Understanding the IKEA Warehouse Processes and Modeling using Modular Petri Nets

Behfar Behzad, Maryam Farzad, Reggie Davidrajuh

Electrical Engineering & CS, University of Stavanger, Stavanger, Norway.
B.Behzad@stud.uis.no; M.Farzad@stud.uis.no; Reggie.Davidrajuh@uis.no

Abstract - **Nowadays, large warehouses handle a huge number of products. Handling the enormity and different types of (range) products also demand complex warehouse processes. In this paper, the IKEA warehouse in Stavanger, Norway, is taken as an example, which stores, manages, and sells ready-to-assemble furniture, kitchen appliances and home accessories. The focus of this paper is to understand the warehouse processes that make the warehouse popular with the customers. Petri net is used to model the processes, and by simulation, the effect of the processes are understood. This paper shows how the processes integrate the large range of products, customer service, and the supply chain. The logistics flow is represented with a modular Petri Net model using the tool known as the General-purpose Petri Net Simulator (GPenSim). The goal of this paper is also to determine and propose any changes for a more efficient warehouse performance.**

Keywords - Warehouse Processes, IKEA, Petri Net, GPenSIM.

I. INTRODUCTION

IKEA is a globally known Swedish company that currently is the world's largest home furnishings retailer. IKEA mainly focuses on offering a wide range of good quality, well designed and functional products that are not only affordable in comparison to other competitors but also has an attractive and creative blueprint. However, without having a proper and on-time distribution through the store, the reputation might get deteriorated and consequently customer dissatisfaction. The logistical and warehouse processes are the heart of the store as it is responsible for handling, off-loading and arranging the goods. The movement of products in the IKEA store must be as efficient as possible to maintain uninterrupted sales.

In this paper: Section-II starts with a short literature review of related works. Also given in this section is the warehouse and logistical processes involved in large warehouses. SectionIII develops a modular Petri Net model of the warehouse. Section-IV implements the model with GPenSIM, and a summary of the simulation results are also given.

II. WAREHOUSE PROCESSES

First, a short literature review of related works is given.

A. Related Works

For successful operation of a warehouse (e.g., IKEA), both the warehouse processes and logistics must work hand in hand. Warehouse processes and logistics are closely related, yet two different functions within the supply chain. A warehouse process is mainly about the storage of products within the storage area, whereas logistics is about transportation of products (e.g., to and from the warehouse). Formally, warehouse processes are defined as the core of the logistics of an enterprise that acts between the production and distribution activities [1], [2], [3]. Whereas, logistics is defined as the processes that involve the operations for inventory and transport of goods [4], [5].

A general literature review on warehouse performance is done by [6], [7], [8] discussing warehouse performance indicators such as time, quality, cost, and productivity. [9] studies the influence of warehouse processes on supply chain performance. This work especially focuses on software that can improve the efficiency of the processes. [10] discusses warehouse management system as an information system that is indispensable for efficient management of warehouse and logistics processes. This work considers the warehouse management system as a subset of logistics information systems.

There are not many works that are related to warehousing modeling and simulation. However, [11] resembles closely to this paper. The difference between [11] and this paper is the following: [11] focuses on the Petri net model and the warehouse processes are kept in the background (invisible), whereas this paper focuses on the warehouse processes. Also, the warehouse processes are studied by direct observations rather than based on the literature.

B. Warehouse Processes

Fig.1 shows a simplified warehouse processes. Large warehouses manage a sheer volume of goods every day. Taking IKEA-Stavanger as an example, the staff starts working at 6 A.M., and they have to finish all the tasks before 10 A.M. when the doors get opened, and customers start arriving. If any task remains unfinished by 10 A.M.,

the task will be postponed until next shift because the movement of goods by driving forklifts between the shelves can endanger customers.

Usually, IKEA retail shops also function as warehouses. In some cities like Stavanger, there is a separate and bigger warehouse near to the retail shop; the warehouse is only a two minute drive from the retail shop. The warehouse contains bulky items which are difficult for customers to load into
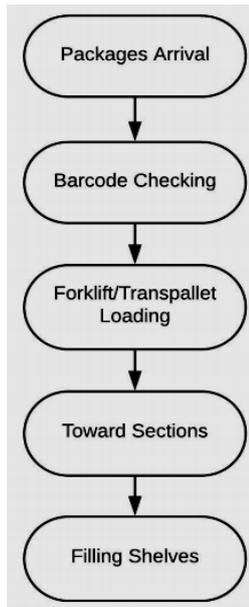
Fig. 1. The main warehouse processes.

their vehicle on their own. These two stores (retail shop and warehouse) have their logistics separately (in-store logistics and out-store logistics). In this paper, the focus is on instore logistics of the warehouse, which is connected to various sections of the retail shop.

