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Improving the performance of a Malaysian pharmaceutical warehouse supply chain by integrating value stream mapping and discrete event simulation

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Abstract

Purpose – Lean implementation is vastly incorporated in core manufacturing processes; however, its applicability in the supply chain and service industry is still in its infancy. To acquire performance excellence and thrive in the global competitive market, many firms are adopting newer methodologies. But, there is a stringent need for production simulation systems to analyze supply chains both inbound and outbound. The era of face validation is slowly disappearing. Lean tools and procedures that provide future state assumptions need advanced tools and techniques to measure, quantify, analyze and validate them. The purpose of this study is to enable dynamic quantification and visualization of the future state of a warehouse supply chain value stream map using discrete event simulation (DES) technique.

Design/methodology/approach – This study aimed to apply an integrated approach of the value stream mapping (VSM) and DES in a Malaysian pharmaceutical production warehouse. The main focus is diverted towards reducing the warehouse supply chain lead time by initially constructing a supply chain value stream map (both present state and future state) and integrating its data in a DES modelling and simulation software to dynamically visualize the changes in future state value stream map.

Findings – The DES simulation was able to mimic the future state lead time reductions successfully, which assists in better decision-making. Improvements were seen related to total lead time, process time, value and non-value-added percentage. Warehouse performance metrics such as receiving, put away and storage rates were substantially improved along with pallet processing time, worker and forklift throughput usage percentage. Detailed findings are clearly stated at the end of this paper.

Research limitations/implications – This study is limited to the warehouse environment and further additional process models and functional upgrades in the DES software systems are very much needed to directly visualize and quantify all the possible Lean assumptions such as radio frequency image identification/Andon (Jidoka), 5S, Kanban, Just-In-Time and Heijunka. However, DES has a leading edge in extracting dynamic characteristics out of a static VSM timeline and capture details on discrete events precisely by picturizing facility modification and lead time related to it.

Practical implications – This paper includes all the fundamental pharmaceutical warehouse supply chain processes and the simulations of the future state VSM in a real-life context by successfully reducing supply chain lead time and allowing managers in inculcating near-optimal decision-making, controlling and coordinating warehouse supply chain activities as a whole.

Social implications – This integrated approach of DES and VSM can involve managers and top management to support the adoption of anticipated changes. This study also has the potential to engage practitioners, researchers and decision-makers in the warehouse industry.

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Originality/value – This study involves a powerful DES software package that can mimic the real situation as a virtual simulation and all the data and model building are based on a real warehouse scenario in the pharmaceutical industry.

Keywords Logistics, Modelling, Productivity, Supply chain management, Simulation, Lean warehousing, Lean supply chain, Discrete event simulation, Value stream mapping, Supply chain lead time, Lead time reduction, Anylogic

Paper type Case study

1. Introduction

A value-driven supply chain can only be built through planned and deliberate strategical initiatives that involve procurement, set-up, inventory and resource planning. The supply chain needs social, behavioural and structural design elements as a mandatory notion. These elements lead to efficient and effective inventory management, transportation and capacity utilization (Melnyk *et al.*, 2014; Barbosa-Póvoa *et al.*, 2018; Calleja *et al.*, 2018; Turner *et al.*, 2018). New technologies will bring in new products and eventually new governance systems, using newer methods and paradigms for decision-making (Jain *et al.*, 2008; Schwab, 2017). Supply chain delays and risks need proper decision-making on lead time and product delivery (Kumar and Kumar Singh, 2017). Especially, a more volatile supply chain seems to be at higher risk without real-time information transparency (Schlüter *et al.*, 2018; Schlüter, 2019). Strategies and methods to handle this volatile supply chain with risk-prone outcomes become the need of the hour (Srinivasan and Swink, 2018).

One of them is Lean supply chain management (LSCM) (Arif-Uz-Zaman and Ahsan, 2014; Schniederjans *et al.*, 2018). It can place an organization in a position to achieve flexibility at all levels. Supply chain planning and supply chain operations are greatly benefitted through Lean implementation in the supply chain (Moyano-Fuentes *et al.*, 2019). LSCM has a direct positive impact on business performance and excellence (Schniederjans *et al.*, 2018). Nowadays, it is even extended further towards customers and suppliers (Press, 2019).

But the advent of more complex supply chains demands a wide range of tools and performance indicators to measure supply chain performance inside a complex inbound warehouse supply chain (Staudt *et al.*, 2015). Facilities and resources inside the warehouse need more attention and care to attain supply chain flexibility and productivity. Warehouse processes can be divided into several sub-processes for a better strategical decision-making approach based on technical and organizational factors (Kłodawski *et al.*, 2017). Mere Lean implementation in the supply chain cannot provide a complete solution to all these issues and needs a backup from other sophisticated tools and techniques such as modelling and simulations (Barnabè and Giorgino, 2017; Shaik and Rodrigues, 2018). Because supply chains are discrete in nature, a discrete event simulation tool is better suited that can be adaptive and effective (Kammoun *et al.*, 2014; Barbosa and Azevedo, 2019).

The digital production scenario directly relies on the indispensable set of technological methods such as simulations that ensure the best outcomes by experimentally validating a system or a process design. Simulations, on the other hand, can heal the negative effects of globalization and never-ending product customization. They help in planning and verifying the ergonomics of a manufacturing system by creating a virtual prototype of production networks, information flows, facility layouts and process designs. A contemporary manufacturing environment is replaced by its alternative advanced counterpart through modelling and simulation technologies (Mourtzis *et al.*, 2014; Erol *et al.*, 2016; Rodič, 2017). Furthermore, a component's product life is thereby increased by avoiding the defects and delays in a production process chain (Afazov, 2013; Pawlewski, 2015).

1.1 Simulations in production operations

Simulations can help us analyze complex production systems that operate under multiple variables and sheer logic. This was a difficult task until many modern simulation packages were invented to achieve organizational excellence (O'Kane, 2003; Johnson, 2017; von Bary *et al.*, 2018). To address this, several core operations in production have been shifted to pre-production virtual models, or in other words, virtual engineering by using the power of computer-integrated simulation (Chan, 2003; Qi and Tao, 2018; Dobrescu *et al.*, 2019), thereby imparting continuous effort to reduce the time taken for product development, production and cost reduction through experimentation and validation of the production operations through a technological focal point, i.e. simulation analysis tools (Mourtzis *et al.*, 2015).

Advanced computer software tools have made it possible for simulation instruments and techniques to produce optimal solutions to be practical. But to ensure that, the identification of appropriate and relevant simulation methods is needed that can alleviate difficult decision-making efforts (Jahangirian *et al.*, 2010). A production shop floor's biggest nightmare is a bottleneck. More efforts are streamed towards taking out unwanted waiting times and bottlenecks to achieve competitiveness (Zahraee *et al.*, 2014). Simulations can capture risk-causing agents among interdependencies and synergic interactions between resources to avoid problems (Thiede *et al.*, 2016). Discrete event simulation (DES) offers the solution for optimizing production lines through proper balancing strategies and enhances production rate and process performance (Zupan and Herakovic, 2015; Baril *et al.*, 2017). It can be used to model systems or events that operate in a discrete-time frame and generate dynamic results (Armbruster and Uzsoy, 2012). It also creates dynamic simulations of a production environment to eradicate process inefficiencies (González and Echaveguren, 2012; Greasley, 2017; Kouki *et al.*, 2017; Sarda and Digalwar, 2018).

In that context, random warehouse operations can be standardized and secured through Lean implementations but there is a pressing need to visualize or quantify those assumptions and predictions. Simulation modelling seems to be one of those tools that can suffice this requirement. This study has mainly focussed on dynamically visualizing supply chain lead time reduction through an integrated approach of value stream map (present and future state) and the discrete event simulation with regard to the pharmaceutical warehouse supply chain. No previous study has extensively investigated the synergic effect of the value stream mapping (VSM)–DES integrated approach in the warehouse supply chain scenario. Specifically, this paper aims to apply this approach to reduce the warehouse supply chain lead time and improve the warehouse operations and warehouse key performance metrics. The first two sections of this paper are introduction and literature review that project the research problem and insights on the supply chain, issues in the supply chain, Lean management and its capability to address those issues, and finally scope for DES as a tool to enhance VSM. The other sections discuss the case organization, the methodology adapted, path to present state and future state value stream map, present and future state DES model development, simulation results, model validation, discussion, theoretical and practical implications, limitations of the study, future research and conclusion.

2. Literature review

2.1 Discrete event simulation in production supply chain scenario

Internal processes do require flexible and strategic continuous improvement to cope up with the oscillating market demands. The inherent uncertainty in consolidating and improving the production lines to meet those demands is very high because of uncertain decision-making attempts. In such cases, a simulation modelling approach can be used to manage this issue (Aqlan *et al.*, 2014; Jackson and Tolujevs, 2019; Miclo *et al.*, 2019). Moreover, DES is very successful in modelling as well as facilitating real-time workshop scenarios. However, it may not be a hundred per cent accurate but it gives useful insights towards constructing real-time working models (Robinson *et al.*, 2014). It acts as a strong tool for decision-making by optimizing real-time governing systems with a reliable and virtual environment (LIORIS *et al.*, 2016). The processing strength derived from the visualizing components of this technique can also be applied in real-world innovative projects (ElNimr *et al.*, 2016; Rane and Sunnapwar, 2017).

