied random storage policy which causes inefficient storing and picking operations. Pickers often visit several storage locations to pick one type of tires which increases the storage and picking time. Locating similar types of tires close together, namely Class-based storage policy, is suggested to increase the efficiency of storing and picking operations. According to company's managers, it is expected that storing and picking operation times are reduced by 20% by applying the class-based storage policy. Table 1 summarizes the challenges face the company and the proposed lean initiatives to resolve them.

Table 1: Operations challenges facing the studied company

Challenges	Lean Initiative	Initiative Type
• Forecasting inaccuracy. • Establishing large number of forecasting plans for SKUs which consume considerable time and effort.	Decreasing the reliance on order's forecasting process and applying pull replenishment strategy.	Replenishment Management
• Inefficient performance of storing and picking operations.	Storing the similar SKUs near together and applying advanced tracking systems – Class-based storage policy.	Storing Management

4 LEAN ASSESSMENT FRAMEWORK

The proposed lean assessment framework consists of five main phases as shown in Figure 1. The process is started by conducting several meetings with the company's managers aiming to gain more understanding of the SKUs characteristics, business processes sequence, operations time, information and material flow, and other company parameters (e.g. equipment utilization, labors scheduling, and customers and suppliers relationships). The five phases of the framework are applied as follows:

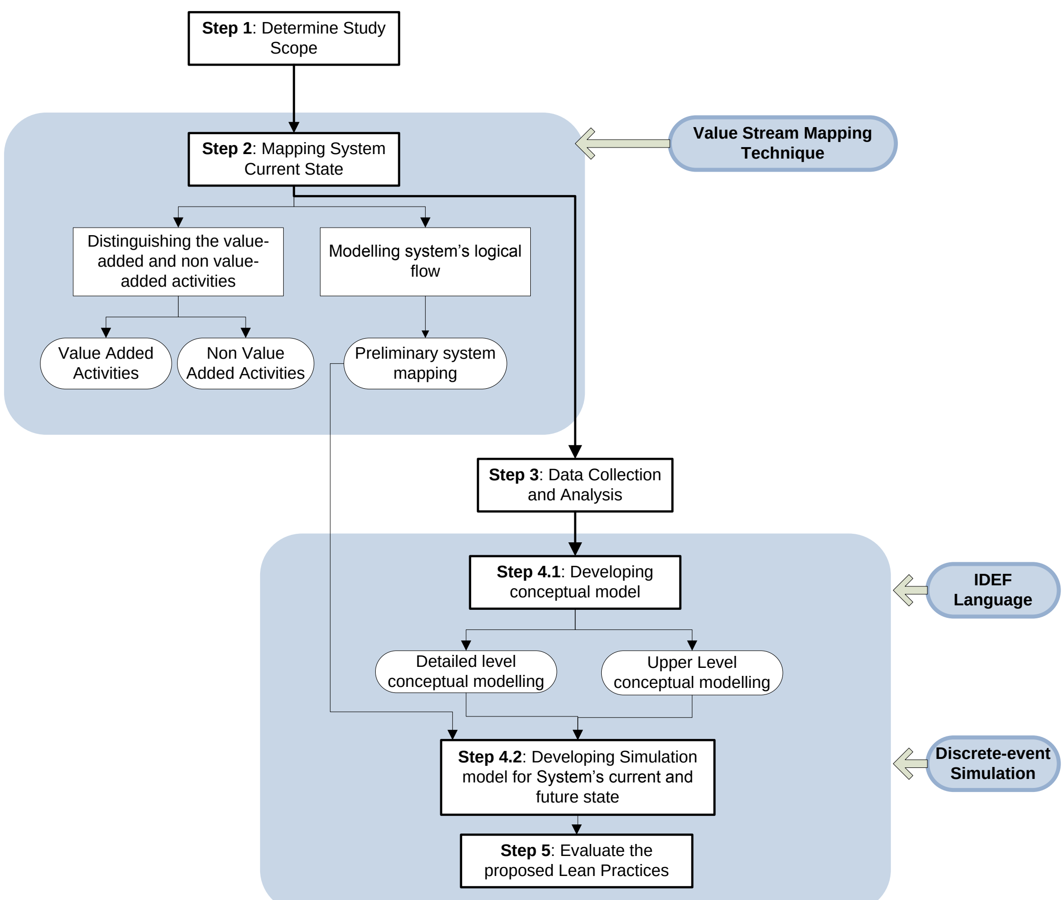

Figure 1: VSM-based Simulation Framework Structure

Step 1: Determine Study Scope

