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Warehouse in Today's Business and Benefits of Simulation in Warehousing

Tuyet Tran

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Jyväskylän ammattikorkeakoulu
JAMK University of Applied Sciences

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Lähdevaara, Hannu Ens

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Lähdevaara, Hannu Ens

Abstract

Warehousing is an indispensable part for most of business organizations, although its existence seems to be threaten by many modern business concepts. Instead of regarding warehousing as a redundant operation that cannot be eliminated, more effort should be put in adapting the warehouse-function to fit into organization's need, as well as improving its performance.

The objectives of the thesis are (a) to provide essential knowledge and useful remarks related to today's warehousing; and (b) to attest the significance of how simulation technology can be used to support improving the warehouse's performance.

The study of warehouse's topics was carried using desk research method. Information was collected from different authentic sources, subsequently, be evaluated and further explored. In term of simulation, a model used in support designing the optimal warehouse for an imaginary case would be constructed step-by-step. A computer-based software called Enterprise Dynamic 9 was employed as platform to build the simulation model.

As a result, the benefits, reliability and suitability of replicated model are clearly demonstrated. The generated reports from simulation runs provided appreciably useful information for the task of identifying problems associated with each activity within the warehouse. Naturally, the model can continue to be used as verifying tool along the amelioration process for the warehouse in illustrative case, e.g., to test any intended changing or solution in prior to implementation.

Keywords/tags (subjects)
warehouse management, optimal warehouse, simulation model, improve performance

Miscellaneous

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1 Introduction

1.1 Study Context

The today's business is getting obsessed with operational efficiency and resources utilization. Under that pressure, warehousing, along with other logistical segments, is forced to continuous improvement: lower operating cost, shorter lead time and higher reliability. Otherwise, it will inevitable becoming a target of elimination or at least minimization. To able to satisfy those expectations, managers not only be obligated to constantly update their warehousing-knowledges, but also need a computer-based application that can assist them in quickly determining optimal solution for each warehousing task, as well as easily coping with the rapid change of operational-related-factors.

For decades, scientific experts have regarded simulation technology as the most outstanding high-tech tool, a marvellous key for numerous “locked barriers” that arise during the operation in various fields; from health care, media, business, to military industry. Nonetheless, plenty aspects of simulation are not well understood by majority of regular businessmen: its efficiency is suspected, its cost is over-estimated, and its pathway from initial approach to final implementation is still a mysterious to many workers.

Consider the above indicated issues, in this thesis, the author intends to introduce and discuss about the usage of simulation in warehousing at entry-level. Such that readers with no-prior-knowledge of simulation can get to know about it. In addition, all the warehousing-related-concern will be studied meticulously: main factors that affect performance of each task; the importance of harmonious cooperation between different function areas; how and in which way operational efficiency of individual activity impact on the overall warehousing system; etc.

1.2 Study Goal

The thesis's prime objectives are to provide readers the most essential knowledges and useful remarks related to warehousing; and to attest the significance of how simulation can be used to support improving warehouse's performance. For a finer demonstration, a supportive model used in testing, correcting, and optimizing the operations within a warehouse will be built and analysed step-by-step. Certainly, the warehousing's key topics will be determined and presented. With the forthcoming provided information, the author expects this thesis to become a useful source for readers, who interest in the warehousing field; as well as workers, who are appeal to creating an optimal distribution centre or reconstructing the existing one for better productivity.

1.3 Study Method

1.3.1 Employed Methods

The study is conducted by using desk research (secondary research) and constructive method (design science research). The warehouse fundamental activities; their principles of operation; the contemporary standard of measurements; as well as other related matters will be collected from different authentic sources and subsequently be examined for further exploration.

In term of simulation, an illustrative model will be constructed, analysed and evaluated using associated or correlative mathematical concepts. In advance, the scientific bases of simulation will be presented to support readers in capturing the technology. Naturally, at the end, those kinds of certified knowledge will help proving the vital role of simulation in warehousing without losing any credibility.

1.3.2 Discussion of Methods

Desk research is a method for the insight study of a subject or field; carrying by access and evaluate the previous findings of other researchers (Travis 2016). The method allows one to rapidly approach a wide range of available information, freely comparing them before select the most significant, applicable and trustworthy disquisitions. Secondary research is the best choice when the field or scale of study is large, such that it is too time-consuming, difficult or costly to conduct the actual experiments to learn about the subject (i.e., primary research). Nonetheless, Prescott (2008) warning that the anterior research can be of low quality or outdated. Therefore, it is crucial to take necessary steps to appraise the reliability and validity of others' research-papers in prior to referring. (ibid.)

Design science research is a method used in designing and developing solutions for the target of improving performance of existing systems (Dreshch, Lacerda, & Antunes 2015, 56). Pasian (2015) claims that the method is about producing a system, which bottom of heart is basing on academic theories, to solve practical problems. Thereby, the study technique helps reduce significantly the gap between academic concepts and real-life practice. (ibid., 95-96.)

The most initial and fundamental requirement for one to successfully carrying a constructive research is must fully comprehend the situation of problems, as well as the set of pertinent theoretical bases that contribute to build the solution. In general, design science research obeying the abductive logic of reasoning that involving both inductive and deductive argumentations. While deductive logic is employed as academic theories being applied to a circumstantial event or process; stating the general conclusion about applicability of results from examined situations requires the use of inductive logic. (ibid., 97-98.)

2 Warehouse In General

2.1 The Importance of Warehouse

Although warehouse often being under-evaluated as just a place to storing goods and its existence seems to be threaten by many modern business concepts, such as integrated strategy, just-in-time technique or lean method. Frazelle (2002, 9) stated that the supply chain collaboration, from initial manufacturing point to final consuming mark, will never reach the optimum level, where the usage of warehousing be entirely terminated. As a matter of fact, warehousing provides a back-up solution to deal with unexpected problems arise in the business world that full of errors: human mistakes, machinery faults, as well as natural disasters. For instance, the stocked materials can serve as quickly compensation for unusual shortage occur along the production lines.

Based on its functions or purposes, Frazelle (2002) classified warehousing into 7 categories:

- Raw material and component inventory: materials be forth-prepared for future requests from manufacturing or assembling chains.
- Work-in-process warehouse: temporary accommodate unfinished products when they are waiting for their turn of transferring to different stages.
- Finished-goods repository: is aimed to cover for any potential shortages or resolve contradictions between customer demand and production schedule.
- Distribution centre: is place where products from associated sources passed by, optionally be split or mixed before shipping to customers.
- Fulfilment centre: provides dispensation service to individual customers with smaller orders.
- Local warehouse: insures quickly-response to clients' desire, as responsible area is more concentrated.
- Value-added service warehouse: is where products having customized packaging or being appended with extra details, such as label, trade mark, price tag. Usually, reversed orders are also processed here. (ibid., 9-10.)

These branches connect closely with one another and form a full-set of warehousing network, which is illustrated in the figure below:

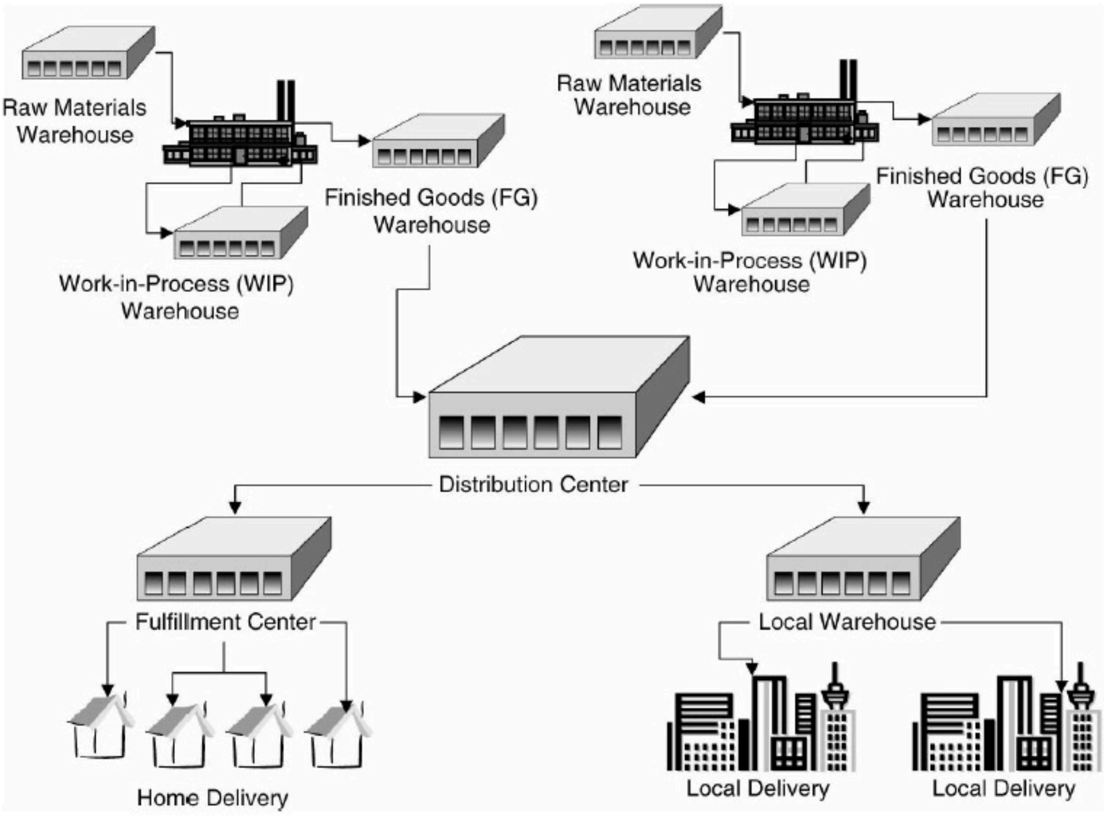


Figure 1. Warehouse types and their connection (adapted from Frazelle 2002, 10)

Comprehensibly, in extensive scale, warehousing benefits the organization by various means. For example, the stocking of materials (products) from mass or seasonal purchasing (manufacturing) can support obtaining the economies of scale. With the similar manner, the employing of local storage and value-added warehouse can respectively help reduce the processing time and improve the customer-service-quality. Besides, on some occasion, food and beverage productions require to hold unfinished goods at fermentation stage in necessary amount of time; this make inventory be one of the compulsory steps. And assuredly, there are many more utilities to name.