A globally dispersed vulnerable production systems demand better supply chain designs. An undesirable effect generated from a small unforeseen segment of the supply chain can do large-scale supply chain disruptions. DES models can be used to visualize those disruptions over multiple echelons (Jeong *et al.*, 2018). It is capable of tabulating time and cost estimations for managerial tasks in the supply chain that can provide holistic calculations and business process improvement adapting with different operational and supply chain strategies (Windisch *et al.*, 2013; Dolgui *et al.*, 2018; Barbosa and Azevedo, 2019). Some breakthrough researches on the application of DES in the production supply chain are given in Table 1.

2.2 Integration of Lean (value stream mapping) with simulations

Visualization of any given Lean system in the form of virtual simulation is needed before and after implementation (Gurumurthy and Kodali, 2011). The dynamic movement of inventories could be modelled against different stochastic production demands after Lean adoption (Deif, 2010). The efficiency of batch production systems can be improved by the VSM-integrated simulations approach by effectively modelling all the improvement alternatives and optimize the level of bottlenecks (Parthanadee and Buddhakulsomsiri, 2014). VSM is adopted numerous times to achieve a Lean operational state in production environments. However, there are major limitations in just applying the "paper and pencil" approach in complex environments. Simulation is the tool that can develop an efficient trade-off analysis when combined with VSM (Schmidtke *et al.*, 2014).

3. Case organization and system description

The pharmaceutical organization approached for this study is one of Malaysia's leading pharmaceutical company providing easier access to affordable medicines to the locals. It produces and supplies award-winning and trusted health products for over 60 years. The company handles RM 100m–120m worth of medicinal products. The company manufactures vials, ampules, syrups, eye drops and ointments for domestic as well as international markets. Its warehouse comprises three levels. The ground level is used for receiving (unloading), sorting, storage and finished goods cross-docking. Levels I and II are used for long-term inventory storage and label printing. Level III is allocated for cold storage, post-production quality check, pick and pack and warehouse management office. The ground level consists of Zones 4, 5 and 6, and Batch waiting zone 7 for inventory storage and transportation. Zone 4 is used to stack important ingredients for preliminary quality checks (QA/QC). The raw materials arrive in closed steel cylinders as active ingredients among which some need cold storage and special attention immediately and others are just supporting materials for the production and packaging. The ground level is divided into four main zones. Zone area 4 is used to store the first 150 containers of active ingredients that require a quality check. Remaining 50 containers are sent to Zone 5 and the raw material related to packaging material is sent to Zone 6. After the quality check at Zone 4, items are sent to Level III for temporary storage and wait for the production call. Later, all

Table 1.
DES-integrated studies in production and supply chain operations (2005–2019) Web of Science core collection and Scopus

Researcher	Research undertaken	Supply chain area	Inference
Umeda (2007)	Development of a framework to integrate DES and system dynamics simulation modelling to combine system performance evaluation and complex system's feedback mechanism	General product manufacturing	Feedbacks were generated in social system mechanism and set specifications for supply chain management gaming protocol through simulation
Pinho *et al.* (2016)	Applied simulation modelling platform (SIMEVENTS) in biomass energy supply chain management	Energy (biomass)	A conceptual model for process-efficient biomass supply chain was developed
Persson (2011)	Development of a comprehensive and dynamic tool for supply chain analysts by combining ARENA and supply chain operations reference (SCOR) model	Supply chain demand and quality	Dynamic effects of the supply chain have a significant effect on production rates and bullwhip behaviour
Hallam (2010)	Discrete event simulator was developed to study cost increases and schedule delays in aircraft production supply chains to reduce lead time and increase production performance	Supply chain cost reduction (aerospace)	The efficient production schedule was designed and also the impact of design change in the traffic was identified based on simulation results
Morrice *et al.* (2005)	Semiconductor production supply chain was modelled using DES Arena software to analyze work-in-process levels and on-time delivery	Semi-conductor production	Inventory control policies and supply chain were positively affected because of lead time reductions
Hachicha *et al.* (2010)	A make-to-order supply chain (MTO) and lot-sizing problem (LSP) are optimized considering important stochastic parameters using simulations followed by response surface methodology (RSM)	General manufacturing process optimization	A prototype for a fixed optimal lot size was achieved in the MTO sector with promising future implications

the raw materials assemble at Waiting zone 7 to be sent to Production despatch bay 9. Figure 1 shows a detailed schematic representation of the warehouse ground level.

A push-based system was used to transmit information on the inventory manually using a report book by the warehouse professionals between different levels of the warehouse. There are only two gates for unloading the raw materials and the same are used for finished goods cross-docking. The temporarily stored raw materials at the ground level demanded proper categorization and importance to avoid huge delays with uneven buffer and inventory stockpile. Electronic data interchange (EDI) and Just-in-Time techniques were not covering all levels because of deterministic demand patterns. The firm had to rely on third-party storage and transportation that weakens on-time delivery of the drugs which ignites further additional inventory carrying time and cost. Moreover, during a few occasions, a very huge amount of inventory is accumulated and stays more than a month at Level III (temporary storage facility) before it is called for production. Some of the warehouse layout

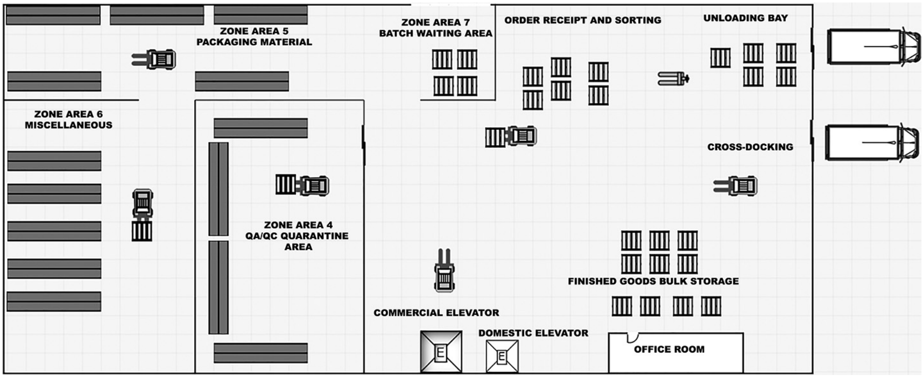


Figure 1.
Schematic diagram of warehouse ground level

and path of material movement seemed to demand redesign and modification for shorter time delays and avoid inventory build-up.

4. Methodology

This case study was carried out in a warehouse of a Malaysian-based pharmaceutical organization. Several semi-structured interviews were conducted with the supply chain officials and employees to understand the whole warehouse system. Some of the activities related to warehouse inventory storage and movements seemed to incur more time delays because of random execution. Supply chain and warehouse managers were not able to visualize the dynamic nature of those processes and experienced difficulties in reducing wastes and non-value-added entities.

According to Martichenko and Von Grabe (2010), the supply chain should be divided into segments for the initiation of the VSM. Therefore, present state and future state value stream maps were built from the raw material receiving end and till the production issuing end. This VSM is completely different from the traditional core manufacturing VSM. The setup time, changeover time and uptime are replaced by process time, lead time and value-added time (Suarez-Barraza *et al.*, 2016). This study is based on a modified framework of the previously adapted version from McDonald *et al.* (2002), Erikshammar *et al.* (2013) and Schmidtke *et al.* (2014).

The idea was to build a warehouse-based VSM and later use this timeline values as data input feed into the DES package along with other core data. The DES software simulated the VSM results dynamically and gave a virtual warehouse setup. Simulation results and graphs generated show lead time differences, pallet processing percentage, worker/forklift throughput, waiting time/delays, receiving efficiency, put away rate and storage rate at different levels of the warehouse. The VSM-integrated DES models were developed using a multi-method simulation software “Anylogic 8.4”. The primary data collection to build a VSM was mainly focussed on the time incurred for all the warehouse activities, waiting time and delays and inventory levels. Face-to-face interviews with the warehouse floor officials and reference to the previous records were the main source of data. However, the core data was obtained by implementing the go-see method (Gemba). All these informations were keyed inside the DES software interface to attain a logical model that mimics the real-time situation. Dynamic visualization of the warehouse activities and lead time related to it were displayed in the form of simulation results as 2D, 3D and statistical graphs. A detailed modified framework adapted for this study is given in Figure 2.

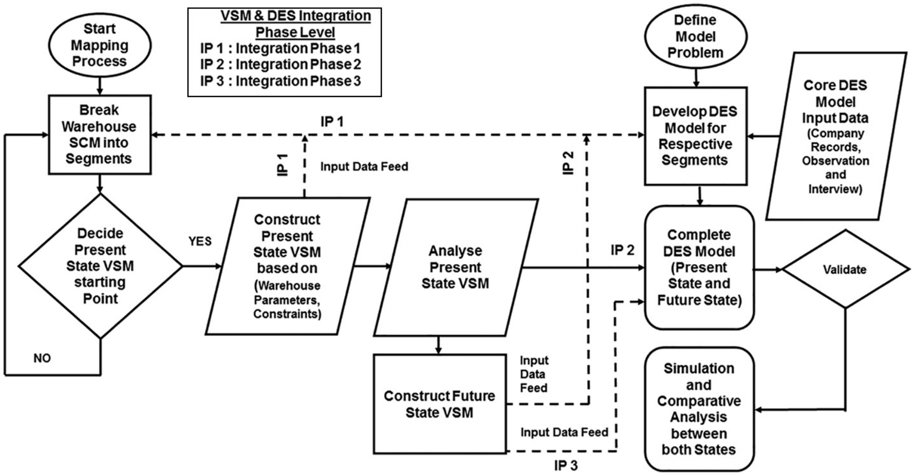


Figure 2.
Developed framework

An ABC chart, lead time graph and product family matrix were constructed to select the product family falling under Category A. Later, a cross-functional diagram, spaghetti diagram and process activity chart were completed for the selected product family, followed by present state and future state VSM and DES model. Figure 3 shows the sequence of steps carried out to complete this study.