The studied company encompasses of various functions including marketing, sales, finance, orders management, inbound, outbound and shipment processes. Different supply chain partners are also engaged in the company's activities and have direct impacts on their performance (e.g. customers, suppliers and government bodies). The study focuses on two basic lean practices that influence the performance of three main distribution functions; order management, inbound operations (i.e. storing), and outbound operations (i.e. Picking). The pull replenishment strategy was proposed for improving order management process, while class-based storage policy was suggested to enhance the performance of the storing and picking operations.

Step 2: Mapping Company's Current State

Customer orders are received either by company's sales team or through online purchasing, followed by an availability check for the required items. For the available SKUs, a picking documents are directly passed to warehouse manager triggering set of operations (i.e. picking, assembly, checking, loading and delivery). Otherwise, a full truck load replenishment order is issued to the company's suppliers. As illustrated in Figure 2, a short time is taken to process customer orders – the upper path – thanks to using an enterprise resource planning (ERP) that facilitates the information flow and reduces the probability of transaction errors.

Inbound planning operation is commenced after receiving the replenished SKUs. It aims to determine the available storage places, printing storage labels, and preparing storing documents. Following that, unloading process is commenced where one handling equipment unit and three staff are assigned for each truck. One staff member with a handling equipment unit is then assigned to store the unloaded tires (i.e. put away). Although the efficiency that ERP provides for processing customer orders, it causes considerable delay for the inbound and outbound operations due to the data inconsistency with the real warehouse information of inventory levels and storage locations.

