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An Integration of Lean and Digital Twin Simulation Modelling for Warehouse Material Handling and Optimization

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Abstract

The accumulation of supply chain lead time caused by inventory handling inside the warehouse, which includes waiting time, queue time, and unexpected delays, makes it difficult to fulfill demand shocks and third-party stakeholder needs. Regardless of how complex production planning is, these issues persist and change. In that instance, studying or mapping a pharmaceutical warehouse supply chain inventory would be a significant difficulty in identifying areas for future development. The study focused on the warehouse of a pharmaceutical firm. Following extensive fieldwork and literature gap analysis, a case study technique was determined to be the most appropriate methodology for this study. Lean unified simulation modeling leverages Supply Chain Value Stream Mapping (SCVSM) and Discrete Event Simulation (DES) to capture, record, evaluate, and decrease inventory waiting times, delays, queues, and other wastes for a specific product family. Following various lean proposals in the future state SCVSM, the findings of this investigation reveal a significant improvement in warehouse lead time. There was significant increase in the value-added time and reduction in non-value added time with the assistance of risk free DES models that replicated the entire operations for the purpose of present and future state simulation along with suggestions for improvements. This study proved to possess strong managerial and practical implications that shall help in better decision-making by deeply understanding the supply chain activities that occur as discrete events inside a warehouse.

Keywords
Lean Management, Supply Chain Modelling, Discrete Event Simulation, Warehouse, Lead Time Reduction.

1. Introduction and Problem Identification

This research is focussed on pharmaceutical warehouse supply chain operations. A leading Malaysian Pharmaceutical firm was approached to carry out this study. According to (Aigbogun, Ghazali, & Razali, 2014) the pharmaceutical industry is growing at a commendable rate and it appears to face problems in the field of on-time delivery (OTD) of medicines. Due to very high demand, hospitals and pharmacies run out of drugs on a few occasions, or some medicines are left unused for expiry on the other side. A percentage of these types of problems come directly from the pharmaceutical warehouse, which is primarily responsible for lead time build up and therefore struggles to align easily with market trends (Friemann and Schönsleben 2016; Leung et al. 2016).

The research examined a firm that was experiencing challenges like as lead time, poor customer service, and supply chain misalignment. The warehouse manager, production manager, and sales manager conducted interviews to better understand the issue. They discovered that the warehouse employed a deterministic inventory model with a push-based approach, with many actions being unpredictable and undefined. The research sought to give a more complete view of the company's difficulties. The warehouse experienced a significant lead time build-up due to random operations and sub-operations. The inbound supply chain was threefold: raw material, production, and packing and shipping. The work-in-process supply chain in the pharmaceutical production building was difficult to map due to regulations and constraints. The warehouse facility and manpower struggled to solve the problem, leading to unpredictable throughput and utilization percentages. A time study was needed to map sub-processes and analyze their contribution to lead time build-up. Standardization and support in inventory sorting, handling, storage, and transportation were also needed to increase performance and efficiency. Inventory handling and movement create vital nodes in a supply chain and enhancing their efficiency is a crucial issue when attempting to avoid unproductive bottlenecks (P.-S. Chen, Huang, Yu, & Hung, 2017; Elisa Kusrini, Novendri, & Helia, 2018; Staudt, Alpan, Di Mascolo, & Rodriguez, 2015). A lean supply chain approach was implemented to eliminate warehouse waste and address issues. A standard lead time mapping lean tool was used to study and analyze pharmaceutical warehouse supply chain operations. Time-based simulations were used to visualize and compare current and future scenarios, focusing on storage, movement, queues, and inventory delays in the Malaysian pharmaceutical warehouse (Uthayakumar and Priyan 2013; Lemmens et al. 2016).

2. Pharmaceutical Supply Chain (PSC) - Issues and Challenges

The pharmaceutical supply chain was chosen for this study out of all the others due to its complexity and significant volume of discrete inventory movement (Xia and Sun 2013). Moreover, according to (Privett & Gonsalvez, 2014) to provide improved services, the pharmaceutical supply chain is continuously in need of ongoing development. The management of warehouse inventory, order processing, lack of coordination, lack of demand information, preventing shortages and product expiration, and supply chain visibility are some of the main issues facing the pharmaceutical supply chain. (Rossetti, Handfield, & Dooley, 2011) stated that these challenges must be addressed individually by researchers and practitioners to develop the efficiency of the supply chain. Among these issues, inventory handling is critical, and there is a lack of research in analyzing the pharmaceutical supply chain disruptions which are the main source of lead time build up. It is one of the critical issues and therefore, demands a detailed assessment at every stage of the supply chain (Garcia 2004; Nallusamy 2016). A Warehouse operational performance setup is shown in Figure 1 below.

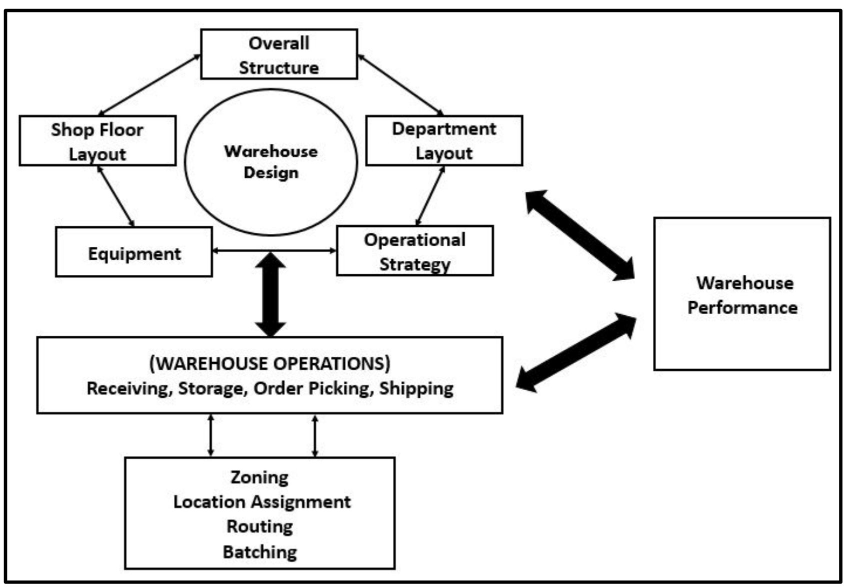

Figure 1. Relationship between Warehouse Operations and Performance

2.1 Lean Simulation

The effectiveness of lean can now be visualized and quantified using modeling and simulation up to some extent. Nowadays, the use of the Lean Philosophy Method and Policy Systems plays an important role in the productivity of corporations. Essentially, the benefit is realized through the elimination of logistic waste. Simulating discrete patterns for each sub-activity in a given set of processes may result in a need for new production or process design (Marvel and Standridge 2009; Chongwatpol and Sharda 2013). Some of the previous studies are very useful in gaining useful and concrete insights on how to carry out the current research.

3. Method

An integrated approach of VSM and DES is adopted to capture the operations inside the warehouse and quantity them in terms of value added and non value added timeline. The Figure 2 shows the research framework applied by this study. A single product family was targeting to map the flow of materials along with all the material handling related to that product family.

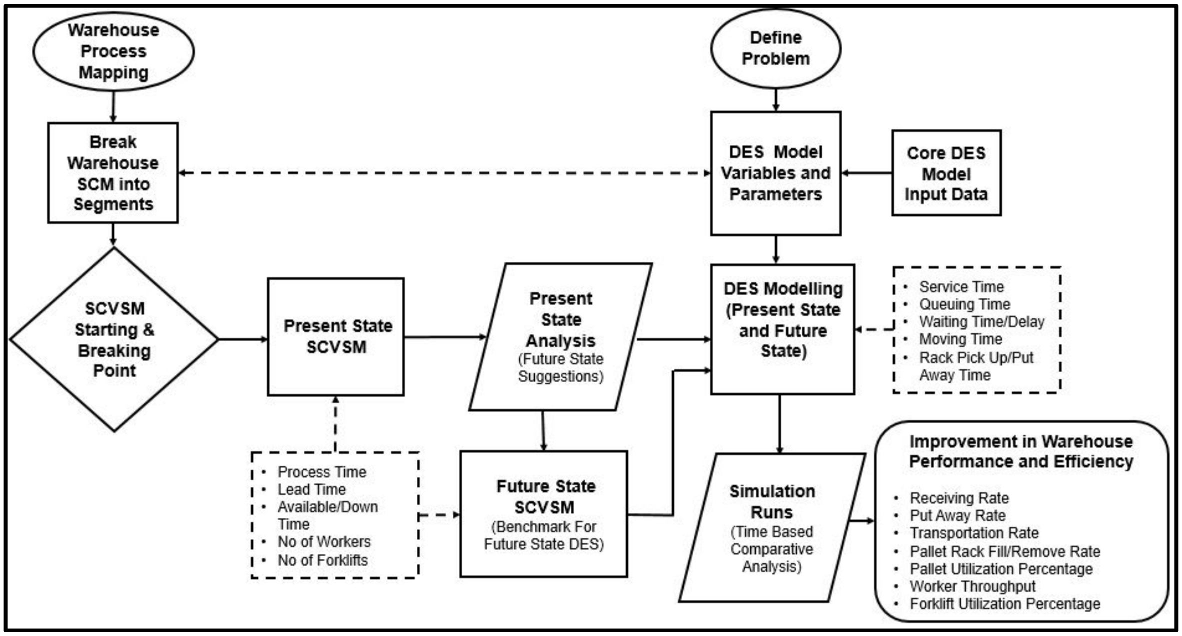

Figure 2. Research Design

4. Results and Discussion

A spaghetti diagram as shown in the Figure 3 is drawn to assist in building the present and future state VSMs as shown in Figure 4 and 5. The spaghetti diagram for model building is drawn again to get a clear view of the various stages and levels. The red route indicates phase 1 (Receiving, unloading, order receipt submission, transportation to Zone 4, 5, and 6. The Green route indicates the movement of inventories from Zone 4 to level III after a quality check. The purple route denotes the movement of inventories from level III, zone 5, and 6 to the batch waiting zone 7 and later the production despatch bay 9. Finally, the yellow line indicates the finished goods receiving process until the commercial elevator. This final route has been added to the model to get homogeneity and completeness in the simulation output even though this part is considered in the next segment of the warehouse supply chain. Now, to further support for additional core data collection that is needed to the complete DES process models, a VSM timeline tabular column is needed to first understand the timeline that also assists incongruently building the DES data feed.