5. Present state mapping

The present state begins with the unloading, order receipt and sorting of raw materials at the ground level. After the strenuous unloading process, it enters the sorting bay where Station 1 and Station 2 are located to sort and despatch order receipt to suppliers and update in the warehouse management system. The present state is built by combining five major processes such as “supplier truck receiving/unloading”, “order receipt/sorting”, “division of load/transportation to quarantine shelf”, “QA/QC process/transportation to Level III” and “production issue”. The process time is the time that a process takes and lead time is the time delay between two processes. Process time for each process was calculated along with value-added and non-value-added time.

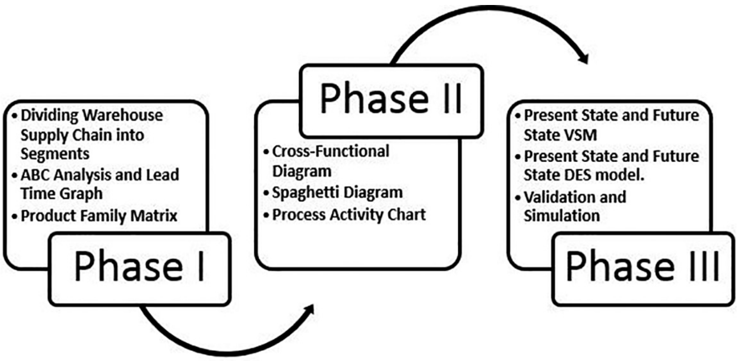
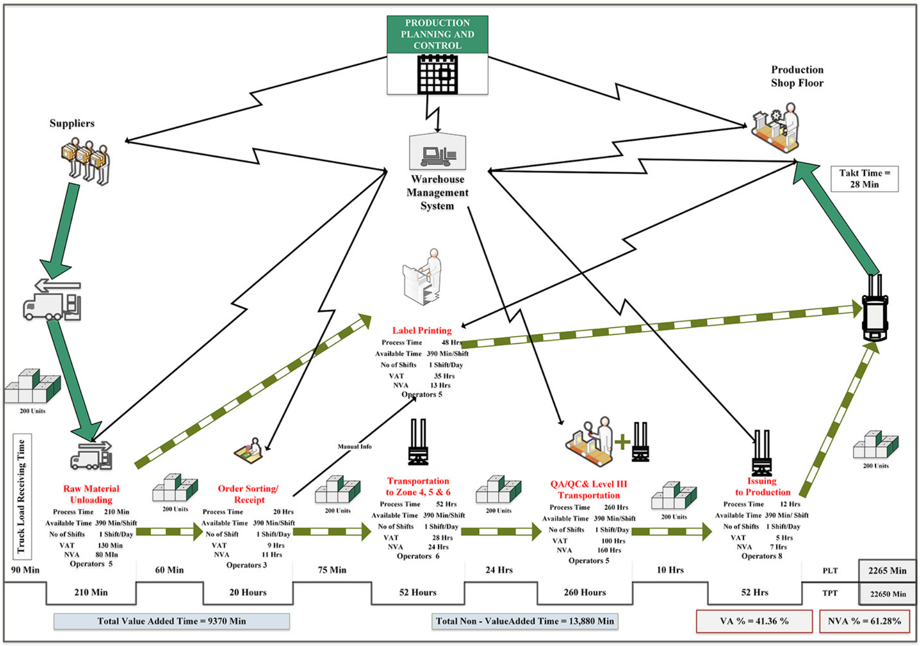


Figure 3.
Sequence of research flow

A period of time where the activities in a process seem to add value to the system is value-added time and the rest is non-value-added. The average demand per month is around 28,000 individual parts (vials), i.e. 350 cartons. Each carton had 80 vials loaded and packed inside it. Total working days were 25 days per month and there was only one shift of 8 h per day. As a whole, there were 1.5 h in a day given for tea and lunch break, so, the available time was 6.5 h per day. The ratio of available time for production per day to the demand of the customer per day is considered as "Takt time". The total process time is the sum of time taken for all the processes. The summation of process time and lead time gives the value of total process time and total production lead time, respectively. A detailed present state is given in Figure 4. Tables 2 and 3 show the details related to the present state value stream map.

6. Future state mapping

After an in-depth evaluation of the present state and construction of a fishbone diagram, several Lean principles and strategies were suggested in the future state value stream map. Facility layout change was proposed at the unloading and receiving end along "5S" to reduce time and standardize that area of the warehouse. A Kanban-based pull network was proposed at the Level III temporary storage issuance division to avoid excess material buffer at Level III and avoid movement of vulnerable active ingredients towards the production unit without a proper production call. Finally, the production issuing process was proposed to undergo a major facility layout change to cut excess lead time and buffer build-up at Batch waiting zone area 7. The value-added percentage increased from 41.36% to 70.57%



Source: Abideen and Mohamad (2019)

Figure 4.
Present state map

and the non-value-added percentage decreased from 61.28% to 29.42%. A detailed future state is given in Figure 5. Tables 4 and 5 display the future state timeline and calculations.

7. Discrete event simulation model development

The warehouse activities were divided into separate discrete events or sub-processes to help build a discrete event simulation model. The DES model was developed using the software "Anylogic".

7.1 Anylogic software

Anylogic is a multi-method modelling software with powerful features that could help create a DES model with ease. These models are mainly used in the industry level for better decision-making and production planning. The software currently has six different libraries, namely, process modelling, pedestrian, road traffic, rail, fluid and material handling library. These libraries are used according to their scope and need. In this study, the process modelling library was used to create apt logic to the model backed up by the material handling library to add resources to the warehouse model.

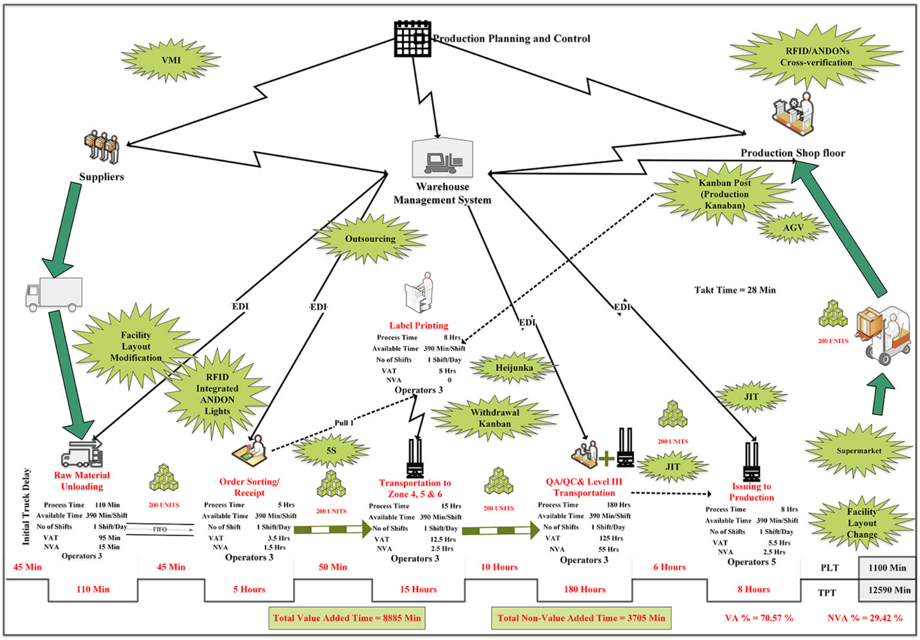
Process modelling library in Anylogic allows industrial and academic analysts to model an operation at a detailed level to facilitate business workflow simulations and process dynamics for better decision-making. The process models allow users to experience real-world systems in terms of computer processes that include the respective waiting times,

Table 2. Present state parameters

Process	Process time (min)	Value-added time (min)	Non-value-added time (min)	Total process time (min)	Total production lead time (min)
Supplier truck receiving/unloading	210	130	80	22,650	2,265
Order receipt/sorting	1,200	540	660		
Division of load/transportation to the quarantine zone (QA/QC Zone 4)	3,120	1,680	1,440		
QA/QC process and transport to Level III for temporary storage	15,600	6,000	9,600		
Issuing to production	3,120	1,020	2,100		

Table 3. Present state calculations

Time parameter	Equation	Value/result
Takt time	$= \frac{(\text{No of working hours} \times \text{No of Shifts} \times 60)}{(\text{Demand/Month} \div \text{No of working days in a month})} = \left(\frac{6.5 \times 1 \times 60}{350 \div 25}\right)$	28 min
Total process time (TPT)	$= TP1 + TP2 + TP3 + \ldots TPn$	22,650 min
Total production lead time (TPL)	$= TPL1 + TPL2 + \ldots\ldots TPLn$	2,265 min
Value-added percentage (VA%)	$= \sum_{n}^{1} VAT \frac{\times 100}{TPT}$	41.36%
Total non-value-added percentage (NA%)	$= \sum_{n}^{1} NVA \frac{\times 100}{TPT}$	61.28%



Source: Abideen and Mohamad (2019)

Figure 5.
Future state map

Table 4.
Future state parameters

Process	Process time (min)	Value-added time (min)	Non-value added time (min)	Total process time (min)	Production lead time (min)
Supplier truck receiving/unloading	110	95	15	12,590	1,100
Order receipt/sorting	300	210	90		
Division of load/transportation to quarantine shelf	900	750	150		
QA/QC check and transport to Level III	10,800	7,500	3,300		
Issuing to production	480	330	150		

Table 5.
Future state calculations

Time parameter	Equation	Value/result
Total process time (TPT)	$= TP1 + TP2 + TP3 + \ldots TPn$	12,590 min
Total production lead time (TPL)	$= TPL1 + TPL2 + \ldots\ldots TPLn$	1,100 min
Value-added percentage (VA%)	$= \sum_{n}^{1} VAT \frac{\times 100}{TPT}$	70.57%
Total non-value-added percentage (NA%)	$= \sum_{n}^{1} NVA \frac{\times 100}{TPT}$	29.42%

queues, material resource and actions that influence the process to enhance animation capabilities. Some of the selected process models and material handling library symbols are given in Figure 6.