2.2 Warehouse's Activities

Despite of being regarded as one of the most complex working environments that includes multifarious constituent functions, warehousing operation complies with a certain set of logical principles. In most cases, tasks must be arranged in a tree pattern and the failure of any activity will undoubtedly affect the others, through direct or indirect manner. Therefore, it is crucial to have a good operational plan, which will help minimize the number of errors, or at least prevent mistakes from further expanding (e.g., by earlier detection). The following text will present the warehouse's activities in corresponding with normal movement of goods within a distribution centre; so that readers can easily perceive their connection as well as their individual contribution.

2.2.1 Receiving and Unloading

Prior to the arriving of any truck at inbound area, the associated carrier must book a schedule and inform warehouse manager about all information related to the shipment. Base on the value, property, and handling unit of goods, the manager will determine an appropriate inspection procedure, unloading method, time required for the job. And assign a place for it in a suitable dock that responsible by certain number of operators, with specific types of forklift vehicle and equipment. For examples, goods of high value will be allocated to the most secured spot; easy damaged products should be inspected thoroughly; dedicated forklift truck and extra equipment often used to support the unloading of heavy or palletized commodity; and so on.

Once the time is set, it is essential to assure that truck drivers stick tight to the timetable and reach the station on time, because the number of docks at each warehouse is limited and they usually in reserved state. Furthermore, the handling tasks must be designed so that it will flow as smooth as possible.

In general, the work of inbound team includes: comparing the quality and quantity of arriving items against information indicated in purchase orders; unloading; and tagging goods by proper unit (if applicable). Also at this point, the team leader addresses all related matters, such as damaged or missing of products, incautious covering methods, late delivery time, along with any other discovered issues; and have it verified by the carrier men. Once the receiving process finished and shipping document collected, an operator is assigned to register all involved data to the company internal information system; so that, other concerned departments (e.g., purchasing, finance or production) be immediately informed about the arriving shipments as well as any arise problems.

2.2.2 Cross-docking

In warehousing context, the term cross-docking refers to the process of directly pushing commodity from inbound entrance to outbound area; where it optional be breaking into smaller pieces, combining with other types of product, consolidating and labelling before being shipped away. As this practice rarely involves the inspection procedure, subjected goods must be originated from trustworthy sources. According to DelBovo (2011), it is favourable applied to low-touch, durable goods with high-volume and restricted number of stock-keeping-units (SKUs), nevertheless, perishable or conditional controlled products are having more and more demand on this method.

It is easy to recognize that cross-docking brings many benefits to the operation of logistics: shorten order's lead time, eliminate inventory cost, reduce transportation cost as well as labour cost through integration and better resource utilization. Yet, it is quite challenging to have the concept set up and operate efficiently. Regarding to the planning phase, DelBovo (2011) have listed 2 main concerns: designing the facility, so that there is enough reserved space for the movement of goods and handling equipment; and establishing a competent metrical-base for the merchandise-selection, since only several ranks of product are economically fit with "crossing" function. Usually, because the cross-docking area has no "back-up" space for shipments to linger around; it is necessary to obtain an effective communication system between distribution centre and customer, carrier, as well as supplier, to secure that materials will arrive and shipping trucks will be ready at the right place, in the right time, with the right amount and category.

2.2.3 Put-away

Shipment that not planned for cross-docking, after undergoing the receiving process, is suggested by Vitasek (2007) to be put-away to its stored-place on the same day, otherwise, it can lead to space congestion, product damaging, as well as hindering the flow of subsequent processes. Sunol (2017) described its main objective as a process of translocating goods to the most optimum storage spot, and listed in detail its core responsibilities:

- Maximizing the space utilization. Start from collecting the consistent and accurate data of products; which include the type, size, height, weight, and their receiving-shipping frequency with associated volume. It is recommended to automate as much as possible the gathering work, so that the collected information is reliable for later analysing and decision making.

- Quickly and efficiently in storing goods. This should be guaranteed by a well-prepared and focusing-on-details plan, with a closely-monitored implementation stage.

- Stocking products are easy to track, find and retrieve. The favourable way is mixing the use of fixed and dynamic locating. When the first method help speed-up the process as operators memorize position of items; the latter one offer flexibility, especially an advantage in handling seasonal products.

- Minimizing the overall travel distance by 2 means. The first approach is determining the shortest pathway of products from inbound area to their assigned place; as well as optimize the allocation of each product type, based on its order frequency and volume, so that the total movement within the warehouse is as smallest. The second one is eliminate the unnecessary-moving through fully monitoring the availability and capacity of warehouse space. This can be obtained by using radio-frequency-identification (RFID) for the automatic recording and real-time dissemination of space's usage status. Or, by using barcode scanner and bin location to control the condition of every individual spot, nonetheless, the efficiency is heavy rely on the cautious of scanning-man.

- Securing the safety of goods as well as warehouse operators. This can be attained through the maintaining of logical-organized and clean warehouse. (ibid.)

The put-away process that fulfil above qualities will not only result in better profit but also happier employees. Without a doubt, a worker who must going around and around looking for the right item to pick, will easier feel frustrated than the one, that can comfortably collect items and finish many orders in the same amount of time.

2.2.4 Picking

Picking is the stage in which goods of proper amount are pull out from its inventory area to fit into different orders, it is the most labour-consumed process and approximately account for 55% of total warehousing cost (Murray 2017a). To explain for this high-attention-requirement of picking activity and compare to the processing of inbound orders, which are usually arrive in bulk quantity; Piasecki (n.d.) claims that it is the natural of distribution structure to have greater amount of outward transactions with smaller and larger number of items to handle; furthermore, the outcome of picking function is significant as it directly linked to customer satisfaction result.

There are many modern technologies available for the paperless order-fulfilment processes, that greatly assist in achieving a more accurate and higher productivity of performance. In which, light-directed picking, voice-directed picking, radio frequency (RF) mobile picking and augmented reality (AR) picking are the most popular and widest applied technologies in contemporary warehousing environments.

In basic pick-to-light system, a light panel is attached in each of the storage bin or rack. When the items belonging to a specific container involved in an order, connected light will be illuminated, with the necessary picking quantity displayed. The operator responsible for that order just simply pick the exact number of items and press confirm button on the panel. Once the light is no longer brighten up, it means that the picking is done with that bin, operator can move to the other ones and doing similar tasks until the order is fulfilled. Using clients reported that this technology help increases the picking velocity to 10 times greater than the tradition paper-based. Moreover, it supports best in international warehousing as well as seasonal-employing-company, since no verbal communication is required during the picking process and workers also can easily manipulate the device without much of training. (Murray 2016a.)

However, for the technique to fully be effective, warehouse building must have enough contrast light and harmonic visibility. And, each storing region may need the minimum of one on-duty-operator being ready for any upcoming signal. The last but not the least, physical installation of light panel around repository can be costly.

The pick-to-voice technology was initially adapted for non-barcoded products, through its speech recognition and synthesis program, warehouse workers can use a headset to interact with warehouse management system (WMS). In general, operators pick the requested items according to voicing command, then report back for verification before continuing with the next instructions. Yet, extra repetitions of command may sometimes be required. This regulation helps reduce from 80 to 90 percent of the ordinary picking errors. Besides, it allows workers to operate freely in different area without much of concern about other vision signs or carrying additional handheld device. (Murray 2017b.)

With RF mobile picking, every scanning action is automatic recorded, enables managing database to capture immediately all information related to products, such as remaining quantity, current location or transfer-status of each individual item. This not only help pushing employees to being more attentive and responsible with their work, but also make it easier for later inventory analysis tasks. (Melendez 2013.)

According to Kennedy (2017), the technology is widely supported by many WMSs and applied well in all kinds of warehousing forms, especially in bigger and more complex system. Nevertheless, maintenance and replacement cost for the equipment can be high due to the reckless in using of employees. It also requires more intensive training for operators to be able to handle the device properly.

AR picking system assist warehouse labours to operate faster and more efficient in various means. Firstly, it displays picking list to workers via the visual field. Next, as a product is picked, an optical reader is used to scan the associated barcode-tag for verification. In the subsequent paces, it guides operators to another most rational picking place and regenerate the same preceding pattern. In addition, because all observable scenes ahead the AR-technology-equipped-employees is captured and saved automatically, it is extreme convenient for any later investigation, either regarding to safety incidents or erroneous shipments. Furthermore, workers can simply show the video of when they encounter trouble or difficulty to ask for help as well as more advanced training from their supervisor. (Montgomery 2016.)