The following subsections present some more detail into the processes.

1) Arrival of Pallets: Different means of transportation may have been used to bring products to a warehouse. For simplicity, let us assume that the products arrive at a warehouse in batches, products sealed and packaged in units of with different sizes, and transported by trucks. Each group of a product is located on a separate pallet for ease of unloading, offloading and moving. These pallets are then unloaded by forklifts to the entrance gate and set in a queue for barcode checking process. All the operations, including sorting, moving and locating the pallets must be completed by 10 A.M., the time the retail shop is opened. Hence, the delivery timing of the trucks needs to be arranged accordingly.

2) Checking of Barcode: After the sealed pallets are unloaded from the trucks, they are queued up at the entrance gate waiting to be registered and processed by the scanning

of the barcode on them. The barcode itself has all the information regarding the section, the row and the shelf they are going to be located.

3) Loading with Forklift: Right after the pallets are unloaded, and processed, registered, and validated by barcode scanning, they are ready to be transferred to their final position in the shelves. A forklift will be used to transport the products to the pre-defined location in the shelves. The shelves are grouped into three main sections:

• The stock section is where the extra products are kept in case of the need for replenishment in the marketing hall, where only one sample is kept.

• Order section is filled according to the customer's ordering. In this section, the products will be stored and kept for a maximum of one week, waiting for the customer to pick them.

• The marketing hall contains two floors. The first floor mostly includes kitchen appliances, home and bathroom utensil, and the smaller decoration items. The second floor generally contains bulky and heavy items like furniture, beds, oven and refrigerator, and other significantly large objects.

4) Transportation within the sections: Once the packages are settled into their corresponding sections, there will be three different paths between the sections. The inter-section transportation scheme is to transport products between the sections quickly. For shorter paths (e.g., between the order section and the other two sections), the transportation is done manually (e.g., with transpallet). Whereas, for a longer path (e.g., between the marketing hall and the stock section), transportation usually requires forklifts and drivers.

Two types of vehicle are used for transportation of pallets:

• Forklifts are driven and are used for heavy pallets, which are usually placed in the upper shelves.

• Transpallets are manually operated and are used for lighter and smaller pallets, which are placed in the lower shelves so that a customer could pick it and carried it away.

Fig.2 shows the two types of vehicles for the transportation of pallets.

Fig. 2. The two types of vehicles for the transportation of pallets: forklift and trans-pallet.

3.2

5) Filling the shelves: This operation is whether or not to unseal a product from its package. The products that are already reserved for (bought by) customers, they will not be unsealed. The products in the stock section: the products that are stored in the lower shelves will be unsealed, for the customers' viewing; The products that are placed in higher shelves need not unsealed. Fig.3 shows the shelves.

In the marketing hall, all the products will be unwrapped for attracting potential customers.

Fig. 3. The Shelves.

III. THE PETRI NET MODEL

The overall Petri net model of a warehouse consists of the following four modules:
1) Arrival module.
2) Stock module.
3) Order module.
4) Floors module.
Also, the modules use the following resources:
1) Staff.
2) Drivers.
3) Forklifts.
4) Transpallets.

The overall model of the warehouse is shown in Fig.4. The starting module of the model is the arrival of pallets by trucks.

The final module of the model is the securing of the products into the corresponding shelves.

In the following subsections, the four modules are described.

A. The Arrival Module

The Arrival module takes care of the processes dealing with the arrival of pallets and validation and determination of shelves by the barcode scanning. After Arrival module, pallets are separated into the three sections as described in the section II-B3 "Loading with Forklift".

The resources used in this module: Arrival module represents the entrance of the warehouse loading bay; The pallets are unloaded from the trucks and are queued at the entrance gate for the barcode checking.

In the Arrival module, 'tPalletGen' is the generator that creates tokens; the tokens represent the number of pallets in each truck. The role of the other places and transitions in the module:

- Transition 'tPalletGen': this transition generates the tokens (pallets).
- Place 'pQueueTruck': the pallets are queued in the place'pQueueTruck' waiting for unloading.
- Transition 'tTruckUnloading': this transition places the pallets in a queue 'pQueuePallet' waiting to be checked.
- Transition 'tBarcode': checks the pallets on a first-comefirst-serve basis. The validated pallets are placed in the place 'pValidate'.