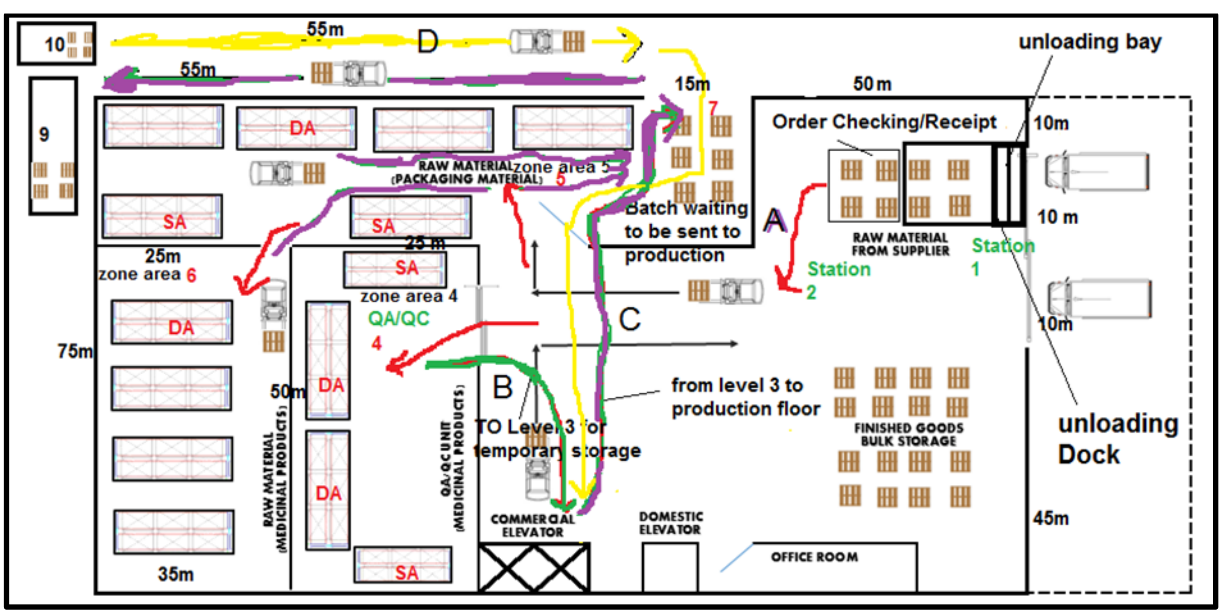

Figure 3. Spaghetti Diagram to Capture the Product Family Flow

The VSM results of segment 1 show that the Total Process Time (TPT) is 11940 minutes and the Total Production Lead Time (TPL) is 4260 minutes. The VAT for each process is calculated by adding all the VAT for each process that is present in the VSM. The VAT percentage seen in this future state VSM is 73.86 %. The time which is not adding value and being wasted to complete a process of a set of sub-processes is called Non – Value Adding Time (NVAT) and the NVAT percentage is 23.13 %. Inferences from the future state map are given below. Therefore, Value-added time has been increased from 8,820 to 24,360 minutes i.e., (53.64 % to 73.86%). And Non-value added time has been decreased from 21,060 to 3,120 minutes (46.36 % to 23.13%). The workforce has been reduced from 51 to 31 (39.21 percent).

4.1 Present State VSM

All the iterations, models and simulation runs are focussing only a specific part of warehouse (Phase 1, i.e. Order receiving, sorting, transportation to Zone 4,5,6 shelves, and also parallelly receiving finished stock from the production to those zones). Phase I of the present state model is started from the unloading process when the trucks arrive with 200 containers, where the first four deliver 50 containers each and the last truck delivers 50 boxes of raw materials for packaging as previously mentioned in several places. There is a 30 min gap between each delivery truck. Unloading time for one truck is 90 minutes. The total time taken for unloading including the time gap is 360 minutes. Two workers sit in forklift and three stands and monitor the unloading process, hence, totally the unloading bay accommodates 5 workers. After completion of the unloading process, order receipt checking (to send the details to suppliers and update in central warehouse system) and tag checking at station 1 and sorting at Station 2 is completed. Station 1 has one worker and station two has two with one forklift to shift packages from station 1 to 2 with certain time delays at the station I and II. After station II, 150 containers go to zone area 4 (QA/QC) quarantine zone and the remaining 50 goes to zone area 6 and the packaging material carton boxes which are a total of fifty goes to zone area 4.

4.2 Present State DES Model

The model building is primarily controlled by the process models with their corresponding process variables adhering to some logic. A few sets of process variables are included to define and monitor the main functions of the truck receiving timeline, truck count, and the number of loads per truck. The process modelling begins with the 'source' process model followed by a 'delay' block. The source here denotes the trucks. A specific number of workers and machinery as stated below in Figures 3 and 4, the VSM are assigned to receive the containers. The 'split' process block is used to split the raw materials into various divisions and locations. The waiting time and delay at different levels were enabled using the 'delay' and 'queue' process block. The transportation of materials from one place to another place is made possible by the 'move to' process block. All these process blocks are connected in a sequence to ensure logic in it and adhere to the VSM process flow. Moreover, all these process blocks are governed by their respective process variables. Corresponding resource pools (workers and forklifts) are added to the model at different levels. The pallet racks are also included in the model to receive, store, and relocate inventories to different locations according to the process flow. The Unloading Process (Current State) – Phase I of the warehouse has been captured portrayed in Figure 5 followed by the Rack Storage at 3 different zones which is shown in Figure 6. Also, the information on pallet racks to production and receiving (Current State) segment 1 is and the Software Window along with Model Attractors and Path Nodes are shown in Figure 7 and 8 respectively. Furthermore, Figure 9 shows the storage and transportation on different zones.

Later on according to the optimized design new logic was modelled as portrayed in Figure 10 showing the process model for unloading process followed by rack storage at zone 4,5 and 6 (future state Phase I) as shown in the Figure 11. Also, the authors have portrayed the future State 2D Visualization with Attractors and Point Nodes in Figure 12 whereas Figure 13 Unloading zone (Station 1 and 2) and Figure 14 portrays the transportation to zone 4 (QA/QC). Figure 15 portrays the rack storage at zone 6 via zone 4. Finally, Figures 16 and 17 show the present state and future state simulation Statistics.