Eventually, AR picking can be regarded as the refined combination of the 3 previous discussed technologies. It inherited most of the strengths and eliminates much of the drawbacks. The little remaining downside is the strictly requirement of visible enough working space.

The ultimate objective of picking function is to complete as much as possible the number of accurate and on-time orders, while ensure the conditions of goods are preserved. Therefore, selecting an appropriate picking method for each type of warehouse is quite critical and challenge. According to Piasecki (n.d.), the affecting factors include: properties of products, number of picks per order, number of items in each pick as well as the total amount of transactions and SKUs.

Often, the picking work is divided into different classes, based mainly on the scale of orders and on integrating level in each pick. With respect to the first criteria, there are 3 groups, name as piece, case and full-pallet picking. In term of the latter standard, picking is binding with 4 methods, which are wave, zone, batch and basic order picking. Piasecki (n.d.) have done a good job on clarifying these categories:

- Piece (broken-case) picking is typical apply for system that possess large number of SKUs with short cycle time, where only small amount of goods being picked at a time. Postal office and spare parts provider are mainly employing this kind of operation.
- Case picking should fit distribution firm with fewer sum of SKUs and higher number of picked items per SKU, compare to the broken-case picking. This mean that the products are having more consistent features.
- Full-pallet (unit-load) picking is the most convenient and simple picking form, where one or several pallets of the same commodity are picked at a time.
- Basic order picking operates so that every individual order is processed separately. It is essential to design a good picking flow, because normally with each order, there is only one responsible operator, who will pick step-by-step all the required items until the order is fulfilled. Besides, bigger and heavier products

or fast-consumed-merchandises are recommended to allocated close to depart area and main aisles.

The size and weight of goods are prime factors that affect the selection on handling-equipment, such as picking cart, pallet jack, turret truck, forklift vehicles; and decision on their storage area, whether they should be placed on static shelf, pallet rack or on the floor. From the executional principle, can deduce that this method works best with small number of orders, which require a great number of picking times. If apply for system having large number of transactions or taking lesser picks in each order, it may result in process congestion and excessive traveling.

- Batch picking allows various orders being integrated and picked together in one trip, meanwhile orders are separated by using different bags or boxes within the picking cart. A typical batch size varies between 4 to 12 orders (which having some proportion of same items). This picking strategy helps reduce significantly the overall movement since same products are picked at a time. However, the detaining of orders to accumulate enough quota for one batch may over-prolong the shipping time.
- In zone picking, storage area is split into several sections. And each one will be responsible by a proper number of workers, such that the flow of picking carts from one zone to another is constantly maintained. Different material-handling technologies may be installed for specific zones based on their distinct characteristics of containing products. Systematically, operators in each zone after picking all the required items within that region will pass the container to others involved zone using conveyor belts. This make the method become the most favoured in dispensation services with high number of SKUs and large number of low-pick orders.
- Wave picking is the mixed method of batch and zone picking. All items from different zones are simultaneously picked and congregated at outbound area, where they are sorted into separate shipments. This practice is suitable for sys-

tem with large number of SKUs when orders comprise of medium to high picking-pieces. But be aware that, although the method helps shorting substantially the overall picking time, it puts greater of work on consolidating and sorting activities. (ibid.)

Each of the above picking system has its own advantages and disadvantages for certain type of goods; imposing a different range of costs in variety of scope, include purchasing, installation, operation and maintenance expenses. The only common tip that being shared is place the frequently handled and massive products close to main aisles and staging area. Therefore, it is worth to be cautious and wise-considered when select the picking methods, handling equipment as well as supporting technologies for each storage region.

2.2.5 Sortation

Sortation is important function for both inbound-process, when commodities be directed to proper storage places, and outgoing-operation that arranging items for different orders. According to Castaldi (2016), there is a wide variety of sorters that can be used to orient goods to appropriate tracks for further processing. Depending on the products’ type, size, shape, weight, as well as handling speed and method, noise allowance and limitation of spendable energy; one can select the suitable sorters from many available options, which include different types of belt, conveyor, pouch, arm, paddle, and so on. (ibid.)

An effective management in sortation is unquestionably improve the fulfilment accuracy, bring time and cost saving, offer parcel traceability and visibility. And can be obtained by the help of technology, for example, in measuring dimensional information of packages, reading and tagging labels, verifying and monitoring the movement of merchandises, etc. (Martins 2017.)

Some examples of being used sortation systems introduced by Castaldi (2016) are described in the following text:

- Tilted-tray sorters: Items manually or automatically enter enclosed conveyor on trays. As soon as tray arrives at the destination, its hinged doors opened so that containing parcels be released and glided to the next processing stage. For the better productivity, trays are placed horizontally against the induction area and then be tilted for later sortation. This configuration is suited for orders with distinctive units of large volume.

- Pouch sorters: Goods of various sizes and weights be hanging on separate pouches that moving on the rollers with possible-maximum-velocity of 10,000 pouches per hour. Attaching items to pouches can be done manually or automatically. Each pouch is identified by its unique barcode or RFID tag, allowing the single-control on each individual item; consequently, make it feasible to prioritize products or activities.

- “Sliding shoe” sorters: The system is applicable for a wide range of goods, regardless of size, shape, weight; and especially designed for fragile products. It gently and smoothly transferring packages in rapid speed, about more than 10,000 parcels per hour. When item arriving at its assigned spot, the associated “sliding shoe” activated to free it from the carrying chain.

- Paddle sorters: These devices are installed on sortation belts to navigate commodities onto powered or non-powered conveying lanes. It perfectly fits to fast operational model that process a large diversity of products with individual weight up to 75 pounds. When collaborating with 450-feets-per-minute-conveyor, it can attain the maximum sortation speed of 60-cartons-per-minute.

- Pusher sorters: This appliance is set up and works similar as paddle sorters, except it only divert products in perpendicular angle. The operational velocity is also lower, can handle up to 40 cartons per minute when be used in conjunction with 250-feets-per-minute-conveyor. As expected, it is suited for warehouse with limited linear space and requires the performance speed of medium rate.

- Cross belt sorters: Processing goods are contained in separate belted trays. Their induction or removal only initiate when the transferring chain being stopped. This help increase the accuracy in product’s navigation and monitoring, making the system perfect for small, fragile or high friction items. Moreover, it is designed to be able to perform rapidly the transportation task.

- Narrow belt sorters: Merchandises are conveyed by various narrow belts and diverted perpendicularly to either sides of the sorters, when the high friction rollers that attached between belts popping up. This type of mechanism is created for high-throughput-warehouse of small to medium sized packages, with restricted operational space.

- Pop-up wheel sorters: The powered pop-up wheels are in advance being installed on the bottommost of conveyor chains. When products arrive at their destination, these wheels are raised up and having physical contact with the basal surface of the containers, forcing them to get off from the chains. Although the technology is quite old and slow, it is employed due to the low expense. Its highest productivity is around 130 cases per minute. (ibid.)

Regardless of the choice on sortation model, Rogers (2011) noticed that the sorters must contains barcode scanners or sensors, which will detect the presence of packages on each stage, and transfer that information to the warehouse control system. In addition, connected monitor program should have a prior-design on how, when and where the flowing-goods be diverted within the conveyor networks. (ibid.)

2.2.6 Packaging

While the imposing of wrappers on goods at manufacturing factory is meant to attract customers’ attention and always be carried following a specific decorative design; the packaging for products that about to enter or in between distribution points is aimed to protect them from damage during the transference. The merchandises can be covered in separated or consolidated manner, with layer dimension increasing from small package or medium case to large cardboard box and entire pallet, depending on the size of each individual item.

The overlaying form and material must be carefully determined so that it can defend products from environmental hazards, such as harmful temperature, waterlog, contamination or static friction, whilst neither expands much in weight nor proportion. For example, paperboard, aluminium and plastic are popularly used materials because of their lightweight and recyclable features. In addition, since pallets and vehicle-containers have fixed dimensions, maximize the utilization of their holding capacity requires the compatible in sizing of smaller parcel, case and box. (Murray 2016b.)

Just as other normal operations, packaging also demand certain level of technological support to perform faster and better, thereby can satisfy the required quality and efficiency. Hobkirk (2016) categorizes the function into 4 scales of automatic implementations, name as manual, specialized, semi-automated and fully automated packaging. The first executional manner expects workers to have a great spread in ability, can handle all involved steps throughout the packaging process. Include skilful-desired tasks such as carton erection, dunnage and sealing, order checking, manifesting and label tagging. This inevitable lead to the inefficient performance. Furthermore, the method requires the purchasing and maintaining of a huge bunch of supportive equipment, from weighting scale, label printer, barcode scanner to dunnage machine, sealing device, etc. (ibid.)

Specialized packaging is a-bit-upgraded version of the manual one, it gains a better productivity, because workers are designated to different roles based on their special skills. In semi-automated packaging, some of the tedious repetitive functions are arranged to be handled by machines, for instances, label tagging and carton erection. On the other hand, some of processes are prepared beforehand or integrated into other functions for the smoother flow of parcels. For example, appropriate holding boxes are made to be ready for the accommodating of items right in the picking stage. Finally, in the most modernized packaging system, all pieces of work are carried out automatically using a series of equipment that wisely connected with one another. (ibid.)