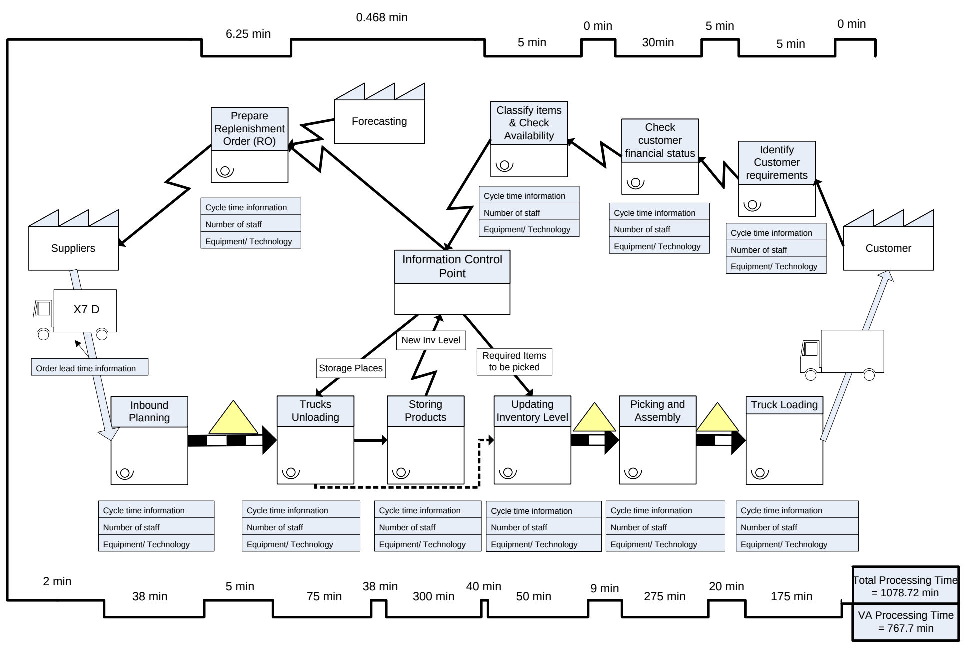

Figure 2: VSM of the current state of the studied company

Step 3: Data Collection and Analysis

- **Identifying input variables**

Five main input variables are determined presenting the main inputs for the company's distribution operations; (1) processing times, (2) machine availability, (3) available inventory space (i.e. inventory capacity), (4) labor capacity and (5) equipment capacity. The first variable (i.e. total order processing time) is calculated using VSM and recorded 2.24 days/order. Based on the maintenance managers and supported by machines breakdown and repair reports, the machine availability is set as 70%. Total inventory capacity – the third variable – is estimated by 60,000 tires with an approximate capacity of 300 tires for each type. Finally, the company employs 13 staff excluding top managerial staff, and 6 handling equipment units with different sizes. The estimations are provided by the planning and operational managers and are verified through various site visits.

- **Identifying output variables (i.e. lean metrics)**

Since lean is a multidimensional philosophy, a single or specific group of metrics will contribute partially in evaluating the leanness level. Based on literature review and several meetings with distribution and supply chain academics, an initial set of lean distribution performance metrics is developed. The metrics are then validated through several meetings with the studied company's managers who selected set of metrics that are currently used to evaluate company's performance; orders cycle time, orders throughput rate, resources utilization, inventory level, distribution cost – including inventory holding cost, ordering cost and stock-out cost, and number of lateness jobs.

Step 4: Developing CVS and FVS Simulation model

- **Conceptual Models**

A detailed conceptual model is developed for the studied company in order to highlight its main functions and processes (Mahfouz *et al.*, 2010, Arisha *et al.*, 2004). Given its ability for modeling complex systems and its hierarchical nature that provides a comprehensive understanding for system's details, integrated definition language (IDEF) is selected to conceptually model the CVS and FVS for the studied company. Each function is modeled in two different levels of details. The generic level of details, using IDEF0 modeling language (Figures 3), showed the sequence of the main functions as well as their inputs, outputs, controls and mechanisms (i.e. utilized resources). Each function is then broken down into-smaller sub functions illustrating the detailed objects flow and the decision points, using IDEF3 (Figure 4).

- **Simulation Model**

Two simulation models are developed for company's current and future states – *CVS* and *FVS*. While CVS model is based on the system's current configurations and policies, FVS model employs the new system's configurations under the proposed lean practices. Some model assumptions were made such as (i) no supplier disruptions are considered and (ii) all received items from suppliers are accepted (no return for item damage or wrong quantities).

Simulation software based on Java and XML technology was used to build the proposed model providing object-oriented hierarchical and event-driven simulation capabilities (Mahfouz and Arisha, 2010). It also used breakthrough activity-based modelling paradigms (e.g. real world activities such as assembly, batching, and branching) for modelling the large-scale applications. The resources were characterised by their availability and breakdown frequency, whereas the product enteritis were attributed by arrival time, processing time, and products characteristics (e.g. processing routing and products type). 150

blocks in a hierarchical form representing; queues, activities, and branching points have encompassed the simulation model.