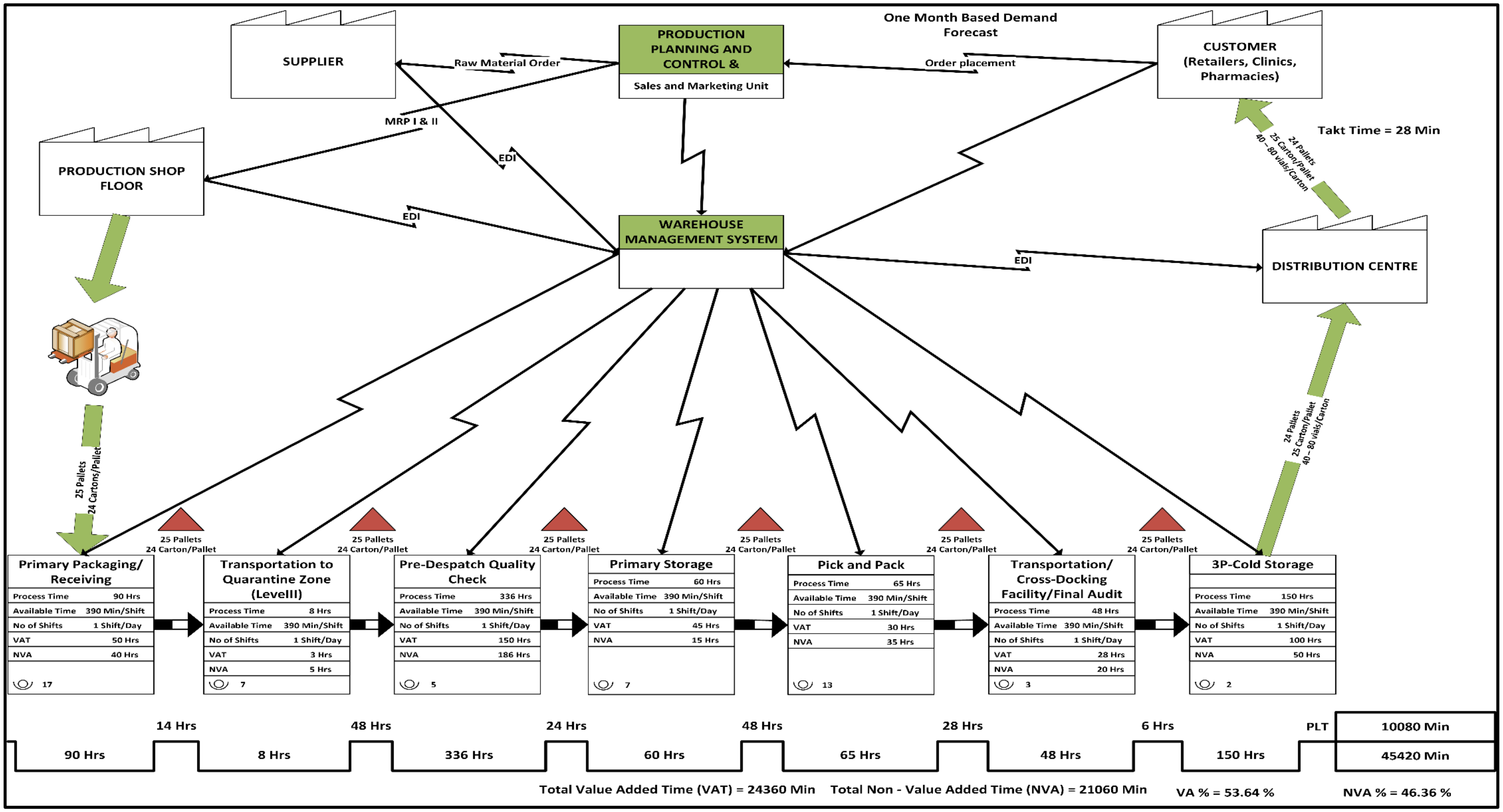

Figure 3. Present State VSM Warehouse

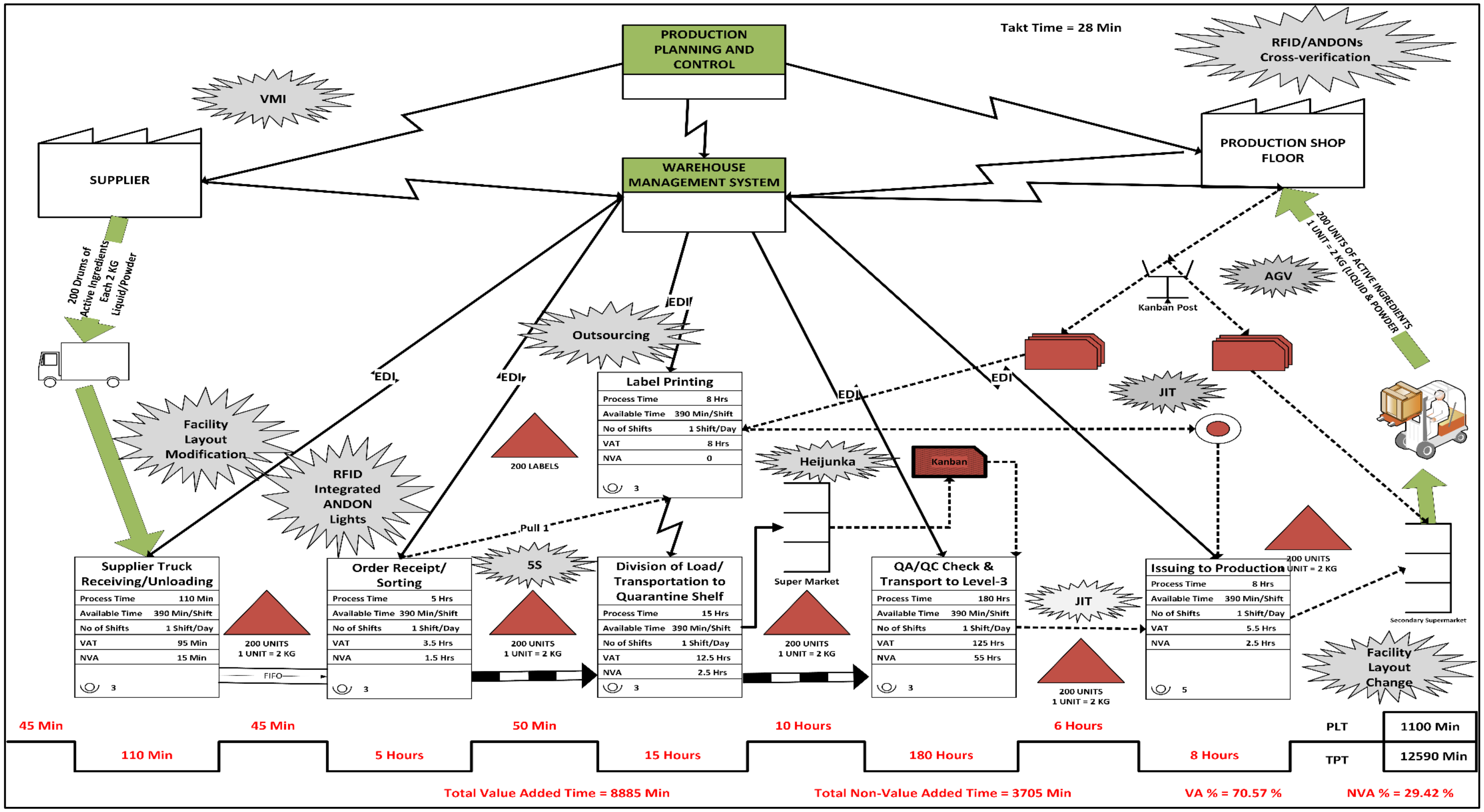

Figure 4. Future State Map

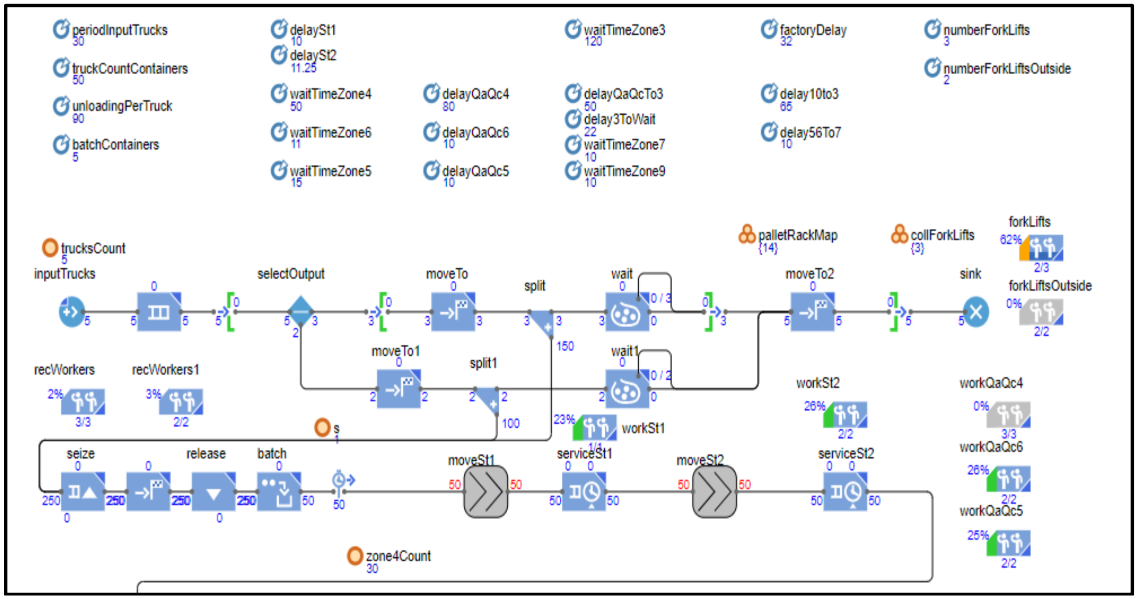

Figure 5. Process Model for Unloading Process (Current State) – Phase I

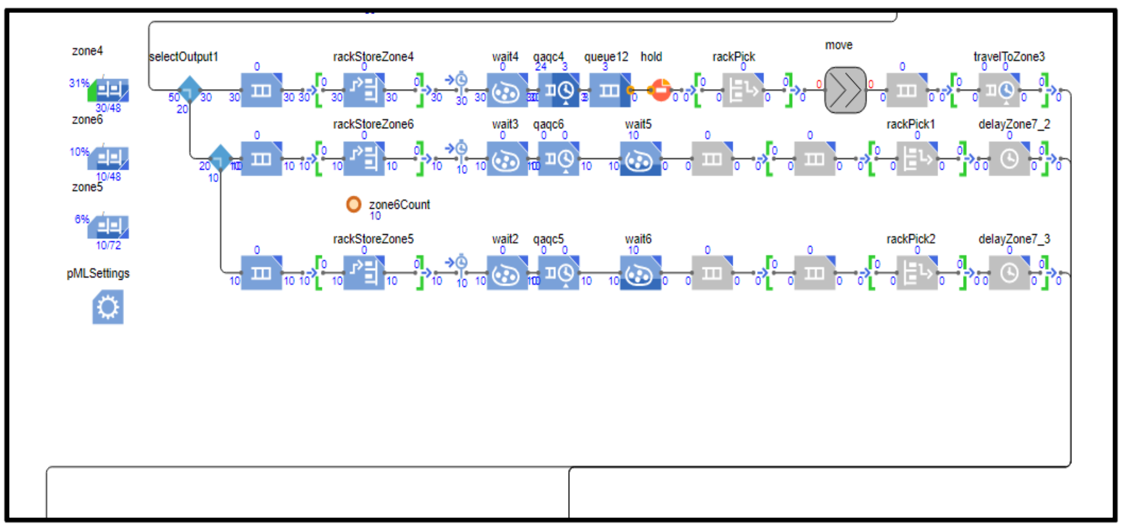

Figure 6. Process Model for Rack Storage at Zone 4, 5 and 7 (Current State)