B. The Stock Module

The stock module handles the following processes:
• A product that is already bought by a customer in the marketing hall; However, the product happens to be too big to be carried out by the customer.
• The product that is already bought is an "item on display" (only one sample in the marketing hall); thus, it can not be released to avoid the emptiness of shelves.
• Keeping extra products to replenish the marketing hall, upon requests from the staff at the marketing hall.

C. The Order Module

In the Order module, two scenarios can lead the movement of pallets toward the order section:
• Online-order: Sales order from the customers who have chosen an item and paid online and they want that item to be sent to the provided address.
• Make-to-order: The items that were not available yet can be paid in-person, and the order was sent to the manufacturer or supplier.

D. The Floor Module

The Floor module handles the process of filling the marketing hall, where customers spend time to find something suitable for them. Heavy, large, and spacious products are kept on the second floor. Whereas, smaller items, like kitchen appliances and decorative items, are stored on the first floor. After unwrapping, a tag will be attached to the products with related information about dimensions, material and price. If the item is unavailable to be picked up at the market hall, the bottom part of the tag informs where to pick up the item in the stock section, see Fig.5.

IV. IMPLEMENTING THE PETRI NET WITH GPENSIM

This section shows some implementation details.

A. GPenSIM

The Petri Net is shown in Fig. 4 is implemented with the software known as the General-purpose Petri Net Simulator (GPenSIM). GPenSIM is a new MATLAB tool that is known for its easiness in programming, and for its flexibility in modeling diverse discrete-event systems [12], [13]. GPenSIM can be freely downloaded from [14]. GPenSIM is developed by the third author of this paper.

In the literature, GPenSIM has been used for modeling and simulation of various discrete-event systems, e.g., automated manufacturing systems [15], flexible-manufacturing systems [16], repetitive manufacturing processes [17], traffic vehicles communication [18], and service-oriented architectures [19]. In this paper, GPenSIM is used for modeling warehouse processes.
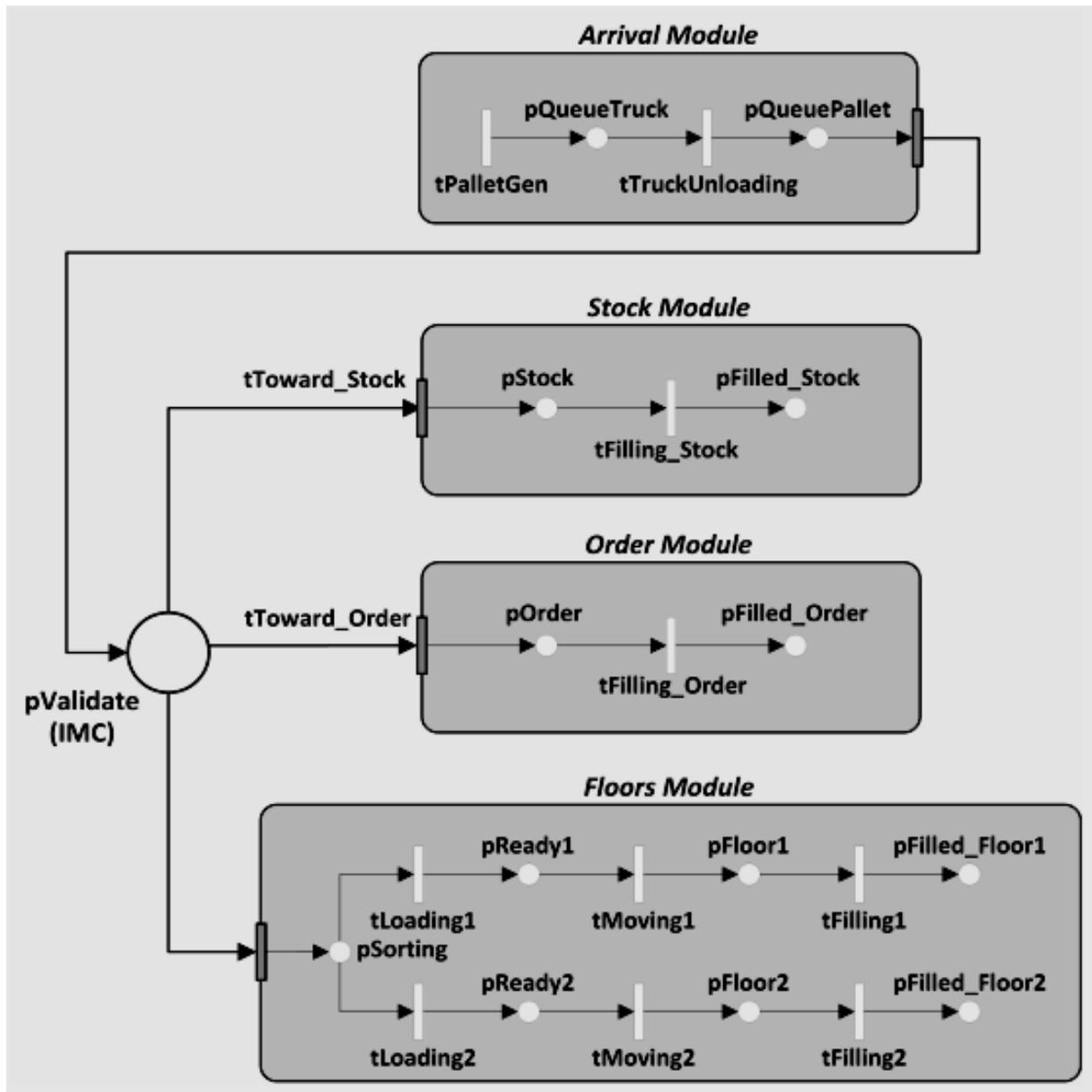
Fig. 4. The overall Petri Net model.
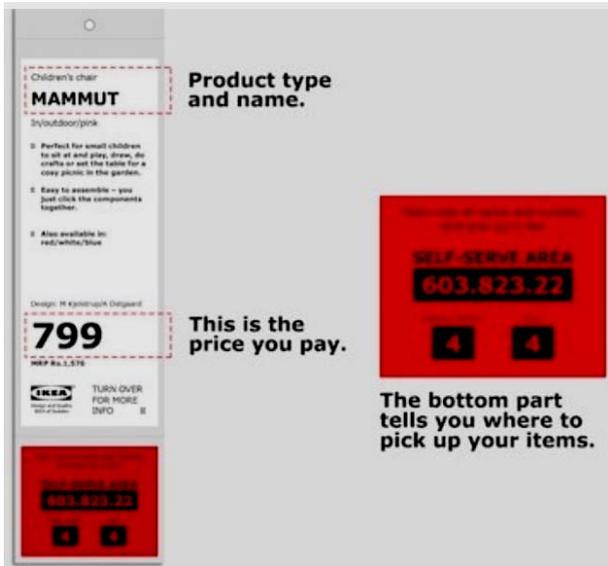
Fig. 5. The tags attached every product on the shelves.