7.2 Rubrics of the present state discrete event simulation model

The VSM's timeline cannot be used to build the whole discrete event simulation model. A DES model needs more in-depth information on materials resources, their routes and time delays in detail from which a selected few are tabulated in Table 6.

7.3 Present state process model (Phase I)

The first phase consists of a set of variables and parameters to model the processes (storage/transport), delays and waiting time from unloading until storage at Zones 4, 5 and 6. Relevant process modelling blocks and its parameters were affixed to control the number of trucks, truckload, time taken for unloading and time delays because of sorting pallets into batches at Stations 1 and 2. The queuing time and service time delays to transport and store raw material at Zones 4, 5 and 6, Zone 4 to Level III, Level III to Batch waiting zone 7 and Despatch to production bay 9 are included in the model. This is clearly shown in Figure 7.

7.4 Present state (Phases II and III)

At the next stage, the storage and rack pick processes that occur at Zones 4, 5 and 6 are modelled, including the QA/QC time delay at Zone 4. After this, the rack pick process models are included followed by the movement of pallets towards the Waiting zone 7 that leads to Production bay 9. Even though the VSMs have not captured the final process of finished good despatch back to the warehouse, it has been included in the DES model to visualize the

Process Model Symbol	Function/Description
Path Point Node Rectangular Node Polygonal Node Attractor Pallet Rack	The path node is used to build a path for the resource pool to move from one place to another. The point node, rectangular node, and polygon node are used to define the specific point and contour respectively. The attractor enables uniform position of the resource pool. Pallet rack is to define a shelf that can be used to store pallets.
Source Sink Delay Queue	These process symbols denote the starting point and end of the resources or work materials and their time delays and queues.
Move To Conveyor Resource Pool Seize Release Service	The first process model symbol denotes the movement of the material inside the system. Conveyor symbol shows that there is a conveyor system incorporated in the system. Resource pool helps to add resources to the system. Seize, release, service are used to stop, despatch and inspect respectively.
Rack System Rack Store Rack Pick	All these three process symbols can be incorporated to add various parameters to the rack system in terms of storage and pick up.

Figure 6.
Selected Anylogic process model and material handling symbols and its logical functions that are used in this study

S.no	Discrete events	Process information
1	Raw material delivery	No. of trucks – 5
2	Total raw materials per order	(200 bottles for two months demand fulfilment) + 50 Closed boxes of packaging raw material
3	Total number of containers per truck	50 (50 × 4 trucks = 200 containers)
4	Fifth truck (separate shipment)	Delivery of packaging material (50 boxes)
5	Gross weight of 1 container	25 kg
6	Time lapse between each delivery truck set	30 min
7	Number of containers loaded on a pallet	5
8	Time taken for unloading	90 min
9	Unloading time for a pair of trucks are the same, and the fifth and final truck is the one that delivers 50 raw material packages	(Time taken for all the trucks to complete unloading process) – 6 h (360 min)
10	Resource utilized (unloading)	2 forklifts No. of workers utilized for unloading (walking or standing at the spot = 3 Total workers = 5
11	Station 1	Order receipt and tag checking (manual)
12	Station 2	Order sorting (manual)
13	Station 1 to Station 2 material movement	Forklift = 1
14	No. of workers at Station 1	1 worker (working at the station)
15	No. of workers at Station 2	2
16	Time taken at Station 1 (delay)	10 h
17	Time taken at Station 2 (delay)	10 h + 75 min
18	Station 2 to (QA/QC – Zone area 4, Zone areas 5 and 6) movement of pallets	3 forklifts
19	Time taken for storage in Area 4 (QA/QC)	50 h
20	Time taken for storage in Area 5	15 h
21	Time taken for storage in Area 6 (all the time taken in S.No. 19, 20 and 21 are also included in some part of unloading time frame)	11 h
22	Pallet rack	Single-aisle (four levels) Length standard industry size (8 m length and 1.5 m wide)
23	Filling up of pallet rack (resource used)	Forklifts = 3
24	Movement of material from QA/QC to Level III Time taken for QA/QC process (delay at Zone area 4)	Forklifts 80 h No. of inspectors for inspection = 3
25	Time taken to travel from QA/QC to Level III	50 h
26	Mode of transport	Two forklift trucks (pallet trolley to move inside elevators) No. of workers in this process = 2
27	Number of containers sent or pallets sent to Level III	150 containers (30 Pallets with 5 containers each)
28	Waiting time of Pallets at Level III	120 h
29	Time taken to send the pallets from Level III to batch waiting area	22 h (including elevator travel time)
30	Pallets from Zone 6 and Zone 5 also join in this process after all 150 items from Level III have been sent to Production bay 9	Time taken for this process = 10 h

(*continued*)

Table 6.
Data required for present state DES model (unloading and transportation to Zones 4, 5 and 6 (current state) and from Zone 4 to Level III)

Table 6.

S.no	Discrete events	Process information
31	Time taken to send pallets from pallet rack from Areas 5 and 6 to Batch area 7	10 h
	Mode of transport for Steps 30 and 31	Forklift=3 No. of workers = 5
32	Maximum number of pallets Batch area 7 can hold	Ten pallets
33	Total time taken from Area 10 to space in front of elevator hours	65 h until it reaches the elevator
34	No of forklifts to take pallets from Area 10 to waiting area	2
35	No of forklifts to deliver from waiting area to the area in front of the commercial elevator	3
36	No. of workers assisting in this process	1 (excluding forklift personal)

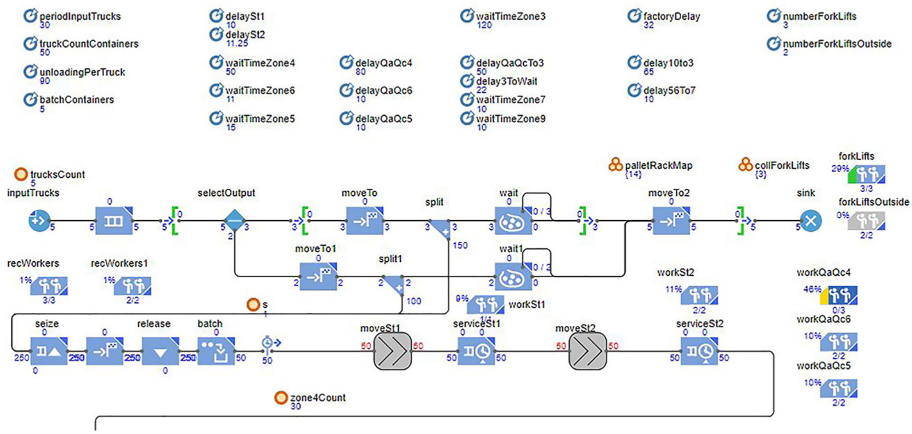


Figure 7.
Present state DES model (Phase I)

finished goods receiving and transport to Level III for post-production quality check. All of this has been modelled in a logical sequence which is shown in Figures 8 and 9. Specific process modelling steps mentioned in all the above present state phases needed Java coding as mentioned in Appendix (Table A1).