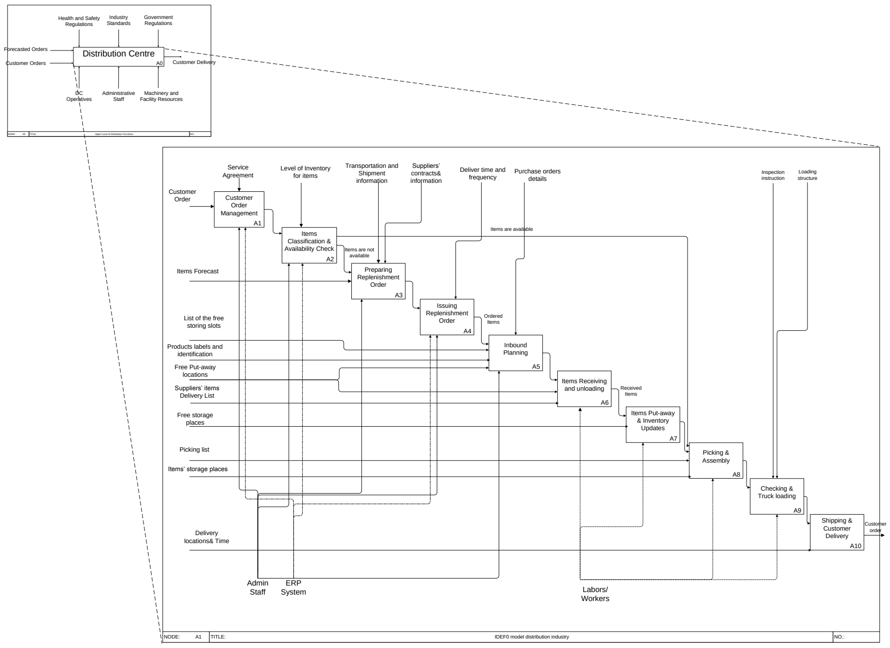

Figure 3 : IDEF0 conceptual model of the studied company

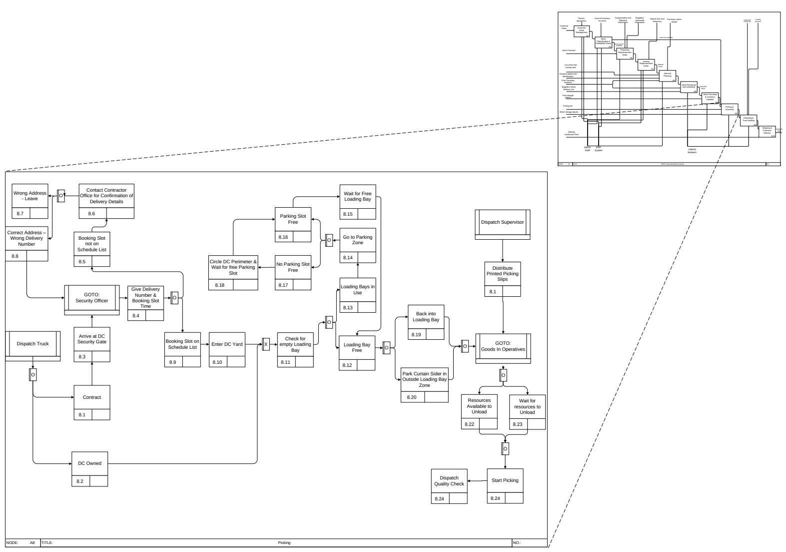

Figure 4 : IDEF3 conceptual model of the studied company

In order to manage the stochastic nature of system's parameters, a theoretical statistical distribution is employed. The analysis of the arrival rate of customer orders resulted in exponential distribution with a mean of 8 orders a day based on sales historical records. The service time was proportional to SKUs quantities and followed a normal distribution. Suppliers lead times were constant based on supplier's locations and conditions of delivery. The frequency of equipment maintenance plans and the rates of breakdown and repair time is also taken into consideration. A snapshot of the simulation model is illustrated in

Figure 5.