2.2.7 Loading and Shipping

Similar with the precise requirement on running schedule at inbound ports, outbound docks should only able to serve trucks that arrive on time. By that way, shipments-backlog, which is especially troublesome for warehouse with limited space, can be avoided. Therefore, it is extremely crucial to determine a proper and reliable carrier-partners for each type of delivery operation.

In most cases, cost, quality and time are the dominant influences; these factors always come as a set. Higher cost-charging carriers normally provide faster services with better quality and vice versa. Besides, as each transport agency has its own business area, offers different kinds of service and capacity; multiple-operations warehousing firm may result in cooperating with various carriers. The other important elements must be taken into consideration are the reliability, stability and sustainability of the haulage company.

In addition to select the right partners to collaborate, for the success of outbound function, loading process should be welly arranged so that it operates as efficient as possible. Stone (2017) suggested to use telescopic conveyor to move products from storage place, all the way to truck-container. Then, an in-charged warehouse operator just stays inside the trailer and finish the loading work right there. With this system, not only performance be significantly improved, but major number of labours and forklifts needed for the final handling stage of goods to lorries also be eliminated. (ibid.)

For the same concern, Woollard (2015) propose to install dock bumpers to help drivers easier parking truck in reverse manner; and to place the lights along wayside as well as docks to make the pathway clearer. He also introduces the new docking technology, which dimension can be retracting and extending to fit different size of transport vehicles. Thereby, terminating the need of diversity, consequently reducing the quantity of required ports.

Above of all other matters, safety is the biggest problem in loading activity. About 25% of warehouse accident happen here; it can be forklift collision, load falling, trailer slipping and so on. These misadventures can be prevented or reduced by employing several solutions. The most essential one is applying motion-based warning system with supporting cameras, flashing lights or audible alerts to help and guide workers along the process. The second advice is designing an ergonomic working layout that has minimum number of bending corner and reaching point, since accidents usually took place at these spots. The next recommendation is having pallets undergo stretch-wrapping stage to increase their stability and security. This process substantially protects products from damage; yet, it is suggested to carried out automatically or at least in semi-automatic manner, because of its labour-intensity requirement. In addition, be sure to place goods or pallet firmly on forklift vehicle and secure truck-container to a fixed position during the operation. Finally, seal the door and using folding gates to restrict access, this is especially important in extreme-temperature-days. Meanwhile, utilize high-volume-low-speed fans and ventilation panels to get rid of engine's exhaust fumes and purify the area's atmosphere. (Stone 2017.)

2.2.8 Cycle Counting

Cycle counting is an inventory management technique, using when a certain proportion of items in storage is counted, and that result will represent for the accurate-level of entire warehouse, both in qualitative and quantitative mean. There are 2 inferences must be clarified and agreed upon the execution. The primary one is taking the item accuracy in cycle count and use it as the whole inventory's accuracy. The second inference is accepting that: other items in the warehouse may have the same error with the one that is found during cycle count performance.

Murray (2017c) introduced 3 associated methods of cycle counting, as described in the following text:

- Control group count: used when start implementing cycle counting for the first time, to test whether the technique is effective. The method focuses and repeats the counting on a small group of goods at each short-period of time, by that, errors are easier detected and fixed. The process is done once its accuracy and efficiency is assuredly confirmed.
- Random sample count: suitable for warehouse with large storage of similar products. At every short-duration of time, such as daily basis, items are selected randomly for counting. This approach guarantees that large proportion of goods are counted in acceptable interval. The contingent selection that subjected to all contemporary holding items is called constant-population-count.

While diminished-population-count excludes already-counted items from random sampling.

- ABC count: based on Pareto principle, which state that for most of events, 80% of problem is caused by 20% of the group's member. Prior to the counting performance, every item in warehouse is categorized as A, B or C. The entire inventory be divided to 20%, 30% and 50% segments; these group respectively account for 80%, 15%, 5% of the total sales, named as A, B and C class. At the next step, the counting frequency for each category is determined. Naturally, A items should be checked and counted more often than the B and C ones. Yet, this can lead to inaccuracy-storage-control for C items, since they may not be checked in enough-regular. The other issue may arise at warehouse with large number of SKUs, where goods being assigned for the count in many times and there are not enough human-resources available to complete the work. (ibid.)

According to Fain (2014), cycle counting bring many benefits to warehouse management. While the traditional inventory counting often require the entire warehouse operation to stop during its processing, as a result, causing major disruptions to the system; the cycle counting technique executed in partial basis and allow other areas to continue with their activities. In addition, the ongoing-cycle-count help forcing workers to continuously assess the inventory. Thereby, increasing the chance to detect errors before they bring too much troubles. The checking in smaller segment at a time not only reducing work stress for operators, but also support them to be able to focus on each inventory subset; and consequently, create better reports for buyer-group. (ibid.)

With similar opinion, Gray (n.d.) believes that cycle counting technique can generate a more accurate and updated inventory data. This helps reduce stock-out situations, even when lower level of safety stock being used. Furthermore, as the current locations of holding items be closely managed, it took smaller amount of time for operator to find and pick the requested items; by that, reducing the shipping lead time and cost. (ibid.)

2.2.9 Replenishment

Replenishment is all about the act of timing and balancing. While carrying an excessive amount of stock would negatively affect the profitability and finance-ability of company; a shortage in reserving goods can lead to sales drop and customers-dissatisfying. These 2 inversing issues make replenishment being one of the most crucial activity in warehousing.

The responsible manager for restocking-operation must deeply comprehend and closely capture the life cycle of each individual product within the warehouse. And thereby, determine the optimum amount of goods to purchase for the re-fulfilment in the right time. So that, new order only arrives after old stock have been used up, considered all potential hindrances along the supply chain. Typically, manager is advised to utilize historical data as well as conducting appropriate classification method, such as ABC analysis to prioritize items and decide the suitable order quantities. In addition, as suppliers often provide different kinds of discount base on the purchasing volume, replenishment manager need to be conscious to balance between these offers, associated costs and actual demand to obtain the most benefit.

According to Curley (2017), there are 3 replenishment tactics that can be used, depending on the nature of each specific warehousing system, concerning its staffing and spacing scale as well as operating principle. Firstly, designed for warehouse where first-in-first-out rotation is necessary and the usage of repository must be optimized due to the limited of space, on-demand replenishment operated so that product only be acquired or transferred to a specific location at around the time it is needed. With the opposite strategy, top-off method is created to help maximize utility during potential downtimes. Generally, there will be a replenishment-team working around the warehouse to ensure that inventory goods are always maintained at certain quantitative levels. With the similar manner, routine replenishment also pulled by order. Such that, the minimum thresholds, which act as the trigger for refill-function is carefully determined in prior to the implementation. Nonetheless, both the top-off and routine tactics may only be used in warehouse of large space. (ibid.)

2.2.10 Quality Conservation and Loss Prevention

Inventory's value can account for a large proportion of company's asset. Therefore, figuring out a proper securing procedure to protect storage-goods from theft as well as maintain its original quality is highly important. In most cases, the inventory loss is found out as warehouse staffs carry the physical counting, and realize differences when comparing the result with information recorded in managing database. The atrophy of quality, on the other hand, detected after raw materials have been delivered to designated manufacturing plants, and not qualified enough to be further processed. Or, when customers claim for the return because of the poor quality of receiving products. Exceptionally, defected goods can be recognized at earlier stage if warehouse operators properly check them in prior to the shipping.

Marfo (n.d.) believes the stock-shrinkage can be resulted from single or combination of several factors; includes internal and external burglary, stock misplacing, error in product shipping and receiving, etc. The suggested solution is installing surveillance cameras around the warehouse, and hiring security service if thievery frequently occurred in the area. In addition, entrust only a certain number of employees for the tasks related to shipments' verification. These workers not only responsible for the receiving, inspecting and monitoring the movement of goods, but also taking care of involved documents, receipts and invoices; ensure that all the files are properly updated and saved to company's managing database. Besides, each employee should be provided with a unique login-account for the electronic register of processed transactions or work history. Thereafter, it is easier to identify the operator, who causing trouble, and whether the mistake is made intentionally or accidentally. (ibid.)

Carrying necessary background check on physical and mental health as well as criminal record of candidates in recruiting phase is greatly recommended. The last but not the least, limit the access of staffs into areas, where goods of high value are stored. By this way, the stealing attempt of employees may be terminated right in the first place.

In term of quality control, a specialized expert should be hired to establish proper processes used in transferring materials within the warehouse. Afterward, communicate those procedures to workers and train them to handle goods with care. Furthermore, as each inventory item often demand certain different storing-conditions, be assure that products are placed in the right room, where their requirements fully provided.

2.2.11 Handling Returns

From client's point of view, a company with good after-sale-support must able to offer its customers the simple and rapid returning service of high equality. To reach that level, the foremost important task for the firms to care is develop and clearly publish their returning policies, based on the nature of their business and characteristics of trading products. In case of commercial deals between businesses, all issues related to transactions, such as when and how shipments be rejected for refund or alternative exchange, must be discussed, agreed upon and plainly stated in contracts. Once the policy is established, a manager should be assigned to monitor the returning-related-activities, which include granting permission; routing the flow of involved shipment; determining what process should it undertake afterward; calculating the incurred costs; and finally inform to all concerned departments about the return.