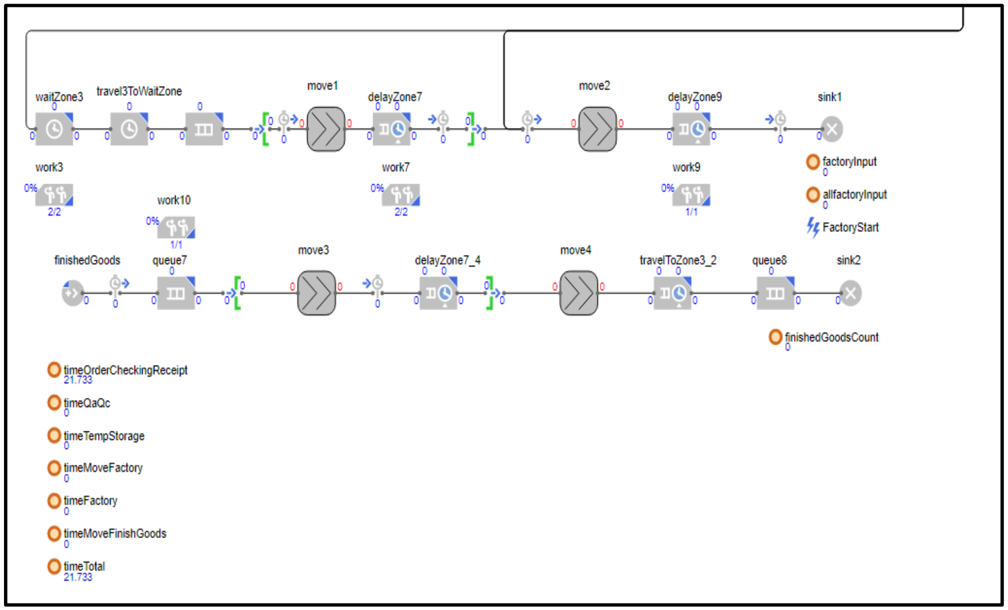

Figure 7. Pallet Racks to Production and Receiving (Current State)

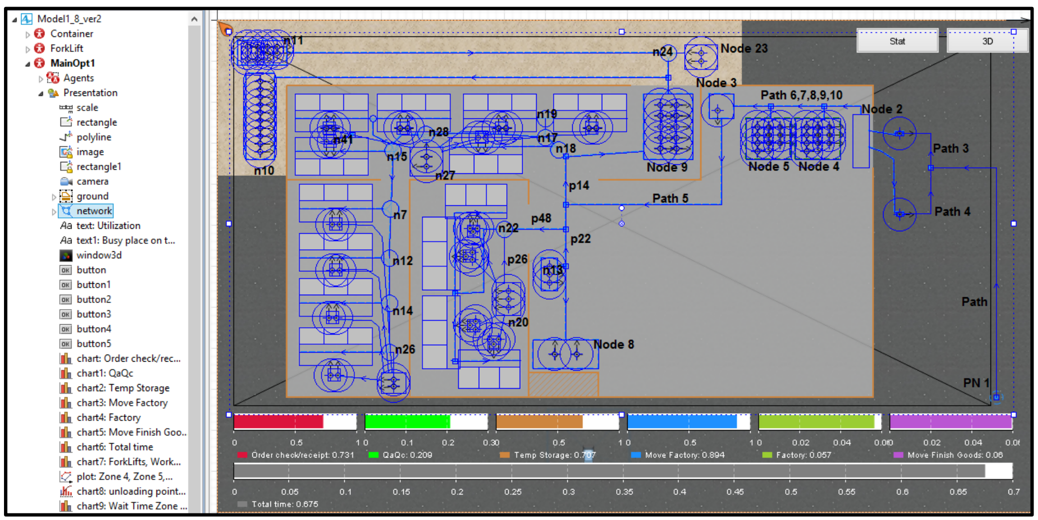

Figure 8. Software Window along with Model Attractors and Path Nodes

Figure 9. Storage and Transportation on different zones

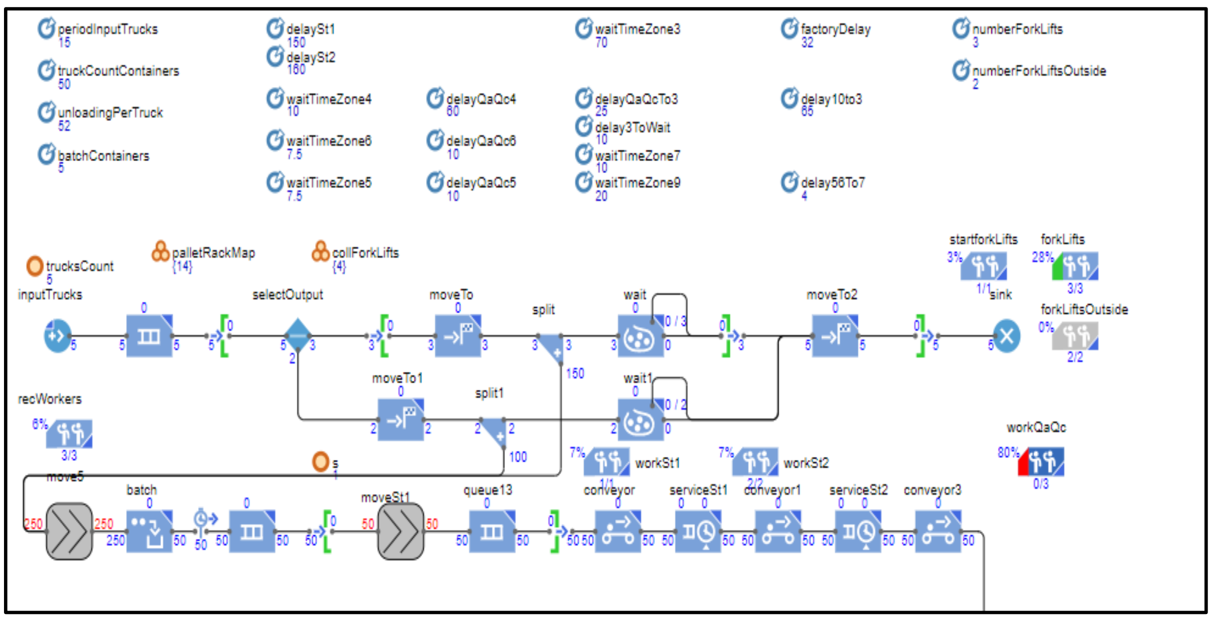

Figure 10. Process Model - Unloading Process - Phase I(Future State)