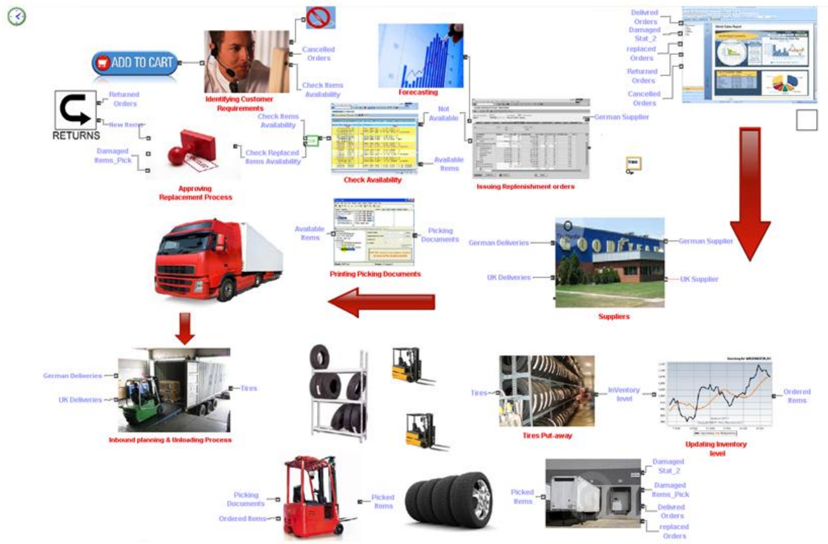

Figure 5 : A snapshot for the simulation model

In an effort to create an accurate simulation model that mimics company's operations, various verification and validation methods are employed. For the verification phase, the decomposition method (i.e. verify every group of blocks) is used. A built-in simulation debugger is also used to avoid any coding bugs. Three validation methods are applied on three phases of the simulation models; data collection phase, conceptual modelling phase and finally simulation results phase. Validation of the data collection phase is aiming to ensure that; (1) no measurement errors in data collection process, (2) the generated data match the pattern of historical data and (3) the identified attribute values within specified range. To achieve that, a detailed examination of data documentation quality and consistency is done with the cooperation of company's managers. The conceptual model is than validated based on interviews with company's managers to ensure that all specified processes, structures, system elements, inputs and outputs are considered correctly. The modelling team also examined the accuracy and consistency of the conceptual model to the problem definition. Finally, "Face validation" approach is used to validate the final simulation results.

Step 5: Evaluation of Lean Distribution Practices

Two lean distribution practices are suggested as a part of lean implementation process in the company, pull replenishment (i.e. FVS1) and class-based storing (i.e. FVS2) policies. The current company's parameters and configurations that are represented in the CVS simulation model are changed based on the special characteristics of each practice.

- **Pull Replenishment Strategy**

The inaccuracy that is associated with items forecasting process as well as the fluctuation of customer demand are two sources of waste the company is facing. However in today's competitive market, the company cannot risk their customer satisfaction by totally replace the push replenishment by the pull replenishment concept. Therefore, an integration between the two concepts is proposed. This integration aims to decrease the inventory cost while at the same time keeps a high customer satisfaction level. In order to effectively apply pull replenishment, various changes are proposed on the current company's configurations as follows;

- *Decreasing the time taken for supplier negotiation*: by developing long term agreements with company's suppliers regarding to items prices and delivery conditions.
- *Establishing new collaboration with alternative suppliers*: aiming to decrease transportation lead time and hence respond efficiently to the rush and unexpected orders.
- *Increasing the frequency of issuing the replenishment orders*: attempting to facilitate items flow across distribution network and reduce replenishment lead time.
- *Reducing replenishment lot sizes*: aiming to decrease inventory level and holding cost.

A simulation model is developed to mimic the new system's configurations under the pull replenishment policy – FVS1. Reducing supplier's lead time, increasing replenishment orders frequency and decreasing order lot sizes are the key changes.

- **Class-Based Storage Policy**

Currently, the company uses a 'random storage' policy where storage locations are selected based on spaces availability. It is simple to follow and often require less space, however it increases the distance travelled by the picker and in turn increases the total storing and picking times. It also requires continuous monitoring and updating for the available storage spaces which adds more time before and after storing operations. Class-based storage (CBS) practice on the other hand provides easy tracking for SKUs, accelerating storing process, and increasing the efficiency of the picking operations. All SKUs in CBS policy are ranked according to their type and then partitioned into different storage classes where warehouse locations are assigned for each class.

According to the company's operations manager, applying CBS policy results an enhancement in storing and picking performance. Some changes are applied on the current state simulation model and its input variables to represent the system configurations under the CBS policy. The main modification, based on company's operations manager, is that processing time is decreased by 20% and the capacity of staff and equipment have also been decreased.

5 RESULTS ANALYSIS

Three simulation models have been run for the company's current and future states; (1) current value stream – CVS, (2) future value stream under pull replenishment strategy – FVS1, and (3) future value stream under class-based storage policy– FVS2. Ten simulation runs were replicated for each model in order to mitigate the impact of the stochastic nature of the variables. Using the identified lean metrics, the three system states are evaluated as follows;

CVS state model: The results of CVS simulation model have shown a poor performance for the company. This can be explained due to four main problems the company faces; (1) the fluctuation of customer demand, (2) the long processing time of storing and picking operations, (3) the frequent breakdown of the handling equipment units and (4) the resources overcapacity (e.g. labors and equipment), especially in low demand periods. The total reliance on forecasting-based replenishment strategy (i.e. push replenishment) with the fluctuation of customer demand causes high inventory level, long order cycle time and increasing in total distribution cost. Operationally, the long time of storing and picking operations, due to applying random-storage policy, is negatively impact the order cycle time, number of lateness jobs and the throughput rate. The equipment and labor utilization are also affected by the frequent breakdowns and the lack of maintenance plans for the material handling devices. Table 2 summarizes the model results under the current company's status.