For the convenience of clients, orders are suggested to delivered with detailed instruction of how they can be returned, if fail to meet customers' expectation. It is popular that the postal address where returned-parcels should head to, along with other necessary labels and documents, also be attached. Obviously, customers are required to submit their returning-request via a web-based form, email or phone-call; and only send the packages after receiving approvals. Since the applications are collected and handled in paperless manner, the processing time is considerable shortened. This not only help gratify customers, but also maintain as much as possible the value of returned-goods, as they sooner be fixed or sent back to original sources.

The most crucial concern in this warehousing stage is meticulously evaluating returning-claims with an objective attitude, so that customers feel content even when their request is rejected. Although the decision must be made follow the firm's published policy, some extent of flexibility is also recommended. On the other hand, all information regarding to the returns should be integrated and stored in company's internal system. By that way, employees from related departments will be notified to track the arising issues down at ahead of time and correct them right away. For example, material purchaser, production engineer and inventory controller are obliged to find if there is any hidden problem in their work, when products are claimed of poor quality. Or, accountants must modify and update their financial reports when products be returned for the refund.

2.3 Warehouse Performance Measurement

To efficiently managing the operation of any business-activity, one must first start with the performance measurement. With a closely monitoring based on the list of established key-performance-indicators (KPIs), manager can know whether a task is properly executed, or be alerted as soon as problem arise in any work-chain. Particularly in the warehousing field, Frazelle (2002, 55) suggests that an organization should compare its own warehouse performance measurements with the third-party providers. Then, if applicable, execute necessary improvement or even reconsider the option of outsource. (ibid.)

Normally, beside from the total-operational-assessment of the whole warehouse, its belonging dominant functions also be evaluated in detail to gain better observation and control. Frazelle (2002) classified the measurements into 5 key-groups:

- Financial: The incurred cost for each activity is estimated, the cost-list will then be regarded as a basis for later budgeting, service pricing or compare warehousing proposals from third-party companies.

- Productivity: The most tradition and desired performance measurement is productivity, which is defined as ratio of the output to required input to obtain that outcome. For example, labour-productivity is equal to the units, orders, lines or weights of shipped-out-commercial divided by number of hours that operators spent for the tasks.

- Utilization: To avoid misleading, productivity-assessment is recommended to carry in conjunction with utilization-measurement; and involve several belonging-key-assets, such as labour, space, material handling system and warehouse management system. It is not usual but sometimes, a too high of utilization-indicator can be a bad sign. For instance, a high value of storage density, which is calculated as the amount of holding-inventory divided by the square footage of warehouse space, may signify the status of overcrowded.

- Quality: Put-away, inventory, picking and shipping are 4 major functions that their outcome's quality is extremely important for any warehousing operation. The performance accuracy is measured by the percentage of item or order being processed without error.

- Cycle-time: Dock-to-stock-time and warehouse-order-cycle-time are 2 popular units used in evaluating performance-speed of a warehouse. The first indicator refers to the duration between the arriving of a product at warehouse and when it completely available for picking. The second term is meant for elapsed time from the point when order is placed at a warehouse until it is ready for shipping. (ibid., 55-57.)

The systematized catalogue of indicators for warehouse performance measurement is meticulously described in the table below:

Table 1. KPIs used in warehousing assessment (adapted from Frazelle 2002, 57)

	Financial	Productivity	Utilization	Quality	Cycle Time
Receiving	Receiving cost per re-ceiving line	Receipts per man-hour	% Dock door utilization	% Receipts processed accurately	Processing time per receipt
Put-away	Put-away cost per put-away line	Put-away per man-hour	% Utilization of put-away labour and equipment	% Perfect put-away	Put-away cycle time
Storage	Storage space cost per item	Inventory per square foot	% Locations and cube oc-cupied	% Locations without in-ventory dis-crepancies	Inventory days on hand
Order picking	Picking cost per order line	Order lines picked per man-hour	% Utilization of picking la-bour and equipment	% Perfect picking lines	Order picking cycle time
Shipping	Shipping cost per customer order	Orders pre-pared for shipment per man-hour	% Utilization of shipping docks	% Perfect shipments	Warehouse or-der cycle time
TOTAL	Total cost per order, line and item	Total lines shipped per total man-hour	% Utilization of total throughput and storage capacity	% Perfect warehouse orders	Total ware-house cycle time (Dock-to-stock time + Warehouse or-der cycle time)

2.4 Designing Warehouse Layout

It is natural that the deeper the root, the stronger the tree can grow. And just as how the tree depending on its root, warehouse operation cannot be success without an effective-designed layout. Accentuated by Murray (2017d), to efficiently support the overall work-flow, the system’s constituent functions should adaptively be arranged, contingent on specific objective of each warehouse. It can be to minimize involved resource and waste, to maximize space-utilization and performance-productivity, or to provide the highest customer service and operational flexibility. (ibid.)

The main task in designing phase is collect and analyse all related information: business purposes; architectural drawings of warehouse space; included activities with their connection, priority, requirements and concerns, as well as needed vehicle, equipment, and so on. The goal of this analysing task is to determine an appropriate allocation and space for main office, rest rooms, constituent functions, intersect aisles; and establish optimal pathways for the flow of works.

Frazelle (2002) introduced 4 popular patterns that suitably used in most of contemporary warehousing, which are U-shape, straight-thru, modular-spine and multi-story. In the U-shape, receiving and shipping area are adjacent located in the front side of warehouse building. Products arrive in at one edge, stored at the back, and shipped out at the other edge. This arranging pattern not only support greatly cross-docking function, but also help maximize resources utilization, as the 3 processes can share the usage. Moreover, because the entrance and exit gates are in the same side, security-execution results in more focus and efficient. Next, the straight-thru layout should only be employed in operation that dedicated for cross-docking activity, where peak receiving and shipping occur almost-simultaneously. In case of large-scale warehouse that every single belonging activity is big enough to occupy an own building, modular-spine configuration is the most suitable option. Finally, the multi-story model is beneficial-designed for warehouse, which land is very limited. Yet, it is unavoidable to encounter some difficulties and bottlenecks during the operation, when materials be transferred between different floors. (ibid., 186-190.) (The visual appearance of these layouts is demonstrated in appendices 1-4.)

Although the designing of layout need to be carried base upon on current business objectives as well as other contemporary warehousing-related-information, it is highly recommended to involve the plans of future growth and expansion in this process. For instance, if the warehouse is expected to able to accommodate more goods, the purchasing of higher-capacity-facilities right in the first place will help avoid unnecessary replacing in the future; consequently, result in economical savings.

2.5 Supportive Technologies and Automatic Scale

In nowadays' extreme competitive and fast-pace business, organizations must employ the help of automation technology in many operations to outstand their position in the field. Warehousing is not an exception, but in contrary, has the most potential of gaining savings from efficient automatizing. In general, warehouse agencies can freely choose the necessary activities to automatize in appropriate scales, depending on their businesses' focusing areas. The available technologies support a wide range of functions, include material handling, storage, retrieving, conveying, sortation, order-fulfilment, manifesting or packaging.

In the previous chapters, the author has discussed about how automated sortation, packaging and material handling systems, RFID, paperless order-fulfilment, and telescopic conveyor can help reduce the amount of required workforce; product damaging; employee injury; as well as increase the performance's productivity and efficiency. To fully complete on this topic, in the following text, the advantages and disadvantages of using automated storage and retrieval system (AS&RS) and automated guided vehicles (AGVs) will be presented. Typically, these two systems are causing the most headache for manager, when making decision on the technology-investment.

Firstly, with the AS&RS, there are various types of system that specifically designed for different storing-unit, load-weight, operational speed, storage-condition, or even the amount of available warehouse space. For examples, the Unit Load AS&RS is suitable for handling product in units of pallet or tote; Vertical Life Module AS&RS offers the great utilization of vertical space and supports well for picking operation of high speed; Carousel AS&RS is used for goods that can be stored on shelves or in bins (Automated Storage and Retrieval Systems n.d.).

The AS&RS often be constructed to maximize the utilization of storage space, consequently saving up usage energy for light and temperature-control. The operation manner also be optimized, so that it is easier, faster and more discrete to access for product storage and retrieval. In most cases, the system can be distantly monitored by using a connected computer software; and the built-in equipment will be guided to rapidly handle all the heavy and repetitive tasks. This not only help increase productivity and efficiency, but also prevent employees from injury. Furthermore, AS&RS can allow real-time tracking and control of storing goods, while limiting the unnecessary access of warehouse workers.

Although the AS&RS promising many benefits, warehouse manager feel hesitates when deciding on the purchasing because of its high initial-investment costs. In addition, once the system is installed, it is very hard to make any changes around the area. The improper using manner also easily lead to large paying costs for repairing. And the most inconvenience is that during the maintenance time, operation must be stopped if it is not possible to switch to manual mode.

For the similar purpose of replacing human manual work by a faster and safer automatic engine, AGV is built with necessary number of supportive cameras and sensors, accompanied by a greatly-designed executional-programme, allow it to operate incessantly, even in the extreme conditions. Although it may not able to handle the tasks as flexible as human does, it helps eliminate significantly accidental events and inaccurate performance.