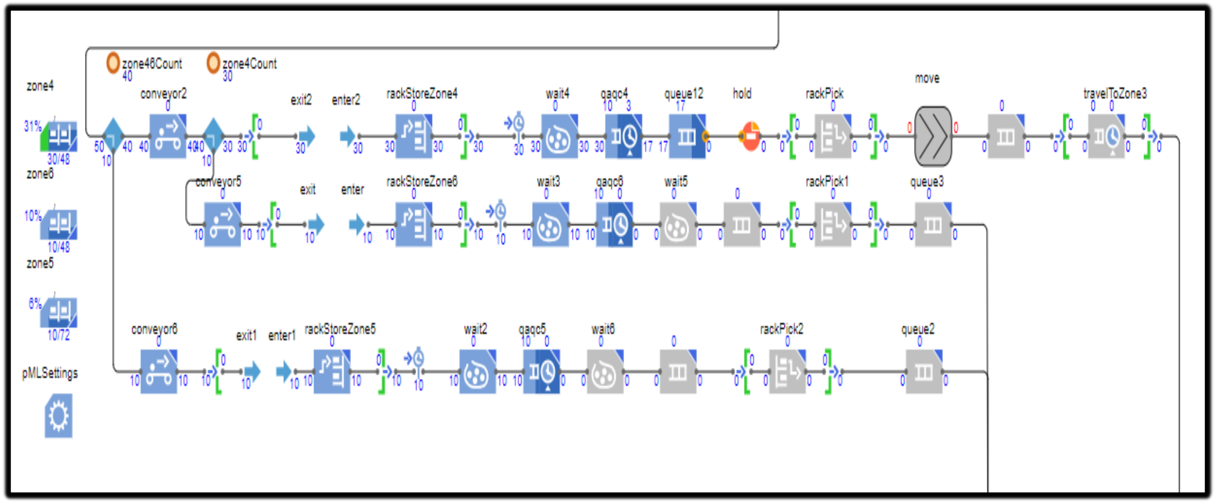

Figure 11. Rack Storage at Zone 4,5 and 6 (Future State) – Phase I

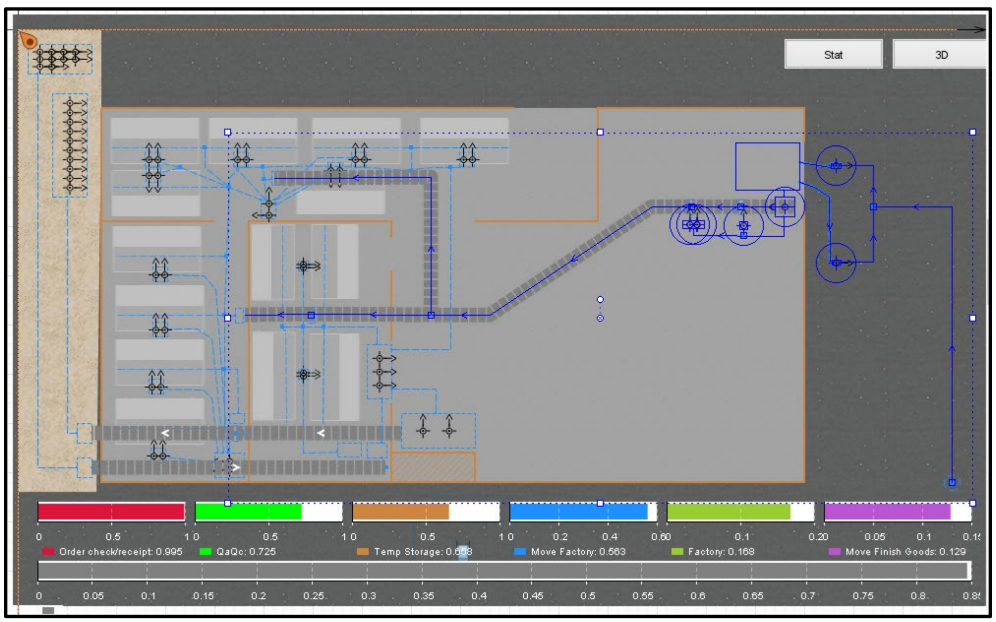

Figure 12. Future State 2D Visualization with Attractors and Point Nodes

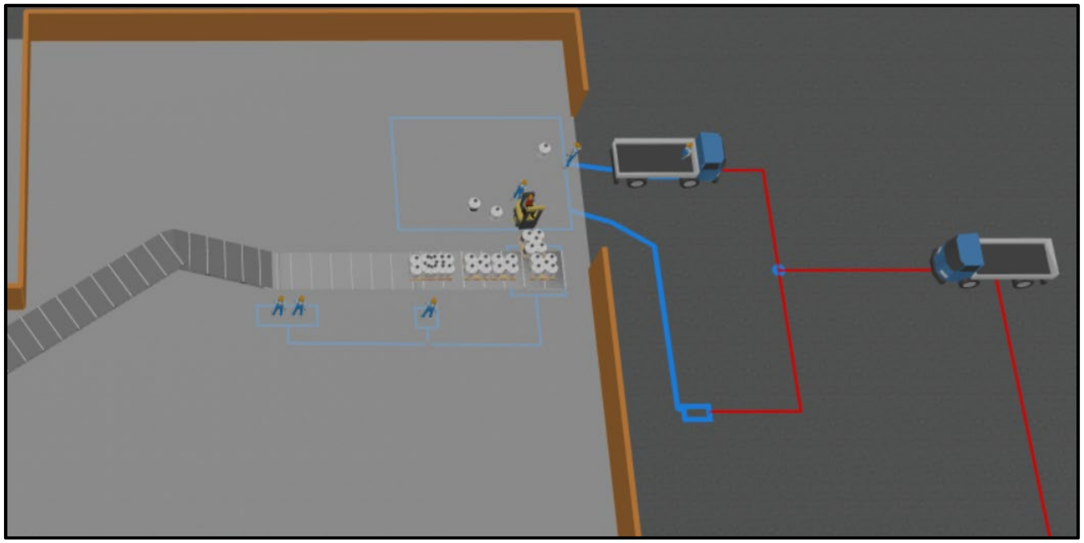

Figure 13. Unloading Zone (Station 1 and 2)

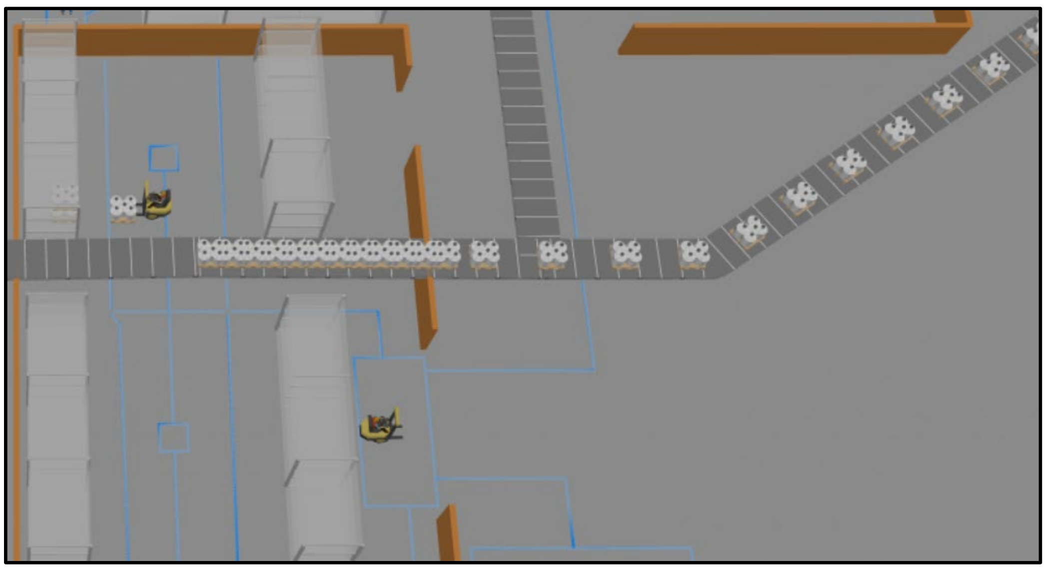

Figure 14. Transportation to Zone 4 (QA/QC)