B. GPenSIM Implementation of Modular Petri Net model

The Petri net model shown in Fig.4 adheres to the definitions for a new modular Petri net proposed in [20] and [21]. By the new modular Petri net, the modules have transitions as input and out interfaces (known as the Input and Output ports or "IO ports" in [20] and [21]). Also, the elements that do not belong to any modules are known as the inter-modular connectors or components ("IMC"). For example, in Fig.4, Order module has the transition tToward Order as the input port, and this module does not have any output port. Also, the lonely place pValidate functions as the IMC as it does not belong to any of the modules. pValidate performs an important function as it connects all the modules.

C. GPenSIM Implementation of the Petri Net model

The GPenSIM implementation of the Petri Net model shown in Fig.4 results in several GPenSIM Files:

1) Main Simulation File (MSF): The dynamic details (e.g. time taken by the different activities, available resources, and initial tokens) are coded in this file.
2) Arrival PDF, Order PDF, Stock PDF, and Floor PDF: The static details (places, transitions, and the arcs) of the four modules are coded in these files.
3) COMMON PRE: This is the common pre-processor file that defines the additional user-defined conditions individual transitions must satisfy before start firing.

4) COMMON POST: This is the common post-processor file that defines any post-firing actions that are to be performed after the firing of individual transitions.

For brevity, none of these files is shown in this paper. However, for reproducibility, the complete code is available on the website indicated in the reference as [22].

D. Data for Simulation

Some data is collected directly by the authors visiting the warehouse or obtained from the staff. The data is summarized in Tables-I to IV.

TABLE I. DATA FOR THE ARRIVAL MODULE

Variable	Data
Maximum number of pallets on weekdays	55-60
Number of pallets per truck	$(\mu = 8, \rho = 1)$
tTruckUnloading: unloading a truck	3-4 min.
tBarcode: barcode scanning	0.5-1 min.
Number of staff, drivers, forklifts, & transpallets	(2,1,1,0)

TABLE II. DATA FOR THE STOCK MODULE

Variable	Data
tTowards_Stock: moving pallets to Stock section	2-3 min.
tFilling_Stock: filling the shelves	3-4 min.
Number of staff, drivers, forklifts, & transpallets	(1,1,1,0)

TABLE III. DATA FOR THE ORDER MODULE

Variable	Data
tTowards_Order: moving pallets to Order section	3-4 min.
tFilling_Order: filling the shelves	1-1.5 min.
Number of staff, drivers, forklifts, & transpallets	(1,0,0,1)

The following two scenarios are analyzed:
• Scenario-1: Weekdays on which the load on the resources are normal.
• Scenario-2: Weekend (Saturday) on which the load on the resources are high.