In summary, automatizing warehousing functions brings in both good and bad effects. To come up with the right decisions, and determine an appropriate level of automation for each activity, ones must first comprehend thoroughly the nature of their business. Next, identify, prioritize and balance between the gains and losses that potentially result in, if an automatic system be employed. Only then, the right answer may be detected. The only assured recommendation is that automatic technology is obviously benefit for long-term-orientation warehouse of large-operation-scale, where the works tend to be fixed in repetitive patterns.

3 Theoretical Bases Of Simulation

3.1 Simulation

Simulation is the acts of executing and observing a computer-based process model, which is a replica of real-world system or process. The technology may be used for carrying virtual experiments or generating “what-if” analyses in a much more convenient and cheaper manner. By that, ones can understand better about the system and its operations; subsequently, prompt and detect necessary changes for performance-improvements, such as increasing throughput, reducing costs, etc. (Lyman n.d.)

With the same opinion, Lahdevaara (2016, 5) believes that simulation can be used to experiment a new design or policies; to verify analytic solutions in prior to implementation; or for the insight study of complex systems. Nevertheless, he emphasises that appropriate and applicable data is extremely essential in building a useful model. (ibid.)

3.2 Poisson Distribution Pois (λ)

In the context that certain events are going to occur at random times and independent of each other. Whereas, the average number of spontaneous events in an interval of time, which is measured as intensity λ, is (approximately to be) constant. Then, the number of spontaneous events X in any specific time interval is Poisson distributed. X is called discrete random variable and its value belonging to the set {0, 1, 2, 3, 4, 5, …}. (Brink 2010, 35.)

Some examples of Poisson distributed events: the number of customers arrive at a store in each 2-hours-period; the number of orders placed at an online shop each day; the number of defected shipments detected daily at a warehouse inbound area; and so on. For each k ∈ {0, 1, 2, 3, 4, 5, …}, according to Brink (2010, 35), the point probabilities in a Pois (λ) distribution are calculated as:

$$P(X = k) = \frac{\lambda^k}{k!} e^{-\lambda}$$

notice that 0! = 1, by convention.

For example, a repair shop can fix on average 2 devices per hour (each type of fault, which is arise randomly and independently, demands a certain amount of effort in repairing). Then, the number of corrected devices in every 1-hour-period follow the Pois (2) distribution, and the point probabilities can easily be determined as listed in the table below:

Table 2. Probability that k device(s) can be fixed in 1 hour

k	0	1	2	3	4	5	6	≥7
P (X=k)	13.53%	27.07%	27.07%	18.04%	9.02%	3.61%	1.2%	0.45%

3.3 Exponential Distribution Exp (λ)

Staying in the same scenario, where events occur spontaneously with intensity λ, and the number of events in a certain time-period is Pois (λ) distributed. It follows that, the waiting time T between 2 successive events is exponentially distributed. And T is called continuous random variable, taking value from the interval $[0, \infty)$. Mathematically, the expected value of waiting time T is $E(T) = \frac{1}{\lambda}$, and the density function of Exponential distribution is formed as $f(x) = \lambda\, e^{-\lambda x}$. (Brink 2010, 45-46.)

Continue with the repair-shop-example, the service time (the time needed to fix a device) is exponentially distributed. Although the expected service time can be computed as $E(T) = \frac{1}{2} = 0.5$ hours, the time required to repair a device is different from case to case. Using the density function, one can calculate the probability of any service-duration within the interval $[0, \infty)$. The table below contains some example of service-time-values with associated probabilities:

Table 3. Probabilities that x hour(s) is required to repair a device

X	0.2	0.4	0.5	0.8	1.4	4	≥6
f(x)	45.24%	40.94%	38.94%	33.52%	24.83	6.77%	7.47%

3.4 Queuing Theory

Queuing theory is a branch of operations-research, regarding to mathematical study of waiting lines. Its results are used in support planning schedule; determining appropriate input resources for each service-activity; improving customer satisfaction; and so on. In the most basic formation, queuing management regulates 3 major matters: how customers or products arrive, how they are serviced and conditions of them leaving the system. (Sherman n.d.)

The arriving of customers at a store, of unfinished-goods at a manufacturing line, of defective products at a repair shop and so on is varying from time to time, but can be approximately estimated by an acceptable constant rate (CR). As discussed earlier, in CR model, the number of arrivals per time-unit and the time between successive arrivals respectively follow the Poisson and Exponential distributions.

To efficiently direct employees in serving customers or handling products, a suitable queue-rule should be selected and apprised in advance. Lahdevaara (2016, 65) divided the available options into 2 main classes, for not-interrupted and interrupted services. The first group contains principles called: first come first served (FCFS), last come first served, shortest processing time first, service in random order, triage-priority and non-pre-emptive priorities. Whereas, the second one includes disciplines named as: shortest remaining service time, round Robin and pre-emptive priorities. (ibid.)

4 Simulation In Warehousing

4.1 Motivation of Using Simulation in Warehousing

The work of a warehouse manager is all about making the right decisions, whether it is to hire and allocate staffs for each operation; to draw plan on operating schedules and employees' shifts; to determine appropriate purchases of equipment and forklift vehicles; to select proper types of dock, rack, AS&RS, conveyor belt, sortation system and so on for installation; to initiate a new executional principle and policy; to design a new operational layout or better paths for the flowing of work and materials; etc. In any of the mentioned cases above, simulation can play a great supportive role along decision-making process.

By having the warehouse system virtually replicated in a computer programme, manager can easily make change to input elements, run the model in desired timeframes and get the corresponding results (in different levels of confidence) immediately. Afterward, he (or she) can compare the proposed alternatives in terms of associated costs, gains and lost, before choosing the most optimal option for implementation.

This procedure assists manager greatly in anticipating posterior difficulties, as well as evading risks and loss resulted from the wrong decisions.

Because simulation model is constructed and executed purely base on mathematical concepts, the calculated outcomes is completely assured (if input data is pertinent and reliable). Furthermore, as computer software can run and display instantly the results of emulated cases, manager should able to make decisions faster. Ultimately, help warehousing firm to catch up with the current business trends.

4.2 Computer Software for Simulation

Since the power of simulation is getting more recognition, many technology companies become engaging in creating a more intelligent and sophisticated simulation system. This lead to the confusing market of simulation software with hundreds of invented programmes, that greatly vary in quality as well as price. Besides, as each company often has its own targeted groups of customers, who are working or studying in a specific professional area; the company's software tends to be generated with certain unique features, that mainly support the simulating and optimizing for operations in that field. Hence, one should be circumspect when selecting the simulation programme to work with.

Fortunately, many companies offer free trial version of their software for customers to test and explore, before deciding on the final purchasing. The duration of free-period is varying from 1 to 4 months, which is long enough for users to understand (in an adequate amount) a programme. It is also recommended to seek information from experts; from articles writing about simulation and the annual best-ranking software; from other users' reviews; and so on, before spending time on any trial version.

In the next chapter, a software called Enterprise Dynamics (version 9) will be used to construct the example model. Since its first release in 1997, the programme has been improved and expanded applications to various areas. Warehousing is one of the main supported field and there is even a warehouse-specific-library integrated in the system. From author's point of view, this is the most user-friendly programme, such that it should only take a few weeks for any newbie to get along with the software as well as its event-and-object-oriented-platform.

4.3 An Illustrative Case

4.3.1 Case-Scenario and Programme-Setup

In this example case, a manager (simply named as S) is assigned to construct a warehouse, which main activities include receiving, cross-docking, registering, sortation, put-away, storage, picking, packaging and shipping. S plans to arrange the operation in the U-shape layout; and have collected the necessary information, regarding to amount of work required in each task, qualification of employees, productivity of machines, capability of supportive technologies and equipment, as well as other involved issues and limitations. Now, S wants to determine the most optimal number of workers, machines, equipment, forklift vehicles, etc. to employ and purchase, so that operating-resources never in the situation of either redundancy or shortage; or at least, it only occur in an acceptable extend.

The initial sketch of the layout is presented in the figure below; there are 3 pathways for the flowing of materials: regular shipments move in as guided by black arrows, cross-docking shipments follow green arrows and finally, outbound orders are processed in the direction of red arrows.

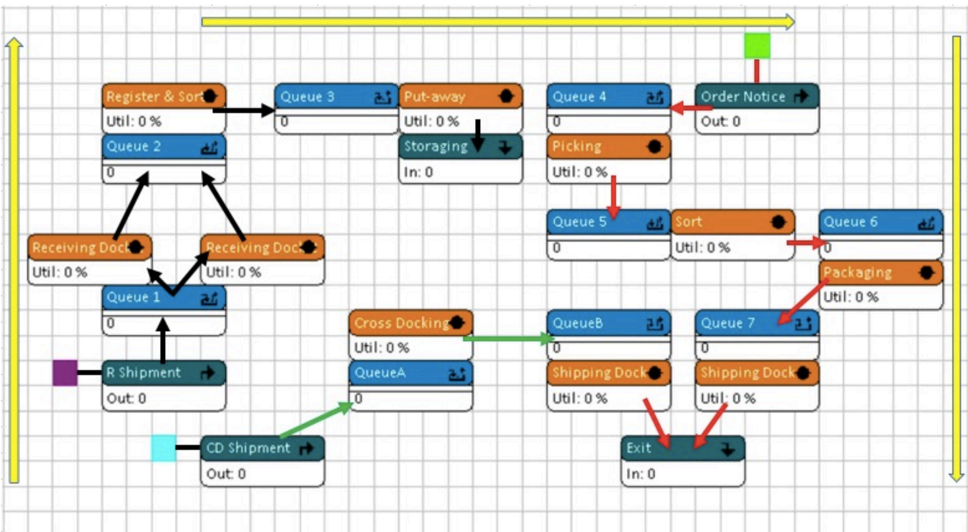


Figure 2. Initial sketch of warehouse layout

The simulated model contains 27 objects. Outbound orders, regular shipments and cross-docking shipments are symbolized by the 3 small squares. Pine-green rectangles act as a place where orders and shipments enter, stay (at storage area) and exit the warehouse. Each orange rectangle represents for a warehousing function. Except, the work in receiving and shipping docks is divided by team. The blue rectangles signify for queues associated with activities. (Appendix 5 exposes how these objects really be connected in the programme.)