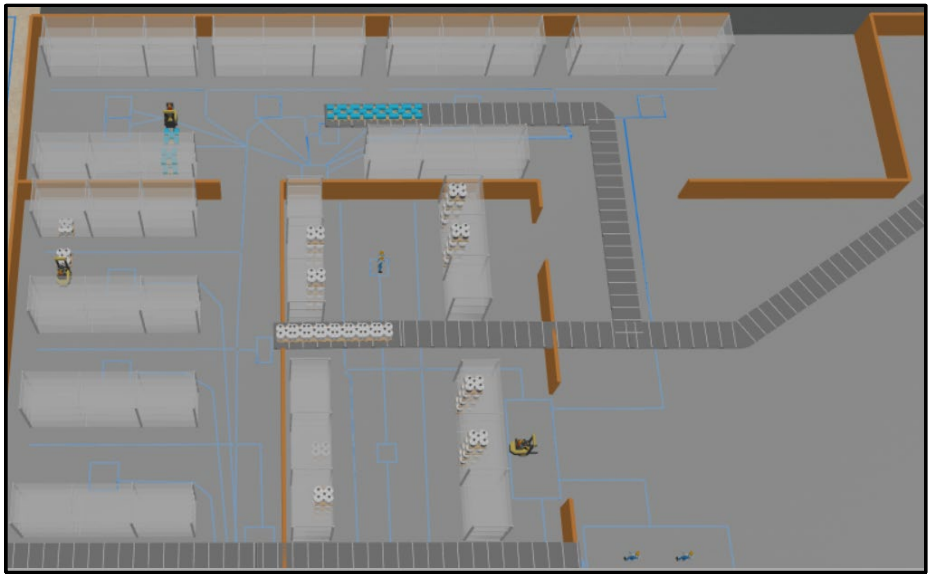

Figure 15. Rack Storage at Zone 6 via Zone 4

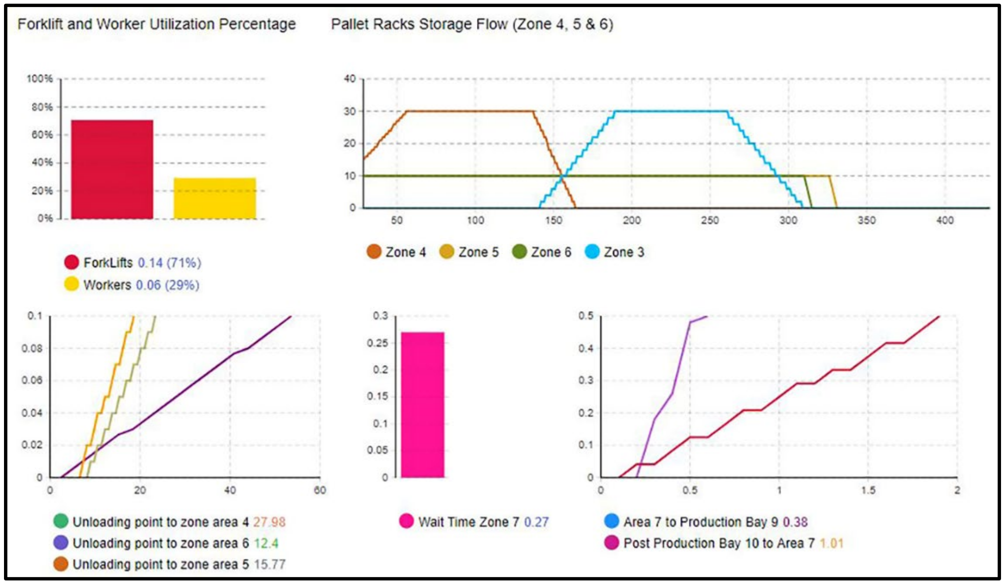

Figure 16. Present State Simulation Statistics

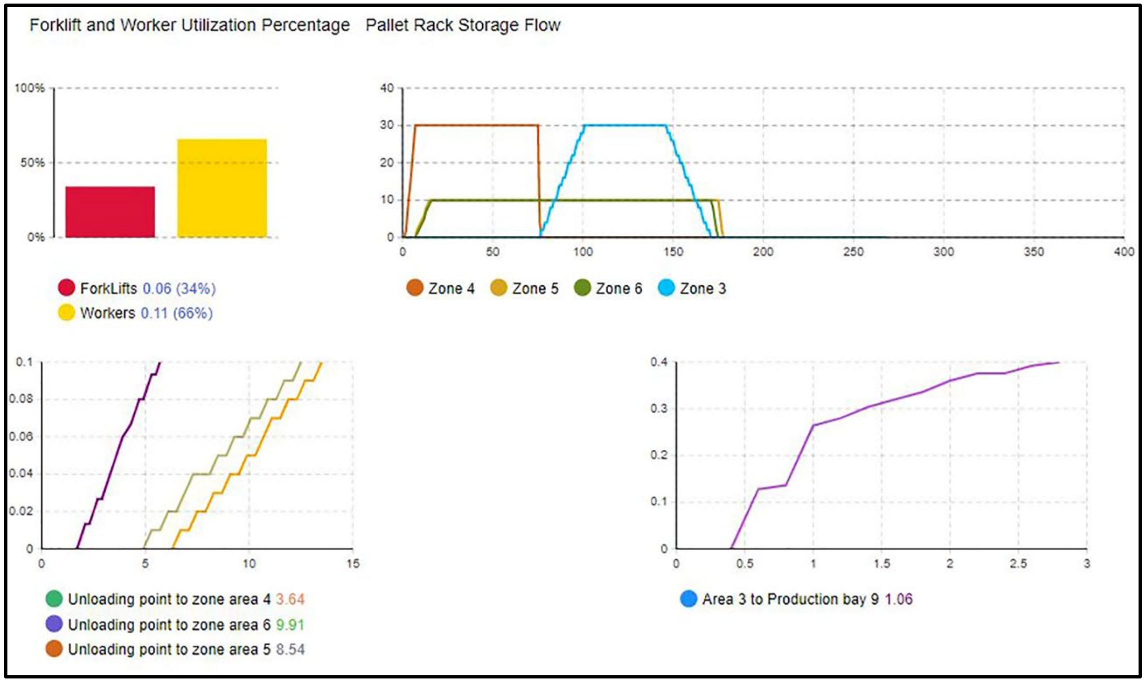

Figure 17. Future State Simulation Statistics

5. Simulation Output Comparison

The main simulation output is a dynamic horizontal single bar graph that shows the time taken in each major phase of the warehouse operations. The first phase is from unloading to order receipt/sorting followed by QA/QC process, temporary storage, production call, production, and despatch from production to level III. The production time taken is recorded as a delay in the model. The total time taken is also shown with a maximum scale of 450 hours. The total time taken for the product family is approximately two months. But this model records the timeline only till the first step after finished goods produced are starting to get despatch to the warehouse. Figure 18 below shows the main statistics graphs which are visible in the 2D layout.

Figure 18. Main Dynamic Statistics Window visible in 2D Layout

5.1 Comparison of Present State and Future State Dynamic Simulation Statistics

The present state simulation has five graphs that can be used to view the dynamic statistics when the simulation is run. The first graph shows the workforce and forklift utilization percentage at all the levels of the warehouse. The second one shows the accumulation of inventory levels in all the zones. Y-axis is the number of hours, and the x-axis is the number of pallets. The third multiple line graph shows a cumulative distribution of time taken from unloading bay to zone 4, 5 and 6. The x-axis is in terms of hours. The fourth bar graph shows the time taken at waiting zone 7. The final iteration shows the time taken from zone 7 to production bay and then from production bay to waiting zone 7 in a form of Cumulative Distribution Function (CDF). The x-axis in this chart is in terms of days since a lot of hours of waiting time is involved.

The CDF is used in probabilistic inventory models and especially in warehouse inventory movement. CDF plots a line graph with respect to a random variable in the form of a distribution. The staircase type of line plots will help practitioners to learn and analyze the problems causing delays and try to analyze them. All the graphs are dynamically varying and can be stopped to analyze at any point of type if the simulation is stopped. The dynamic statistical simulation window for the future state can be seen clearly, Since the main agenda of this study is to conduct time comparisons between both states, the simulation charts are designed to view the changes in the sub-process in detail. The dynamic graphs are in the same window for the managers to understand the process and their delays better and review them later.

The CDF graph gives a value of inventory level which is either equal to or lesser than the actual predefined inventory level in each of the zone areas in the form of a distribution function. Furthermore, the flow or number of pallets entering each zone given at a time is tabulated in another stepped line graph with the number of pallets on the x-axis and number of working hours or time taken at each zone on the y-axis in both present state and future state. The difference in lead time reduction can be easily seen by comparing both. There is a significant increase in the percentage of pallets that all the zones have witnessed with respect to time. The future state simulation shows an 8 to 15 percent increase in pallet percentage in zone 4, 5, 6 and level III as shown in Table 1. Table 2 shows the worker and forklift utilization percentage at different levels of the overall system. The forklifts utilization percentage has gone down during many instances to reduce time delays. These data are tabulated using the values acquired from the DES process model by stopping at specific points during the simulation.

Table 1. Percentage of Pallet Rack Transportation/Storage at the end of various levels inside Zone 4, 5, 6 and 3 (Note: PT-Present State; FT-Future State)

		Zone 4		Zone 5		Zone 6		Zone 3	
Levels	**Process Description**	**PT**	**FT**	**PT**	**FT**	**PT**	**FT**	**PT**	**FT**
I	Items Receiving, Unloading	2%	6%	-	-	-	-	-	-
II	Transportation to Zone 4, 5 and 6 and rack Storage	26%	31%	3%	6%	6%	10%	-	-
III	QA/QC and Transportation to Level III and waiting time at Zone 5 and 6	47%	59%	9%	13%	10%	20%	7%	10%
IV	Transportation from Level III and Waiting Zone 7 and Transportation to Production	-	-	-	-	-	-	55%	67%

Table 2. Worker and Forklift Throughput/Percentage (PT-Present State, FT-Future State)

	Worker Utilization Percentage		Forklift Utilization Percentage	
Level	**PT**	**FT**	**PT**	**FT**
I	40%	61%	60%	39%
II	23%	31%	77%	69%
III	34%	72%	66%	28%
IV	31%	67%	69%	33%

The reduction of lead time between two states was possible due to the removal of waiting time at zone area 7, Unloading bay, station 1 and 2, QA/QC, Level III storage and transportation to production. Table 3 portrays the detailed lead time reduction percentage at every level.

Table 3. Lead Time Reduction Percentage

Simulation Phases	Present State (Min)	Future State (Min)	Lead Time Reduction Percentage
Order Check/Receipt	1303.80	189.60	14.54%
QA/QC	8380.80	4374.60	52.19%
Storage at Level III	8843.40	5671.80	64.13%
Transportation to Production	1950.60	592.8	30.39%

Improvement in Warehouse Performance Metrics

Some of the warehouse performance metrics were calculated for both present state and future state to visualize the changes and improvement. Warehouse performance metrics such as item receiving rate or raw material unloading in this case and put away or transportation to pallet racks, in this case, and storage rate or pallet rack storage in this case mainly depends on timeline or rate at which the inventory is received, transported or stored within a specific unit time. The receiving efficiency put away productivity, and storage efficiency is obtained by dividing the volume of inventory by total working hours at each phase. Similarly, this procedure can be applied to all the warehouse levels and the performance metrics can be compared and evaluated.

Table 4 displays selected warehouse performance metrics that are obtained from the initial phase of the warehouse model. The unloading rate, put away and storage rate shown positive results. There is a forty-four percentage decrease in receiving time, twenty four percentage decrease in put away time, and sixty seven percentage of storage time respectively.

Table 4. Warehouse Performance Improvement (Phase I)

Warehouse Performance Metric	**Present/Future State**	**Time to Complete Total Items (Minutes)**	**Efficiency/Productivity Rate**	**Percentage Increase**
Receiving/Unloading Process	PT	120	2.08	44%
	FT	67	3.73	
	PT	1275	0.19	24%
Put Away Process	FT	310	0.80	
Storage Process	PT	76	3.28	67%
	FT	25	10.01	

6. Conclusion

The efficiency of the supply chain processes is very challenging to streamline because firstly it is a major challenge to split the system into parts, pick a product line and then analyze and standardize any series of random inventory movements. In fact, it is entirely different in the warehouse environment when compared with a central production shop floor. In a production shop floor with a variety of instruments, machinery, and workpieces, system parameters are predefined, which can be studied, monitored, and adjusted according to the study requirements, or purposes. This cannot be achieved with the supply chain systems. However, in this scenario, the VSM process parameters are completely different from the core production-oriented VSM with set-up time, changeover time, uptime, etc. An SCVSM focuses mainly on process time, lead time, value-added, and non-value added time (Martichenko and Von Grabe 2010; Suarez-Barraza et al. 2016).

The pharmaceutical warehouse approached for this study was facing lead time build-up inside their warehouse as one of their major problems. Hence, supply chain lead time reduction was the main focus of this research. A strong lean tool like SCVSM was required to map the lead time and process time timeline of the warehouse operations which cannot be done randomly and haphazardly and requires a proper standard of operations. Unlike a traditional VSM that is done in manufacturing where there are machines with easily acquirable process parameters, the supply chain based VSM requires a different approach which is clearly depicted in the first three chapters.

Initially, the warehouse operations were first divided into two segments. In order to initiate the VSM building process certain standard of operations was followed. At first, a product family that shares similar operational characteristics, revenue generation, and process timeline was scrutinized and selected by completing product family matrix, ABC Pareto chart, and lead time chart respectively. Later, the route map and movement of that particular product family were projected in a spaghetti diagram that helped greatly in Gemba walk. The cross-functional diagram was built to help in understanding the sequence and simultaneous warehouse operations. The Gemba walk was performed to conduct a detailed time study and collect data that initially was tabulated as process activity charts. Later present state SCVSM was constructed by dividing the process activity charts into a set of a given number of processes with the process and lead time. This set of operations accomplishes objective one.