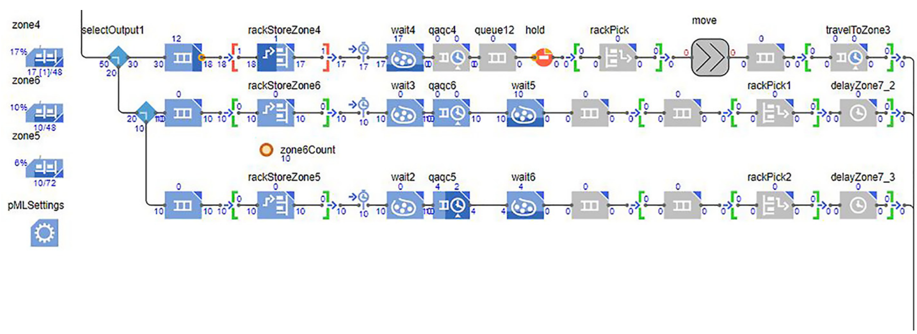


Figure 8.
Present state DES model (Phase II)

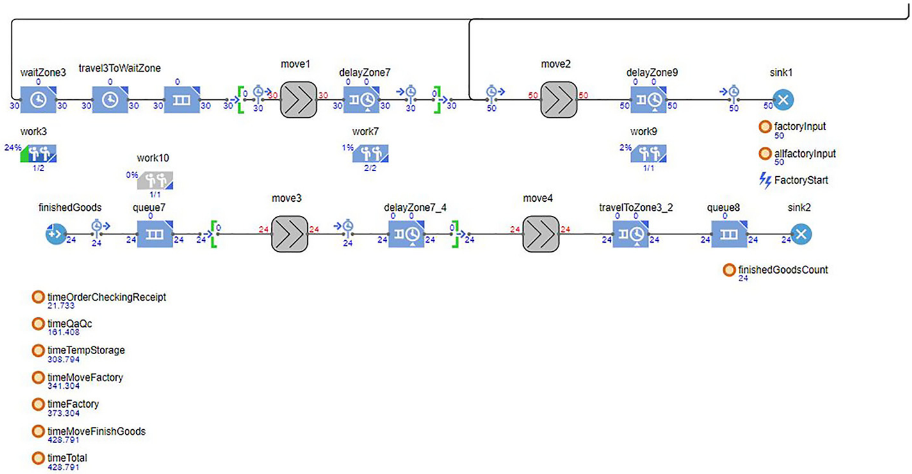


Figure 9.
Present state DES model (Phase III)

Figures 10 and 11 show the 2D and 3D visualization of the overall setup considered for this study. The space mark-up elements, process modelling sequence and the usage of variables to build the DES models are seen in 2D and 3D formats. The light blue lines denote the pavement or path of the resources that are utilized in the model and the grey rectangular boxes are the pallet racks that are used for the storage of raw materials. And a dynamic lead time-oriented timeline is given at the bottom of Figure 10 to witness the change of time at each stage of VSM in a dynamic fashion.

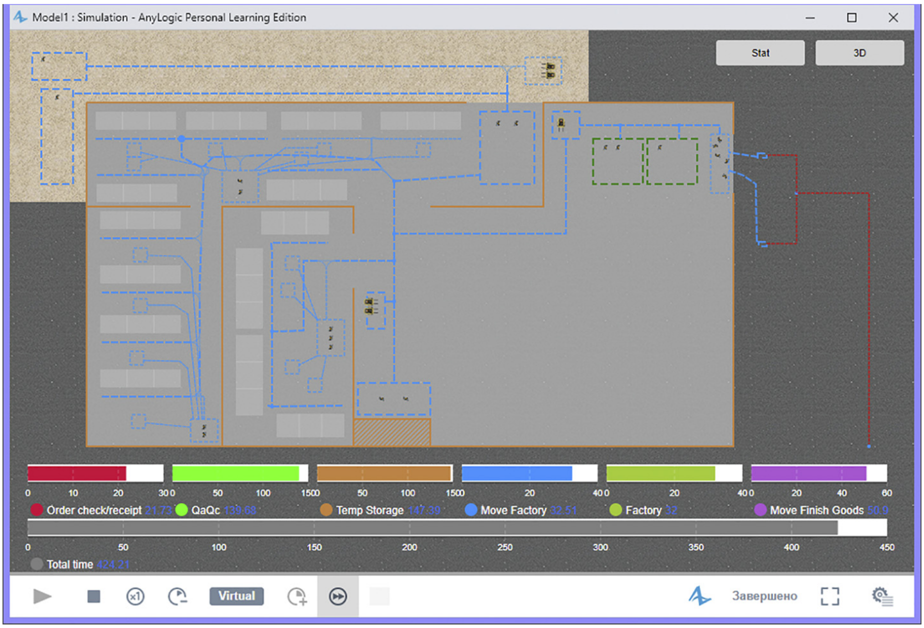


Figure 10.
Present state 2D visualization

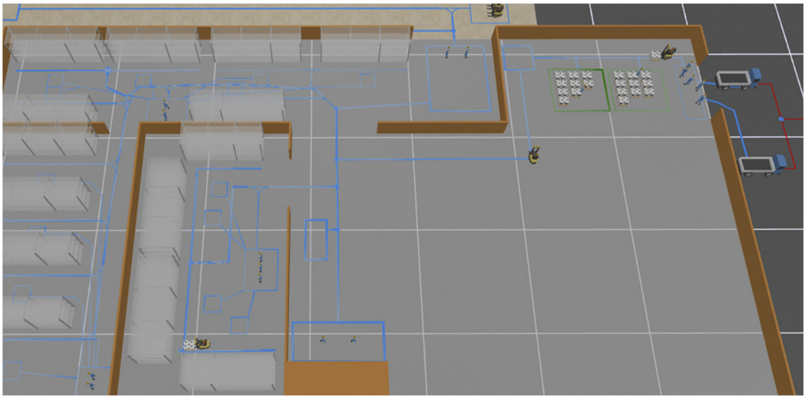


Figure 11.
Present state 3D visualization

8. Model validation (present state)

According to Djamali (2018), the process of validation in dynamic systems modelling can be measured using a mean absolute percentage error (MAPE) test where the behaviour of modelling (data simulation) and real system (actual data) are compared with each other, i.e. the estimated simulation result and actual data. Of course, models cannot exactly reflect the real system, but they can be equivalent to the real-time system and fall between a certain range of approximation. MAPE was executed with the help of equation (1).

$$MAPE = \frac{1}{n} \times \sum \frac{|xm - xd|}{xd} \times 100 \tag{1}$$

xm = data of simulation result, xd = actual data, n = number of data.

If the result is less than 5%, it is considered as very accurate and if it is between 5% and 10%, it is accurate and greater than that is not accurate. The entire system is divided into different levels and data from both real-time and simulation results are compared. The MAPE test for this study is shown in Table 7.

9. Results

9.1 Future state discrete event simulation model

Many manufacturing operations are created and conceived based on several overly simplistic assumptions, which stop manufacturing authorities from recognizing the

Table 7.
Present state validation

S.no.	Process	(xd) VSM time frame (min)	(xm) DES time frame (min)	MAPE (%)
1	Items receiving, unloading	1,560	1,485	4.8
2	Transportation to Zones 4, 5 and 6 and rack storage	4,626	4,620	0.1
3	QA/QC and transportation to Level III and waiting time at Zones 5 and 6	16,200	15,000	7.4
4	Transportation from Level III and Waiting zone 7 and Transportation to Production	3,100	3,120	0.6

incidence and risk they may experience (Alrabghi and Tiwari, 2016). Dynamic visualization of the future map would eliminate all the gaps and questions present in a Lean manager's mind, particularly in situations of supply chains where procedures can be very random. Some of the time-reducing techniques and methods such as radio frequency image identification (RFID), Andon lights and artificial intelligent (AI) sensors and smart conveyors were suggested and modelled to reduce resource usage, delays and buffers. The tentative time assumptions were only taken into account rather than modelling the complete functionality of all the resource or process blocks as mentioned above due to various limitations. Table 8 tabulates some of the selected core data used to build the future state DES model (Phase I). The whole model is split into three phases for a better explanation.

9.2 Future state process modelling (Phase I)

Raw material receiving, sorting and processing at Stations 1 and 2 denote Phase I. The initial process of unloading is fastened by assuming there are other two gates specially created for finished goods cross-docking. Hence, the truck waiting time can be seen considerably reduced. The unloading process is attended by a lesser number of workers on this occasion at Stations 1 and 2 where RFID-integrated AI sensors with Andon display lights are assumed to be installed to quicken the raw material sorting procedures and later transport them to Zones 4, 5 and 6. A conveyor design setup is included in the sequence for transportation of raw material to Zones 4, 5 and 6 by equally dividing them. The forklift travel duration and worker delays are eradicated greatly in this process. The process variables for truck unloading, delays during transport and waiting time at various levels can be seen in Figure 12.

9.3 Future state discrete event simulation model (Phases II and III)

In the second phase, the conveyor system is designed in such a way that the raw materials needed to be stored in Zone 4 (pallets with cylindrical containers) are separated from the other members (pallets with blue boxes) with the help of turntable that goes towards Zone 6. Later, after dropping all the containers belonging to Zone 4, the conveyor proceeds towards Zone 5. In this model, the Batch waiting zone 7 is completely avoided and a special route for the pallets to reach Production bay 9 is designed and the same route is used for receiving finished goods from Batch despatch zone 10. All these process models with a logical sequence are shown in Figures 13 and 14. Specific process modelling steps mentioned in all the future state phases also use respective Java coding as mentioned in Appendix Table A1.

The three forklifts are now strategically placed outside Zone area 4 to pick up the pallets from conveyors to move to the racks and vice versa. The conveyors are elevated to a certain level to allow forklift and workers to move freely below them. A 2D and 3D model of the future state is shown in Figures 15 and 16.

9.4 Simulation output

The initial simulation window was designed to portray Figure 16 and Figure 17 which displays all the important parameters and its values in the very first screen before streaming the main simulation run. The final window shows a 2D and 3D simulation along with a few graphs and histograms. In addition to that, the DES model is displayed on the right side of the screen. Figures 17 and 18 portray the first simulation window. In future endeavours, this window can also be designed to enter values to see the changes in the system.