E. Scenario-1: Weekdays

Table-V presents the available resources on the warehouse on weekdays.

TABLE IV. DATA FOR THE FLOORS MODULE

Variable	Data
tSorting: sorting earliest pallets to floor section	3-4 min.
tLoading1: loading pallets to 1st floor	1-1.5 min.
tMoving1: moving loaded pallets to 1st floor shelves	2-3 min.
tFilling1: filling 1st floor shelves with earliest pallets	2-3 min.
tLoading2: loading pallets to 2nd floor	1-1.5 min.
tMoving2: moving loaded pallets to 2nd floor shelves	4-5 min.
tFilling2: filling 2nd floor shelves with earliest pallets	3-4 min.
Number of staff,drivers,forklifts,& transpallets	(7,2,2,3)

TABLE V. AVAILABLE RESOURCES ON THE WAREHOUSE ON WEEKDAYS

Variable	Data
Number of pallets on a weekday	55 - 60
Number of pallets on each truck	$(\mu = 8, \rho = 1)$
Av. duration for unloading a truck	45 min.
Number of staff, drivers, forklifts, & transpallets	(9,6,9,4)

Simulation results show that the resources are much underused. However, there are still some pallets left unloaded and processed at 10:00 AM. Thus, this work has to be postponed to the next shift. This result shows that even if the resources are underused, delays in completion of the processes can be expected. In this case, increasing the resources will not do any good (will only increase the costs of operation), as the reason relies on the scheduling of the processes.

F. Scenario-2: Weekends

During weekends (Saturdays, as shops are closed on Sundays in Norway), the number of pallets normally increases by 40%. The Saturdays are considered the busiest day for business in the warehouse. Table-VI presents the available resources on the warehouse on Saturdays.

TABLE VI. AVAILABLE RESOURCES ON THE WAREHOUSE ON SATURDAYS

Variable	Data
Number of pallets on a weekday	70 - 75
Number of pallets on each truck	$(\mu = 8, \rho = 1)$
Av. duration for unloading a truck	45 min.
Number of staff,drivers,forklifts,& transpallets	(11,6,9,5)

G. Discussion and Results

Specifically, what problem are we trying to solve with the proposed model? In this paper, we are not trying to solve any specific problem. The paper is about creating a mathematical model from the direct observation made. The simulation results presented in this paper are simple as it comes from the rough Petri Net model. Later on, we are going to improve the model with the application of data science so that that different scenario can be made. Though warehousing and data science are used together for business intelligence, this is done by professional business packages (e.g., Oracle

NetSuite [23]), where the underlying mechanisms are not transparent to the user. We aim to go the fundamentals, by which both the mathematical model (Petri Net) and application of data science will be visible to the modeller. By combining the mathematical model as the lower layer and data science on the upper layer, different scenarios can be analyzed; this is the ultimate goal of the work initiated in this paper.

V. CONCLUSION

The mathematical model that is developed in this paper is with the help of a new modular Petri Net. The Petri net follows the flow on pallets, entering the warehouse at the loading bay, and leaving as products taken away by the customers. Also, the Petri net model is a modular Petri Net meaning it will be easy to integrate the module for warehouse with other modules, e.g., suppliers, manufacturers, and distributors. Thus, the modular Petri net enables modeling and performance analysis of virtual enterprising [24].

Timing and scheduling are core issues in warehouse processes. As resource constraints are a serious concern on the performance of a warehouse, the Petri net model is used to analyze how the resources (e.g., staff, drivers, forklifts, and transpallets) influence the timing involved in the flow of pallets and the corresponding tasks.

As in any observational study, some critical data might have been omitted in the model development. However, based on the input data, some of the simulation results gave unexpected results which indicated low resource usage. The simulations show that several forklifts (at least half of them) are not utilized. Further work: It is important to note that the seasonal effects are not included in this model. For example, the warehouse will receive a massive number of products and customers in the Christmas and New Year period. The model presented in this paper will not tolerate the seasonal effect; thus, the pressure on the resources and the performance (in timing) of the processes during this period cannot be measured with this model. Hence, as further work, an extension of this model is proposed that can cope with the seasonal effects.

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