To complete objective two, wastes were identified in the present state VSM that was built by Gemba walks and interviews to capture the queues, delays, waiting times during and in between operation. This was further identified and divided into value-added and non-value-added time in the VSM timeline. Pertaining to the wastes located at different warehouse levels specific lean procedures and tools were suggested to build an effective future state. These steps were carried out for both the warehouse segments and the SCVSMs were face validated by the warehouse official.

Alterations Improvement seen in Warehouse Segment 1

There has been a significant difference in the process time and production lead time between both the states of the SCVSM. A significant drop in both process time and production lead time of individual processes is witnessed. In segment 1, the Total Process Time (TPT) was 22650 minutes and the Total Production Lead Time (TPL) was 2265 minutes which later was brought down to 12590 minutes and 1100 minutes respectively after the lean suggestions in the future state map. The value-added percentage of this selected supply chain segment has increased from 41.36% to 70.57% and the non-value added percentage has decreased from 61.28% to 29.42 %. As mentioned, the tentative time that can really be utilized to complete a process is value-added time and delays and queues make up a non-value-added time. The process time is the time given in the trough of the VSM timeline. Each process time value in the trough is considered to create this graph. Lead time is the time stated at the crest of the VSM timeline. The detailed information on process time and lead time comparison graphs including the value-added and non-value added percentage were also tabulated.

The time wasted in receiving the raw materials and excess delays and queues that lead to higher non-value added time have seen a considerable reduction. The estimated order sorting time at stations 1 and 2 in the future state witnessed tremendous reduction by concentrating more on the time that adds value thereby increasing the value-added time. The RFID/ANDON coupled with facility modification shall assist in quickening the unloading and sorting process. The put-away rate and truck waiting time was also greatly reduced. Later, the estimated time taken to transport inventory from station 2 to three different locations of the warehouse was also reduced by suggesting facility modification and 5S. The waiting zone 7 has been completely removed to delete the batch queueing that occurs around waiting zone 7. A separate conveyor powered pathway eases this process. Warehouse window to production window and vice versa has seen great time reduction based on the assumptions in the future state. The timeline related to AS/AR setup suggested at zone 4 eased the pallet storage and pick up process. On the whole, all the time reduction was checked for its feasibility by modelling simulating the VSM time which in turn gave satisfactory outcome.

Inferences from DES Modelling and Simulation

The details in the VSM along with additional data were utilized as given in the protocol for the data acquisition on the model-building in order to satisfy objective three. The VSM timeline was effectively integrated into the DES models. The logical sequences implemented in the DES modelling and simulations were developed in such a way to gain lead time-based iterations. To complete objective four the results from the main dynamic statistics window were made to show changes in the timeline in a dynamic fashion. The warehouse official was able to simultaneously visualize the commendable delays and queuing time inside the warehouse comparing both the 3D model and 2D statistics window.

The forklift and worker utilization percentage have shown great improvement and pallet rack storage flow rate into various zones that are also graphically displayed and tabulated. The considerable decrease in time of storage and transportation are dynamically projected in the 2D analytics window. The time reductions in the transportation time from unloading point (Stations 1 and 2) to the storage locations are also displayed along with waiting time at waiting zone and lead time reduction from production to warehouse and warehouse to production lane. Moreover, the lead time reductions at various levels directly affect performance metrics like workforce utilization, machinery utilization, unloading or receiving rate, put away rate, storage rate, and pallet utilization rack pick up rate.

Theoretical Implication

Advancement in information technology and communications can make a firm excel but still, there is a scope for any organization to look for opportunities to implement lean not just in manufacturing but also in other segments of production especially in supply chain operations (Shah and Khanzode 2017; Engelseth and Gundersen 2018). The pharmaceutical firm is handling a very large variety of product families and different types of medicines which becomes a very challenging job nowadays. A suitable theory and methodology backed by the latest technological tools need to be applied to suffice the requirements of this complex pharma warehouse supply chain activities. According to (Fattahi, Govindan, & Keyvanshokooh, 2017; Heydari, Mahmoodi, & Taleizadeh, 2016; Jamshidi, Fatemi Ghomi, & Karimi, 2015), time consumed at every step of the supply chain plays an important role and may add up more time to the on-time delivery.

Addressing these issues, this study helped in redefining the complex pharmaceutical warehouse supply chain operations by designing and developing a new set up for the continuous implementation of lean. The VSM-DES integrated dynamic simulations improved the performance of the warehouse supply chain by reducing the cycle time, queuing time, and delays of each activity and finally support supply chain lead time reduction. Manufacturing core operations can be mapped very easily but it is always a challenge to map dynamic operations which include a lot of material movement. Simulation results developed from this study will help perform an in-depth analysis of each activity inside the warehouse regarding specific product families that tend to contribute more to the revenue of the firm. Thus, Pharma firms can apply this suggested approach and framework developed from this study to control and design warehouse operations to get the best results. This study has a good scope in adding quality scholarly literature to the body of knowledge by filling up the empirical and practical gap through comprehensive lean based simulations in a pharmaceutical warehouse. Moreover, this study uses supply chain-based VSM and then later VSM-DES integration in a pharmaceutical warehouse environment which portrays a strong theoretical gap. This study shall prove to be the stepping stone for other hybrid simulation approach in supply chain arenas. In the future, lean based key performance indicators should be imparted in the DES modelling software to directly and approximately quantify the effect of lean in a future state VSM.

Though DES is an older technique, here it was used to model a sequence of processes with a series of discrete events. Each process can have separate process parameters and a timeline that can be keyed in the DES model. Nonetheless, a DES model itself is a sophisticated tool that helps in validating a VSM (Schmidtke et al. 2014a; Sparks and Badurdeen 2014). According to (Jarkko et al. 2013), the VSM timeline and DES timeline may not necessarily match exactly since the DES needs additional core data and key parameters to be considered to be converted into a virtual simulation.
Most of the previous studies are not directly related to warehousing operations or truly comprehensive in nature. The existing studies only capture fewer practices associated with the supply chain at the shop-floor level of an organization. Thus, this research fills a gap in the academic literature and in practice on comprehensive lean warehousing backed up by dynamic DES simulation that dynamically provides specific, actionable items for better managerial decision making. Furthermore, the insights from this can be analyzed to better understand the practical implementation and underlying factors of lean warehousing. Consequently, the research outcomes are two-fold, both filling the gap in the development of a warehouse supply chain based lean simulation model in the academic literature while providing insight into the actual implementation of lean warehousing for the present warehousing sector.

Practical Implication

In this study, the VSM for the warehouse activities related to a specific set of product families that are selected after a detailed ABC analysis and lead time graph was developed to find out problem areas, delays, and wastes and suggest suitable lean tools and practices. Then the processes and sub-processes were later transformed into DES models to visualize the system in 2D and 3D simulation. DES assisted VSM helped to improve lean warehouse performance metrics which portray the output in the form of queueing time, throughput time, facility and machine utilization percentage, and worker performance. This, in turn, shall help the management to make better decisions on lean warehousing and continuous improvement. DES shall enhance the future state VSM and provide dynamic simulation results that could be suggested for trade-offs for future improvement (Schmidtke et al. 2014b).

A clear approximate quantitative data can be visualized using a DES simulation. Similar to this effort, every warehouse activity with respect to other product families was simulated and visualized at a certain level or boundary. The insights gained from this approach or study can also be used in improving other pharma-warehouses. The main practical implication of this study is, this methodology adopted in this study allows the practical experts to view the current systems and also view the future supply chain systems in detail to make better decisions regarding inventory handling, transportation, and storage. Though optimal inventory management related models are adopted in the real scenario, the supply chain disruptions and queues that contribute to the lead time are impossible to be captured. A standard setup or flow of operations must be incorporated to further extend the scene for other approaches like mathematical modelling, heuristics network designs, and batch flow optimization.

This study can help develop better pharmaceutical warehouse operations because it can capture the process flows to a more accurate extent whereas other tools are just for strategic decision making and mathematical results (Institute of Electrical and Electronics Engineers. et al. 2008; Günal and Pidd 2010). Timeline incurred for the Kanban method as suggested in the VSM could enable smooth flow of medicines in batches from one process to another process. The Kanban post derives signals from a process to send it to activate production kanbans that wait for those signals to control the flow in specific inventory sources and control supermarkets. Withdrawal kanbans are also proposed to inform the employees about the inventory required to be pulled from a supermarket and returned to the next step of the value stream to add value. These systems directly contribute to Just-In-Time (JIT) production. 5S principles have been proposed at certain stages of the warehouse where there are uneven inventory buffer storage scenarios, especially near the cross-docking area. Kaizen works on five major principles such as specify the value, identify the value stream, flow, customer pull, and continuous improvement. Several areas in the warehouse have been tagged with proper kaizen bursts to impart great value to the supply chain. Effective policy and decision making can also make a great deal of difference to strengthen a value stream. Some of the tools, techniques, and procedures stated inside a kaizen burst are Vendor Managed Inventory (VMI), RFID integrated ANDON lights, Automated Storage and Automated Retrieval Systems (AS/AR), Automated Guided Vehicles (AGV), Layout redesign and Jidoka (Partial Automation). However, there is still difficulty in directly quantifying a lean proposal but the expected time taken for all the above proposals was included in this study.

Simulation and quantification were not done to target a single lean tool, but the relative lead time reduction was incorporated in the model which was later validated by the warehouse expert.