Based on historical data, on average, 2 batches of regular shipment and 1 batch of cross-docking shipment are estimated to arrive at inbound area in every 1-hour-period. This makes inter-arrival time (waiting time for a shipment to arrive) of them to respectively be 0.5 hours and 1 hour, following the Exponential distribution. In the same duration, an average of 10 orders are demanded by customers, meaning that orders' inter-arrival time is 0.1 hours and exponentially distributed.

After collecting the related information from human-resources department and supply-partners, S has come up with the first proposition. Such that, with an appropriate executional principle and policy, accompanied by certain numbers and types of workers, machines, equipment, vehicles and technologies, the performance-rate of each activity obtains a specific level as declared in the following table:

Table 4. Performance rate corresponding to initial proposition

Operation (Rule: FCFS)	Cycle Time (Hour(s))
Receiving dock 1	1
Receiving dock 2	1
Registering and Sortation	2
Put-away	0,5
Picking	0,2
Sortation	0,1
Packaging	0,3
Cross-docking	1

The rate is evaluated using indicator called cycle time, and in this case, it is measured as the length of time required to handle a batch of inbound shipment or an outbound order. The average number of batches (or orders) processed are approximately constant (Poisson distributed), impelling the rate to follow Exponential distribution. Exceptionally, for the reduction in transportation costs, delivery-truck only leaving the warehouse when fully loaded with about 4 batches of cross-docking shipment (at shipping dock 1) or 40 orders (at shipping dock 2). However, it not means that 4 batches of shipment have the same load-dimensions with 40 outbound orders, but trucks of different sizes are being used for the 2 docks.

An appropriate queue-capacity is presumably assigned for each object (queue imitation), to emulate the allocation of reserved space for different warehouse functions. This assigning is subjective and should be changed easily in accordance to the upcoming simulation result. (The detail of capacity-setting is summarized in appendix 6. And the programme-setup of some representative objects are displayed in appendices 7-10. Note that the unit of time is in second.)

4.3.2 Simulation Results and Suggested Actions

After having the model run in a timeframe of 8 hours – 1 day working hours (in real time, it only took a few minutes) for several times, the most frequently-occur result is recorded as shown in the figure and table below:

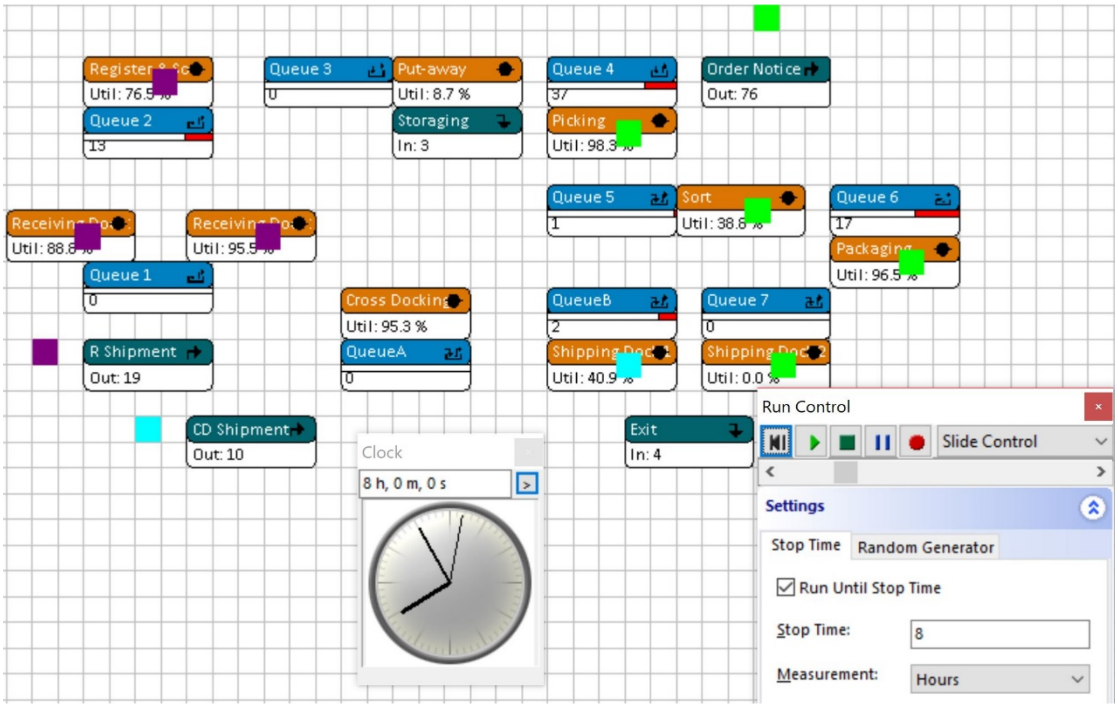


Figure 3. Simulation recorded result: utilization level of individual function

Table 5. Simulation recorded result: processing of products (or orders)

Summary Report				
Object	Current Product	Throughput		Unit
		Input	Output	
R Shipment	0	19	19	Batch
Receiving Dock 1	1	9	8	
Receiving Dock 2	1	10	9	
Register & Sort	1	4	3	
Put-away	0	3	3	
CD Shipment	0	10	10	
Cross Docking	0	10	10	
Shipping Dock 1	4	8	4	
Order Notice	0	76	76	Order
Picking	1	39	38	
Sort	1	37	36	
Packaging	1	19	18	
Shipping Dock 2	18	18	0	

To examine the status at waiting lines, a series of 20-days-simulation is launched and the maximum number of products at each queue in each run is captured. Subsequently, the statistics used in limit-control (average – central line, lower bound, upper bound) are computed with 95% of confidence. The corresponding result is tabulated as below:

Table 6. Simulation report of queues' status

Observation-period:	576000			
Warmup-period:	0			
Number of observations:	20			
Simulation method:	Separate runs			
Object	**Average**	**L-bound(95%)**	**U-bound(95%)**	**Unit**
Queue 1	4	2	5	Batch
Queue 2	8	7	10	
Queue 3	1	1	1	
Queue 4	40	36	45	Order
Queue 5	3	3	4	
Queue 6	15	12	17	
Queue 7	1	1	1	
Queue A	3	2	4	Batch
Queue B	2	2	3	

Taking as an example to explain for the meaning of these statistics, regarding to the Queue 1 (queue for Receiving function), one can be 95% confident that the maximum number of products in this queue within 1-day-period is greater than or equal to 2 (batches) and less than or equal to 5, and on average it should equal to 4. By fitting the data into Normal distribution and using the related formulas, these statistics can easily be evaluated. Conveniently, there is a built-in statistical tool in the software that automatically handle this calculation when users place the demand. This is the reason why the author omits Normal distribution concept in the chapter of theoretical bases.

The simulation results plainly signify that the designed warehousing system contains various problems. For a clear and systematic reporting, issues associated with each activity will be identified and discussed case-by-case in the following table:

Table 7. Warehouse's initial proposition: Imperfections and Solutions

Activity	Discussion and Recommended Actions
Receiving	Utilization rates at receiving area are quite good (88.8% and 95.5%). In the recorded day, 17 out of 19 batches (of product) were successfully forwarded to the next pace. Nonetheless, with 2 batches left behind until the next day, and an average of maximum contents must linger in the queue is confidently estimated to be 4, a little improvement is needed.
Register & Sort	This is the activity that cause dangerous blockage at inbound area. There were only 3 out of 17 batches be processed to the next stage. According to this operational speed, the remaining large proportion of products must be stacking up for days. Despite so, the function's utilization almost reached 77%. Meaning that, either the area is deserved to be assigned more resources (operator, machine, vehicle, equipment), or a better registering and sortation system should be employed, for the function to be able to fully accomplish its duty.
Put-away	Because the previous process had hindered substantially the flow of materials, there was not much of them available to be put-away in this phase (extremely low utilization rate of 8.7%). Hence, it is essential to reallocate or integrate resources for the 2 adjacent areas (Resister & Sort and Put-away), so that a more balance of utilization rates and a greater amount of throughput can be attained.
Cross-docking	The operation of cross-docking has been designed well. In the recorded result, its utilization rate reached 95.3% and all demanded workload was completely handled by the end of the day. Confidently, manager can now decide the final amount of reserved space for the activity's connected-queue, which average of maximum contents is expected to be 3 batches (95% assurance).