Time taken from unloading point to Zones 4, 5 and 6 and time taken from warehouse to production and vice versa are displayed in the form of cumulative distributive function (CDF) to understand the behaviour of the inventory movement in discrete intervals. The

Table 8. Data for future state DES model (unloading, transportation, rack storage and despatch)

S.no.	Process/activity	Process information
1	Time Lapse or gap between each delivery truck pair and the final one	15 min
2	Max number of containers loaded on a pallet	5
3	Time taken for unloading per truck set (set of two trucks)	52 min
4	Time taken for two pairs of trucks and the final one	52 + 52 min
5	Resource used (Station 1 to Station 2)	Conveyer (roller) Number of workers at unloading section = 3
6	Station 1	Order receipt and tag checking (artificial intelligence-based sensor RFID reader)
7	Station 2	Order sorting (RFID)
8	Station 1 to Station 2 material movement	Conveyer
9	No of workers at Stations 1 and 2	1, 2
10	Time taken at Station 1	150 min (No. of workers = 1)
11	Time taken at Station 2	160 min (No. of workers for inspecting = 2)
12	Station 2 to QA/QC (Areas 4, 5, 6) – resource used	Conveyer
13	Time taken for storage in Zone area 4 (QA/QC) through Node 3	10 h
14	Time taken for storage in Zone area 5 through Node 4	7.5 h
15	Time taken for storage in Area 6 through Node 5	7.5 h Number of workers = 3
16	Pallet rack (information)	Single-aisle (four levels) Length standard industry size (8 m length and 1.5 m wide)
17	QA/QC process time duration	60 h (No. of worker inspecting QA/QC process = 2)
18	Time taken to travel from QA/QC to the area in front of the elevator	5 h No. of workers = 2
19	Time taken to travel to Level III and at Level III	25 h
20	Number of containers sent or pallets sent to Level III	150 containers (30 pallets/5 containers in each pallet)
21	Waiting time of pallets at Level III	70 h
22	Time taken to send the pallets from Level III to the area in front of the elevator	10 h
23	The total time delay from the moment the 150 containers disappear at the area in front of the elevator and again reappear in the same area	105 h
24	Time taken for 150 containers to reach from the area in front of elevator to the Batch waiting area 9	20 h No. of workers = 2
25	Numbers of pallets waiting at Areas 5 and 6	10 and 10, respectively
26	Time taken to send pallets from pallet rack from Areas 5 and 6 to Batch awaiting bay 9	4 h
27	Mode of transport	Forklift truck = 3
28	Maximum number of pallets Batch area 7 can hold	10 pallets at a time (50 min – average delay for each set)

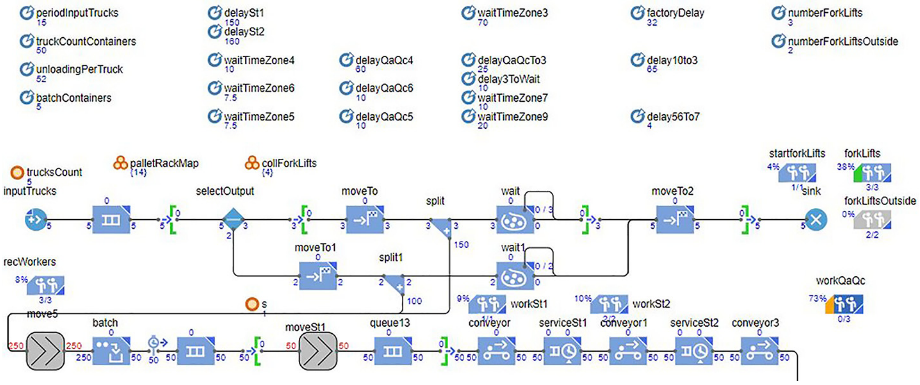


Figure 12.
Future state DES model (Phase I)

CDF graph gives a value of inventory level which is either equal to or lesser than 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 into each zone given at a time is tabulated in another stepped line graph with the number of pallets in x-axis and number of working hours or time taken at each zone in y-axis that is clearly shown in Figure 19 (present state) and Figure 20 (future state). The difference in lead time reduction can be easily seen by comparing both.

10. Discussion

There is a significant increase in the percentage of pallets that all the zones are witnessing with respect to time. The future state simulation shows an 8%–15% increase in Pallet Processing Percentage in Zones 4, 5, 6 and Level III. Table 9 has been tabulated with the help of Figures 11 and 18. Table 10 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.

The reduction of lead time between two states was possible because of the removal of waiting time at Zone area 7, unloading bay, Stations 1 and 2, QA/QC, Level III storage and transportation to production. Table 11 portrays the detailed lead time reduction percentage at every level.

10.1 Improvement in warehouse performance metrics

Some of the warehouse performance metrics are tabulated comparing both present state and future state to visualize the changes and improvement. Warehouse performance metrics such as item receiving rate or raw material unloading; put away or transportation to pallet racks; and storage rate or pallet rack storage are directly proportional to the 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 are 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 12 displays selected warehouse performance metrics and its details related to Phase I. The unloading rate, put away and storage rate showed positive results. There was a 44% decrease in receiving time, a 24% decrease in put away time and a 67% decrease in storage time, respectively.

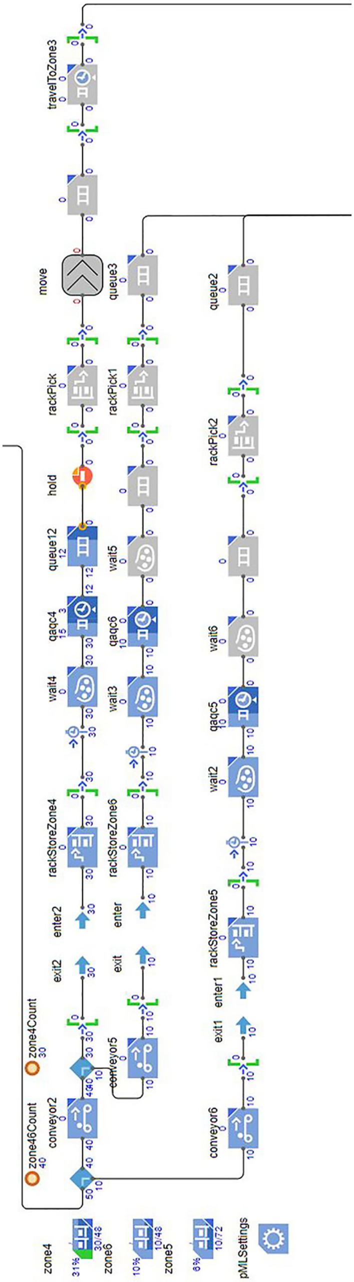


Figure 13.
Future state DES model (Phase II)

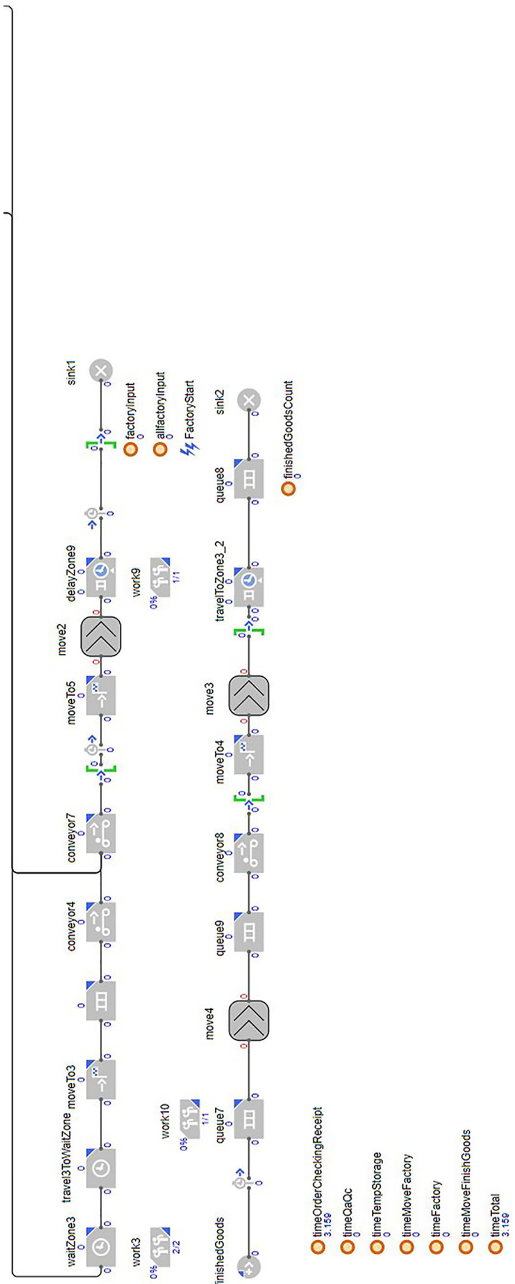


Figure 14.
Future state DES model (Phase III)