This integrated strategy can be directly used for effective decision making and production process planning from the perspective of warehouse related problems. The lean supply chain needs a strong strategy to validate its existence and effectiveness. The supply chain VSM is very much helpful in sorting the causes of buffers and queues in the process charts. The performance and efficiency of the supply chain and in this case a warehouse is seen to be changing positively. The scope for reduction of waste, waiting time, unwanted buffering and handling the work in process inventory was greatly magnified. Overall inventory related activities inside the warehouse were visualized thoroughly. Integration of static future state VSM and analytical DES widened up the scope for the development of the warehouse activities and help in better decision making on cutting down wastes in terms of lead time. This study provides useful suggestions for improving inventory handling and storage procedures effectively inside the pharmaceutical warehouse and also can be adapted to other sector warehouses. The results of this can help warehouse managers to structure their warehouse management contingent on the context in which the warehouse operates

Since the study is conducted in one of the Malaysia's leading government based pharmaceutical firms, this may pave the way for other small scale industries all over the world to learn and find insights towards lean warehousing and take better decision making after a detailed DES simulations. Step by step standard of operations according to the practical industrial procedure backed up by literature support were followed in this study to build the present and future state VSM and later build DES models. The proposed VSM and DES integration framework that was applied to study this warehouse can also be adopted by other firms to improve their warehouse. However, the successful lean implementation in the warehouse will face several hurdles in its course. According to the inferences gained from this study, the scope for supply chain VSM was abundant, especially in pharmaceutical warehouse scenarios. Some of the literature cited in this paper can be used to set a goal and redesign a new work-plan for an effective supply chain. The significance of the framework proposed by (Schmidtke et al. 2014a) was adapted in this study to understand the gaps in the current system. Effective decision making and optimal resource allocation can be done by modelling a set of warehouse activities using the VSM-DES integrated approach and also with an strong material handling library. It can also be used nowadays to analyze time taken and reduce costs in the warehouse environment. Insights from this research can break down complex supply chain systems and model into minute discrete events in order to display the relationship between the activities and the time and performance that impacts the overall system.

Moreover, complex warehouse behaviors were modelled by a flexible modelling approach to note down interactions between environment, population, and individuals using this software tool. The model moves forward in time at discrete intervals. It is used to solve a wide range of problems. Entities, attributes, queues, assets, and time form the core concept model in this study. Entities are the initiators or starters of a model. Attributes are feature dependence and carry information regarding the previous entity. Other parameters are queues (waiting time), assets (inventory), and time (time taken for each module and sub-module. All these were used to quantify the benefits of lean. Time-based performance statistics were obtained to visualize details on inventory, transportation, manpower, and equipment usage was visualized under a time-based graphical output which can portray a performance measure of any activity.

References

Aigbogun, O., Ghazali, Z. and Razali, R. A Framework to Enhance Supply Chain Resilience The Case of Malaysian Pharmaceutical Industry. *An International Journal* 6(3), 2014.

Chen, P.-S., Huang, C.-Y., Yu, C.-C. and Hung, C.-C. The examination of key performance indicators of warehouse operation systems based on detailed case studies. *Journal of Information and Optimization Sciences* 38(2), pp. 367–389, 2017.

Chongwatpol, J. and Sharda, R. Achieving Lean Objectives through RFID: A Simulation-Based Assessment. *DECISION SCIENCES* 44(2), pp. 239–266, 2013. doi: 10.1111/deci.12007.

Engelseth, P. and Gundersen, D. Lean and complex systems: a case study of materials handling at an on-land warehouse facility supporting subsea gas operations. *International Journal of Design & Nature and Ecodynamics* 13(2), pp. 199–207, 2018. doi: 10.2495/DNE-V13-N2-199-207.

Fattahi, M., Govindan, K. and Keyvanshokooh, E. Responsive and resilient supply chain network design under operational and disruption risks with delivery lead-time sensitive customers. *Transportation Research Part E: Logistics and Transportation Review* 101, pp. 176–200, 2017. doi: 10.1016/J.TRE.2017.02.004.

Friemann, F. and Schönsleben, P. Reducing Global Supply Chain Risk Exposure of Pharmaceutical Companies by Further Incorporating Warehouse Capacity Planning into the Strategic Supply Chain Planning Process. *Journal of Pharmaceutical Innovation* 11(2), pp. 162–176, 2016. doi: 10.1007/s12247-016-9249-6.

Garcia, F.C. Applying lean concepts in warehouse operation. *Iie Annual Conference and Exhibition 2004* (1), pp. 2819–

2859, 2004.

Günal, M.M. and Pidd, M. Discrete event simulation for performance modelling in health care: a review of the literature. *Journal of Simulation* 4(1), pp. 42–51, 2010. doi: 10.1057/jos.2009.25.

Heydari, J., Mahmoodi, M. and Taleizadeh, A.A. Lead time aggregation: A three-echelon supply chain model. *Transportation Research Part E: Logistics and Transportation Review* 89, pp. 215–233, 2016. doi: 10.1016/j.tre.2016.03.006.

Institute of Electrical and Electronics Engineers., S., Mousavi, A. and Komashie, A. *Simulation Conference, 2008. WSC 2008. Winter : [7-10 December, 2008, InterContinental Hotel, Miami, Florida, USA].* IEEE Service Center, 2008.

Jamshidi, R., Fatemi Ghomi, S.M.T. and Karimi, B. Flexible supply chain optimization with controllable lead time and shipping option. *Applied Soft Computing Journal* 30, pp. 26–35, 2015. doi: 10.1016/j.asoc.2015.01.033.

Jarkko, E., Lu, W., Lars, S. and Thomas, O. Discrete Event Simulation Enhanced Value Stream Mapping: An Industrialized Construction Case Study Erikshammar et al: Discrete Event Simulation Enhanced Value Stream Mapping: An Industrialized Construction Case Application. *Lean Construction Journal Lean Construction Journal Lean Construction Journal*, pp. 47–65, 2013.

Kusrini, E., Novendri, F. and Helia, V.N. Determining key performance indicators for warehouse performance measurement–a case study in construction materials warehouse. In: *MATEC Web of Conferences*. EDP Sciences, p. 1058, 2018.

Lemmens, S., Decouttere, C., Vandaele, N. and Bernuzzi, M. A review of integrated supply chain network design models: Key issues for vaccine supply chains. *Chemical Engineering Research and Design* 109, pp. 366–384, 2016. doi: 10.1016/j.cherd.2016.02.015.

Leung, N.-H.Z., Chen, A., Yadav, P. and Gallien, J. The Impact of Inventory Management on Stock-Outs of Essential Drugs in Sub-Saharan Africa: Secondary Analysis of a Field Experiment in Zambia, Yukich, J. ed. *PLOS ONE* 11(5), p. e0156026, 20. 2016.doi: 10.1371/journal.pone.0156026.

Martichenko, R. and Von Grabe, K. *Building a Lean Fulfillment Stream: Rethinking Your Supply Chain and Logistics to Create Maximum Value at Minimum Total Cost*. Lean Enterprise Institute. 2010.

Marvel, J.H. and Standridge, C.R. A simulation-enhanced lean design process. *Journal of Industrial Engineering and Management* 2(1), pp. 90–113. 2009.Available at: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84975320381&doi=10.3926%2Fjiem.2009.v2n1.p90-113&partnerID=40&md5=87d45eb1a76cae884261ce787b0da591.

Nallusamy, S. Efficiency enhancement in CNC industry using value stream mapping, work standardization and line balancing. *International Journal of Performability Engineering* 12(5), pp. 413–422. 2016.

Privett, N. and Gonsalvez, D. The top ten global health supply chain issues: Perspectives from the field. *Operations Research for Health Care* 3, pp. 226–230. 2014. doi: 10.1016/j.orhc.2014.09.002.

Rossetti, C.L., Handfield, R. and Dooley, K.J. Forces, trends, and decisions in pharmaceutical supply chain management. *International Journal of Physical Distribution & Logistics Management* 41(6), pp. 601–622. 2011. doi: 10.1108/09600031111147835.

Schmidtke, D., Heiser, U. and Hinrichsen, O. A simulation-enhanced value stream mapping approach for optimisation of complex production environments. *International Journal of Production Research* 52(20), pp. 6146–6160. 2014a. doi: 10.1080/00207543.2014.917770.

Schmidtke, D., Heiser, U. and Hinrichsen, O. A simulation-enhanced value stream mapping approach for optimisation of complex production environments. *International Journal of Production Research* 52(20), pp. 6146–6160. 2014b.doi: 10.1080/00207543.2014.917770.

Shah, B. and Khanzode, V. Storage allocation framework for designing lean buffers in forward-reserve model: a test case. *International Journal of Retail & Distribution Management* 45(1), pp. 90–118. 2017.doi: 10.1108/IJRDM-07-2016-0112.

Sparks, D. and Badurdeen, F. Combining Sustainable Value Stream Mapping and simulation to assess supply chain performance. *IIE Annual Conference and Expo* 2014.

Staudt, F.H., Alpan, G., Di Mascolo, M. and Rodriguez, C.M.T. Warehouse performance measurement: a literature review. *International Journal of Production Research* 53(18), pp. 5524–5544. 2015.

Suarez-Barraza, M.F., Miguel-Davila, J.-Á. and Vasquez-García, C.F. Supply chain value stream mapping: a new tool of operation management. *International Journal of Quality & Reliability Management* 33(4), pp. 518–534. 2016. doi: 10.1108/IJQRM-11-2014-0171.

Uthayakumar, R. and Priyan, S. Pharmaceutical supply chain and inventory management strategies: Optimization for a pharmaceutical company and a hospital. *Operations Research for Health Care* 2, pp. 52–64. 2013. doi: 10.1016/j.orhc.2013.08.001.

Xia, W. and Sun, J. Simulation guided value stream mapping and lean improvement: A case study of a tubular machining facility. *Journal of Industrial Engineering and Management* 6(2), pp. 456–476. 2013. doi: 10.3926/jiem.532.

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