Table 2: Results of CVS state

Output Variables – lean metrics	Simulation Results under CVS configurations
Total Order Cycle Time	30 days
Throughput Rate	2.46 orders/day
Labor Utilization	30%
Equipment Utilization	40%
Number of Lateness Jobs	301 orders
Total Inventory Level	13304 SKU

FVS1 state: In general, the implementation of the pull replenishment strategy resulted a better values for the orders cycle time, number of lateness jobs, inventory levels and throughput rate, Table 3. The results indicate that pull replenishment approach has an advantage over the forecast-based replenishment under two conditions; (1) providing a short orders lead time by establishing a robust collaboration with company's suppliers and (2) efficient replenishment process with short replenishment cycle time. Without realizing these conditions, pull replenishment strategy cannot deal with the fluctuation of customer demand causing huge loss in customer service level as well as distribution cost.

Table 3: Results of FVS1 state

Output Variables – lean metrics	Results of CVS simulation model	Results of FVS1simulation model
Total Order Cycle Time	30 days	22 days
Throughput Rate	2.46 orders/day	3 orders/day
Labor Utilization	30%	68%
Equipment Utilization	40%	63%
Number of Lateness Jobs	301 orders	240 orders
Total Inventory Level	13304 SKU	7500 SKU

FVS2 state: Table 7 shows a dramatic decrease in total order cycle time and the number of lateness jobs by applying the class-based storage policy. Comparing to CVS model, a better values for the throughput rate, labor utilization, equipment utilization and inventory level have been obtained. The result indicates the importance of enhancing storing and picking operations in order to obtain efficient lean distribution performance. Applying class-based storing policy has improved the efficiency of the storing and picking operations by reducing the travelling distance of labors and equipment in both operations.

Table 7: Results of FVS2 state

Output Variables – lean metrics	Results of CVS simulation model	Results of FVS1 simulation model	Results of FVS2 simulation model
Total Order Cycle Time	30	22	17.82
Throughput Rate	2.46	3	2.8
Labor Utilization	30%	68%	55%
Equipment Utilization	40%	63%	50%
Number of Lateness Jobs	301	240	101
Total Inventory Level	13304	7500	10000

The models result have provided clear vision of the consequences of the two lean strategies. It was concluded that applying Pull Replenishment policy reduced order cycle time by 26%, increased the throughput rate by 21%, decrease the number of lateness jobs by 20%, reduce inventory level by 40% and enhanced resource utilization by 38% and 23% for the labors and machine utilization respectively. While on the other hand more enhanced figures for orders cycle time and number of lateness jobs were achieved by applying class-based storage policy.

6 CONCLUSION

Inefficient distribution performance is a serious challenge against developing a streamlined and waste free supply chain network. Despite the critical role that the distribution industry plays in improving supply chain performance, there are few publications which addressed lean distribution implementation and assessment process. Without evaluating lean practices' impacts on companies' performance, it would be ineffective to plan the lean implementation process. For this purpose, Value Stream Mapping and Simulation were integrated in order to develop an effective approach to evaluate lean distribution practices.

Two lean practices – pull replenishment and class-based storage – were evaluated against the current company state. Although the implementation of the studied lean practices has achieved a better results for the lean matrices, companies that are able to implement the complete set of lean distribution practices and techniques will attain a distinctive improvement in performance. Lean is a multidimensional philosophy where the implementation of one or specific group of practices will contribute partially in achieving the required leanness level. Hence, it is recommended for further research to use the proposed VSM-based simulation model to evaluate more than one lean practices and explore their impact on the lean metrics.

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