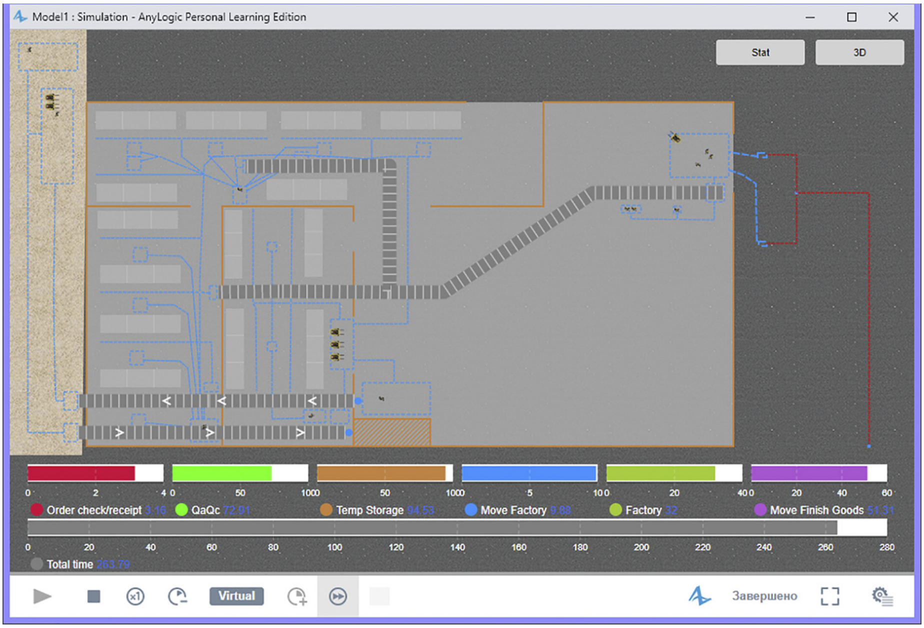


Figure 15.
Future state 2D visualization

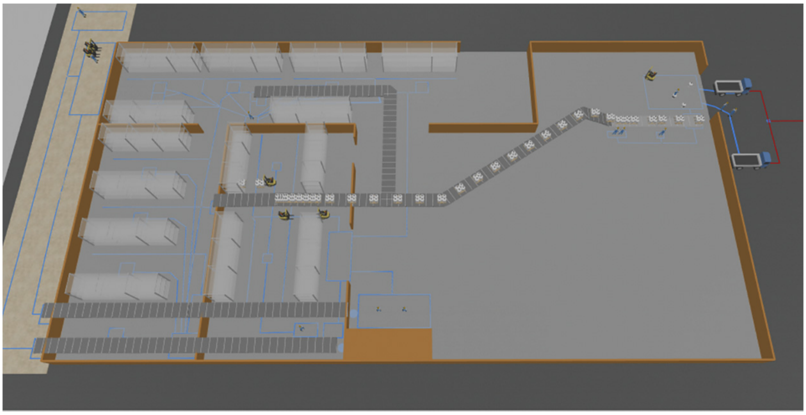


Figure 16.
Future state 3D visualization

11. Theoretical and practical implications

Supply chains of the pharmaceutical industry have to be more value-oriented, smart and agile to facilitate competitiveness and sustainability in the current Industry 4.0 environment. The sustainability barriers need to be cut down from the chain to allow better operational efficiency. For this, a flexible and effectively coordinated system of the pharma supply chain is needed to shorten the time and costs involved and help in autonomous decision-making and benchmarking (Ding, 2018). It is difficult to do so without understanding the value of pharmaceutical items that are being handled within the supply

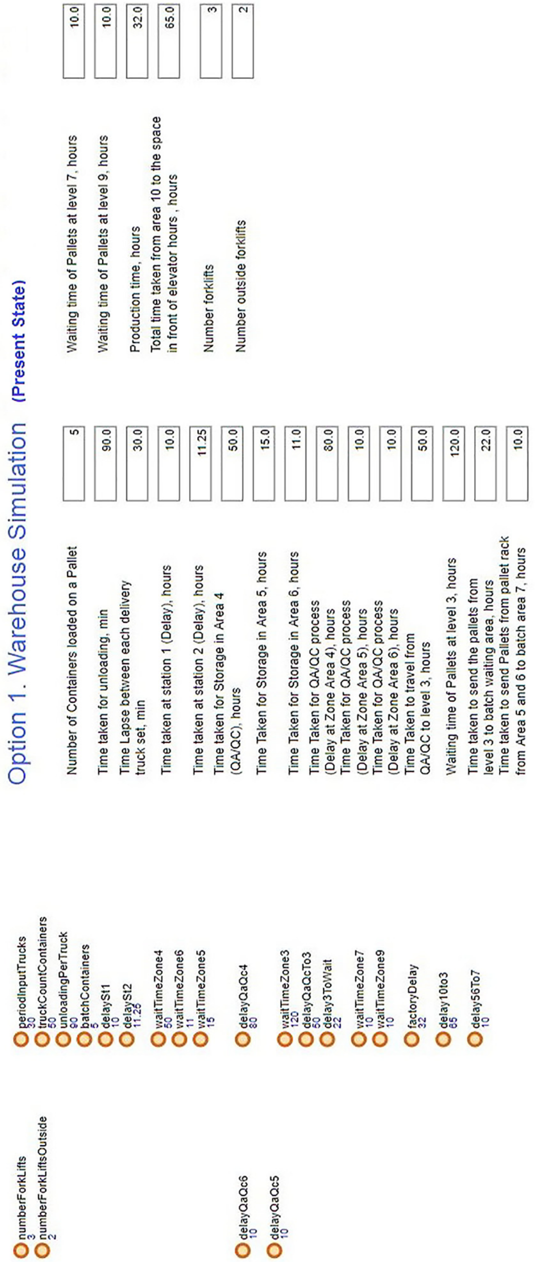


Figure 17.
Present state
parameter window

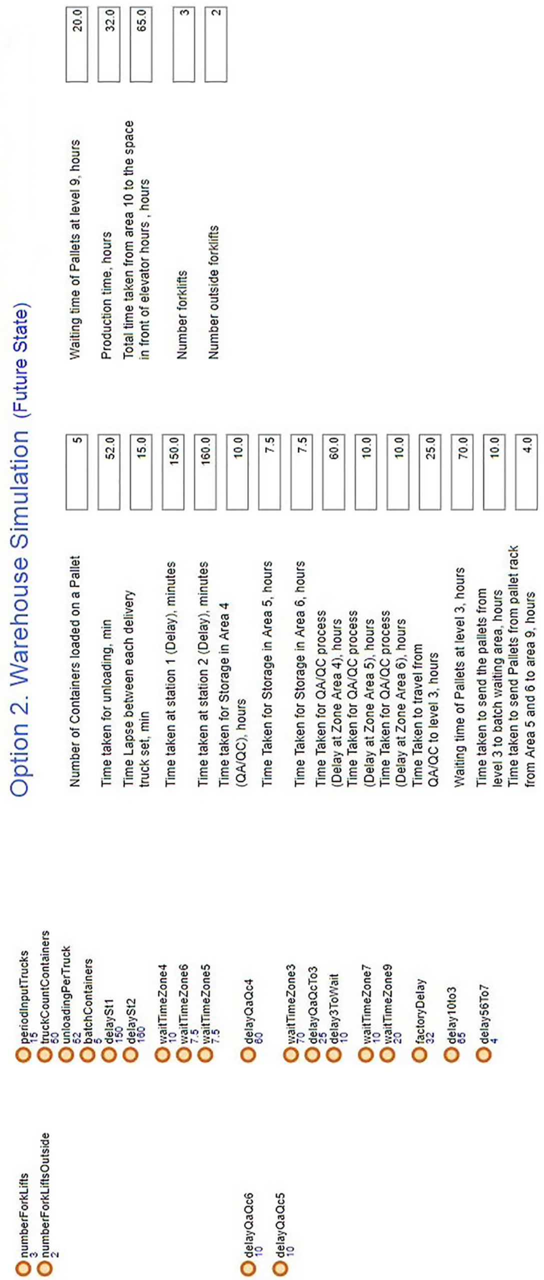


Figure 18.
Future state parameter window

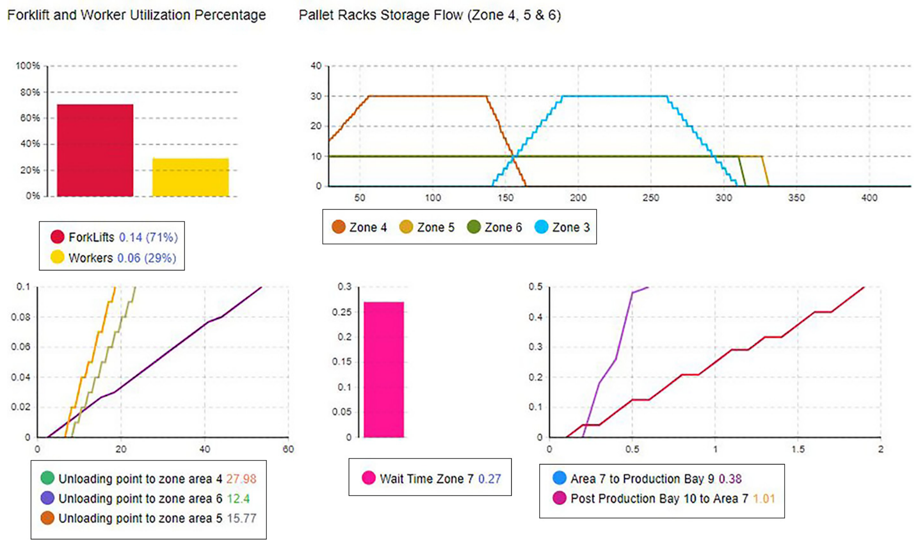


Figure 19.
Present state simulation graphical results

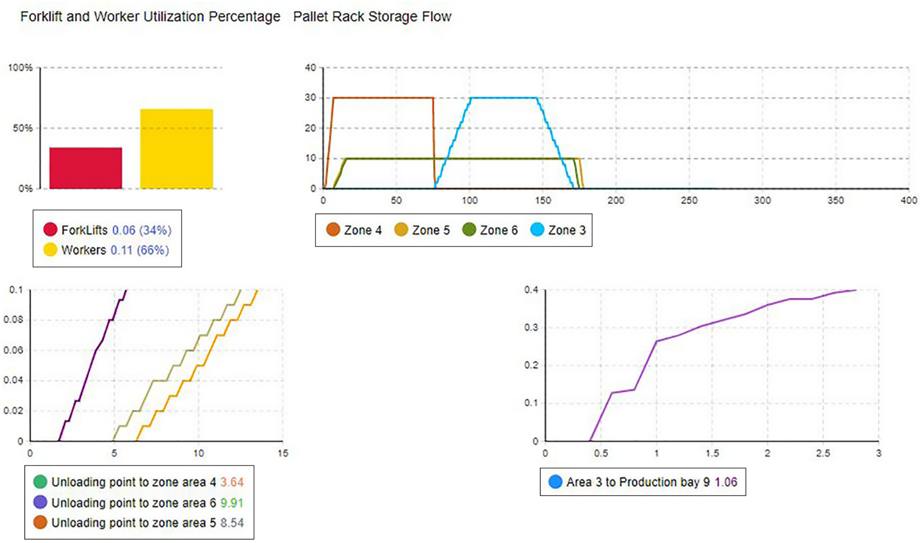


Figure 20.
Future state simulation graphical results

chain that are inbound. Pharma supply chains are more risk-prone than their counterparts and crucial precautions are taken for secure transport both inbound and outbound (Goshorn and Usswald, 2014).

Moreover, pharmaceutical firms are forced to change their strategies now and then because of variations in the market economy. Predicting the correct volume is a major challenge because of relentless and fluctuating demand and more risk assessment measures are taken at critical points (El Mokrini *et al.*, 2016). Old logistic methods are least supply chain responsive and get saturated and become incapable of meeting new challenges (El Mokrini *et al.*, 2018). And inadequate information flow can hamper the supply chain growth rapidly. On the other hand, handling complexities is much more difficult because of social and governmental regulations. Integrated information systems can handle these drawbacks and further possible challenges (Yousefi and Alibabaei, 2015). In some cases risk zones, security and safety functionalities can be offered by Auto-ID technologies (Papert *et al.*, 2016).

DES-assisted VSM may help improve Lean performance measures 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 and this approach can also be used to build more simulations after Lean

Table 9. Percentage of pallet rack transportation/storage at the end of various levels inside Zones 4, 5, 6 and 3

		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 Zones 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 Zones 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

Notes: PT, present state; FT, future state

Table 10. Worker and forklift throughput/percentage

	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

Notes: PT, present state; FT, future state

Table 11. Lead time reduction percentage

Simulation phases	Present state (min)	Future state (min)	Lead time reduction (%)
Order check/receipt	1,303.80	189.60	14.54
QA/QC	8,380.80	4,374.60	52.19
Storage at Level III	8,843.40	5,671.80	64.13
Transportation to production	1,950.60	592.8	30.39
Production time	1,920	1,920	–

warehousing and continuous improvement. According to Schmidtke *et al.* (2014), DES shall enhance the future state VSM and provide dynamic simulation results that could be suggested for trade-offs for future improvement. A clear approximate quantitative data can be visualized using a DES simulation.

Even though the accuracy and optimality of the model could not reach the absolute real-time scene, the model provided us with a real virtual dynamic visualization of a system's future states. This study shall be useful for other researchers and practitioners to adapt the methodology in other warehouse environments and also experiment with other simulation techniques.

11.1 Limitations of the study

The dynamic nature of the supply chain processes, especially inside the warehouse, is so complicated and difficult to catch almost all the events and study them and not all Lean tools and its effects can be completely simulated and visualized. Moreover, this study was limited within the boundaries of warehouse setup and related operations. The DES software packages cannot directly simulate or visualize Lean outcomes but allow detailed parametric data input to acquire optimal results for other Lean constructs to some extent.

12. Conclusion

The comparison of future state VSM and present state VSM was done to acquire the percent of increase and decrease of lead time. In the VSM timeline, the production lead time and total process time have decreased by 51.43% and 44.41%, respectively. The value-added percentage increased from 41.36% to 70.57% and the non-value-added percentage decreased from 61.28% to 29.42%. From the DES simulation output, the future state showed an 8%–15% increase in pallet processing percentage value. The average worker throughput was increased by 26.23% and forklift usage was reduced by 25%. Warehouse performance metrics such as the receiving efficiency, put away efficiency and the storage efficiency for Phase I at ground level was increased by 44, 24 and 67%, respectively. The cumulative total process time was decreased by 19.5 h and the cumulative lead time has decreased by 137.6 h for a two-month demand cycle.

The average lead time reduction in the overall system is 40.31%. The MAPE validation results according to Djamali (2018) show that the present state DES model is 3.22% accurate to that of the actual or real system, which comes under acceptable norms. The future state DES simulations were used to witness the time reduction percentage at various levels of the warehouse. The simulation results show 2D and 3D visuals to understand the inventory movement and storage delays at discrete time events. All the Lean assumptions and results were face-validated by the supply chain official of the firm. This study proved to be very helpful to the managers to understand their warehouse even much better for better decision-

Warehouse performance metric	Present/future state	Time to complete total items (min)	Efficiency/ productivity rate	Percentage increase (%)
Receiving/unloading process	PT	120	2.08	44
	FT	67	3.73	
Put away process	PT	1,275	0.19	24
	FT	310	0.80	
Storage process	PT	76	3.28	67
	FT	25	10.01	

Table 12. Warehouse performance improvement

making and also agreed for the inclusion of separate sophisticated Lean simulation systems in the firm's warehouse to study and optimize warehouse operations.

12.1 Future research

The modern reimbursement environment prioritizes the maximization of operational efficiency and the reduction of unnecessary costs (i.e. waste) while maintaining or improving quality. As health-care organizations adopt this, significant pressures are placed on leaders to make difficult operational and budgetary decisions. In lieu of vast data, decision makers often base these decisions on subjective information. DES, a computerized method of imitating the operation of a real-world system (e.g. health-care delivery facility) over time, can provide decision makers with an evidence-based tool to develop and effective operational solutions prior to implementation.

Unproductive bottlenecks mainly arise in the logistic warehouses which are considered as the critical nodes in the supply chain. Simulation runs could suffice the need to understand those problems either at the design stage or during the operational stage (Ribino *et al.*, 2018). Unlike core manufacturing processes that have predefined parameters, supply chain activities and processes are random and cannot be measured with the same scale. Lean has not yet applied to supply chain and service areas on a larger scale. Integrating Lean methods and tools with a simulation-based technique to visualize different implications and insights are the need of the hour. Other modelling and simulation methods such as system dynamics, agent-based modelling and multi-method modelling can be used to integrate with VSM or with other Lean tools to get different results and implications. Lean supply chain and warehouse scenarios can also be explored with other techniques such as the Taguchi method, fuzzy logic and heuristic network optimization to optimize a supply chain and improve its efficiency.

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Appendix

S.no.	Process step (location)	Code
1	(Source block) – source truck count	new Truck(++trucksCount)
2	(Source output block) – controlling container output from truck	!restrictedAreaStart1.isBlocked()
3	(Split block) – split containers into batch	original.id==5?new Container(1):new Container(0)
4	(Seize block) – task priority to the agent	-agent.type
5	(Batch block) – before batch split up to Stations 1 and 2	new Pallet(s)
6	Release (pallet batch)	s= agent.type;
7	Service station (on exit)	timeOrderCheckingReceipt = time(); timeTotal = time();
8	Acquiring pallets from rack system	agent.node = palletRackMap.get(self.getPalletRack (row));
9	Zone 4 (QA/QC) delay	timeQaQc = time(); timeTotal = time();
10	Zone 4, Delay 2	if (wait2.size() == 10) wait2.freeAll();
11	Delay 3	if (wait3.size() == 10) wait3.freeAll();
12	Level 3 (on entry)	agent.visible = false;

13	On exit	agent.visible = true;
		timeTempStorage = time();
		timeTotal = time();

14	Sink 1	timeMoveFactory = time(); timeTotal = time();

15	Finished goods (sink)	finishedGoodsCount++;
		timeMoveFinishGoods = time();
		timeTotal = time();
		if (finishedGoodsCount == 24) finishSimulation();

16	Waiting zone 9 delay (on entry)	factoryInput++;
		if (factoryInput == 30) {
		wait5.freeAll();
		}
		if (factoryInput == 40) {
		wait6.freeAll();
		}

	On exit	allfactoryInput++;
		if (allfactoryInput == 50) {
		create_FactoryStart(factoryDelay, TimeUnits.HOUR);
		}

17	Service wait time (Travel to Zone 3_2)	if (wait4.size() == 30) wait4.freeAll();
18	Queue 12	if (queue12.size() == 30) hold.setBlocked(false);
19	Select Output 1 (receiving finished goods)	Condition30 > zone4Count On exit (true)zone4Count++;
20	Select output 3	On exit (true)zone46Count++; On exitenter.take(agent);
21	On entry	enter1.take(agent);
22	On exit	Enter2.take(agent);

Table A1.
Sequences and steps using Java codes

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