Picking	Picking is another function that need more support. Although its resources have been utilized up to 98.3%, only half up the orders (38 out of 76) were fully picked for delivery. It is not surprise that the possible maximum number of orders must endure in the queue is not lower than 36. These are clear impellent signs for manager to consider engaging with the paperless-picking technologies (if not yet), beside from increasing the number of workers in this area.
Sort (Outbound)	Only used 38.8% of the assigned resources, but rapidly sorted out the input orders for the next stage of packaging. Therefore, a certain proportion of operators should be translocated to work in other areas, such as picking or packaging.
Packaging	From the fact that packaging area could only process out half of the inputs (18 out of 36), even though 96.5% of its capacity has employed in the operation. It can enrol in the list of functions, which not getting as much support as desired. Among the orders-handling-queues, packaging's queue places as the second, in term of number of maximum contents recorded at the line (15 orders on average).
Shipping	As mentioned earlier, the work at shipping area is arranged so that there will be one truck parking at each dock, waiting for cross-docking products to reach 4 batches (dock number 1), or outbound orders to accumulate to 40 packages (dock number 2). This principle explains for the low utilization rates at the 2 docks. The problem is that, by the end of recorded day, there was only 1-time truck leaving the shipping area from dock number 1. The other 4 available batches must wait until the earliest of the following day. Regarding to the dock number 2, only 18 orders were successfully gathered after 1 working day, 22 more orders still needed for the truck to leave. This executional manner causes major delay in delivering products to customers. Therefore, it is better to outsource this activity and cooperating with a third-party carrier, that can come and pick the products in more frequent times. Otherwise, the current using trucks should be replaced by smaller vehicles, which, for example be fully loaded with 2 batches of cross-docking products, or 6 outbound orders. However, this may result in higher transportation costs.

Although the initial proposition seems to be fine at a first sight, many drawbacks become visible after having the simulated model run and consequent results generated. While some function areas be assigned with too much of resources, the other operations have to suffer with the heavy workload, compare to their equipped capability. The inappropriate executional principle at shipping docks also prevented about two-thirds of shipments from departing for delivery, in the recorded day. And overall, the warehouse only shipped out 4 batches of products from the request of 76 orders plus 10 batches of cross-docking shipments – an extremely low productivity.

By now, the manager must realize that the established plan is seriously bad. More efforts should be putting in refining the performance principles; balancing the resources for involved activities; and providing greater support for functions with heavy workload. Along the process, simulation should also be used as a verifying tool for any change that manager intends to, even a very small one. This way, the model can be improved in a more reliable and steady manner.

In term of space allocation for the queues as well as area for each activity, decision should be made based on simulation results of model, which emulated the final version of warehouse design. However, from author's point of view, the ideal number of products linger at each queue should not larger than 3 batches or 10 orders.

4.4 Conclusion

Since the example model is built based on pertinent and verified mathematical concepts, belonging objects also be connected to interact with each other exactly in accordance to the established performance principles, the simulation model as well as its generated results are totally reliable, provided that the collected data (arrival pattern and inter-arrival time of inbound and outbound orders, cycle time of functions) is updated, relevant and accurate. It is worth to alert once again that a model failing to guarantee any of the above-mentioned standards during the construction phase is useless. And employing a wrongly built simulation model (without awareness) as a lodestar along decision-making process may lead to terrible consequences. Hence, it is crucial to examine and verify the quality and reliability of a model before the usage.

The current simulation technology has greatly developed such that it is possible to replicate exactly any real-world event or process into a 3-dimensions (3D) computer-based model. For instance, different types of automatic conveying, sortation, packaging system can be emulated as 3D simulation models; and virtually be implemented to examine and identify the most suitable ones for a certain range of products.

In fact, the previously used programme (Enterprise Dynamics 9) also offers 3D simulation features. But to able to build that kind of complex model, a certain larger amount of time and effort must be spending on gather the necessary information. And this time, the accuracy requirement on collected data should be stricter to avoid any probable domino effects. Model designer also expected to possess a solid enough mathematical base, accompanied by a skilful level in software manipulation. Nonetheless, if warehouse manager does not want to bear the learning of advanced mathematics and simulation software, then just simply hire a simulation specialist, who can easily create any demanded model, provide specialized advices and assist him (or her) along the painful decision-making process. The total cost is not more than a periodic subscription fee of simulation software and monthly salary for a valuable expert.

Although the model created in the illustrative case is quite simple, that basing only on a couple pieces of data and mathematical concepts, with some utilities of a simulation software involved, it works best for warehousing firm, which operations are pure and plainly connected with one another. In the situation that a supportive model is in urgent need and where there is not much of accurate and reliable data available at the time, this kind of focus and solid model is more preferred than a large and complex one, with various potential errors associated. Besides, the level of simulation knowledge of general warehouse managers should also be taking into consideration when deciding on the complexity scale of a model. As the extent of benefits that a simulation model can bring in depending on how much it can be utilized by the user.

References

Automated storage and retrieval systems. N.d. Page on the Integrated Systems Design's website. Accessed on 12 January 2018. Retrieved from http://www.isddd.com/storage-retrieval-systems

Brink, D. 2010. *Essentials of statistics*. 1st ed. Ventus Publishing ApS.

Castaldi, C. 2016. *How to pick the right sortation system*. Accessed on 4 November 2017. Retrieved from http://www.dmwandh.com/pick-right-sortation-system/#.WgsQAraB1-X

Curley, R. 2017. *3 styles of warehouse replenishment*. Accessed on 15 December 2017. Retrieved from https://info.archon-interactive.com/blog/3-styles-of-warehouse-replenishment

DelBovo, M. 2011. *Cross-docking rediscovered*. Accessed on 24 September 2017. Retrieved from http://www.mhlnews.com/transportation-amp-distribution/cross-docking-rediscovered

Dresch, A., Lacerda, D. P., & Antunes Jr., J. A. V. 2015. *Design science research*. 1st ed. Springer International Publishing Switzerland.

Fain, B. 2014. *Five benefits of cycle counting over annual inventory counts*. Accessed on 10 December 2017. Retrieved from https://www.stitchlabs.com/blog/benefits-cycle-counts-over-annual-inventory-counts/

Frazelle, E. 2002. *World-class warehousing and material handling*. 1st ed. McGraw-Hill Education.

Gray, C. N.d. *The importance of cycle inventory counting*. Accessed on 10 December 2017. Retrieved from http://smallbusiness.chron.com/importance-cycle-inventory-counting-24718.html

Hobkirk, I. 2016. *10 ways to achieve e-commerce distribution success: optimize packing*. Accessed on 19 November 2017. Retrieved from http://www.commonwealth-sca.com/10-ways-to-achieve-e-commerce-distribution-success-part-6-of-10-optimize-packing/

Kennedy, T. 2017. *How voice picking stacks up against paper, RF scanning and pick-to-light*. Accessed on 21 October 2017. Retrieved from https://blog.highjump.com/how-voice-picking-stacks-up-against-paper-rf-scanning-and-pick-to-light

Lahdevaara, H. E. 2016. *Simulation and queuing theory*. Lecture slides. JAMK University of Applied Sciences, School of Technology.

Lyman, P. N.d. *Process simulation and its benefits*. Accessed on 16 January 2018. Retrieved from https://www.crbusa.com/process-simulation-and-its-benefits

Marfo, A. N.d. *How to reduce inventory shrinkage*. Accessed on 17 December 2017. Retrieved from http://smallbusiness.chron.com/reduce-inventory-shrinkage-19240.html

Martins, F. 2017. *Why automate your parcel sortation operation*. Accessed on 12 November 2017. Retrieved from https://www.pitneybowes.com/us/blog/why-automate-parcel-sortation-operations.html

Melendez, K. 2013. *Benefits of real-time RF scanning*. Accessed on 21 October 2017. Retrieved from http://info.mkmdistribution.com/blog/bid/342267/benefits-of-real-time-rf-scanning

Montgomery, K. 2016. *Why use augmented reality in your warehouse or DC*. Accessed on 22 October 2017. Retrieved from https://talkinglogistics.com/2016/01/26/why-use-augmented-reality-in-your-warehouse-or-dc/

Murray, M. 2016a. *Pick to light warehouse systems*. Accessed on 14 October 2017. Retrieved from https://www.thebalance.com/pick-to-light-warehouse-systems-2221456

Murray, M. 2016b. *Packaging in the warehouse*. Accessed on 18 November 2017. Retrieved from https://www.thebalance.com/packaging-in-the-warehouse-2221182

Murray, M. 2017a. *Order picking in the warehouse*. Accessed on 29 September 2017. Retrieved from https://www.thebalance.com/order-picking-in-the-warehouse-2221190

Murray, M. 2017b. *Pick to voice warehouse systems*. Accessed on 14 October 2017. Retrieved from https://www.thebalance.com/pick-to-voice-warehouse-systems-2221457

Murray, M. 2017c. *Cycle counting in the warehouse*. Accessed on 2 December 2017. Retrieved from https://www.thebalance.com/cycle-counting-in-the-warehouse-2221188

Murray, M. 2017d. *Planning and optimizing your warehouse layout – supply chain impact*. Accessed on 7 January 2018. Retrieved from https://www.thebalance.com/planning-your-warehouse-layout-2221065

Pasian, B. 2015. *Designs, methods and practices for research of project management*. 1st ed. Gower Publishing Limited.

Piasecki, D. N.d. *Order picking: methods and equipment for piece pick, case pick, and pallet pick operations*. Accessed on 29 September 2017. Retrieved from http://www.inventoryops.com/order_picking.htm

Prescott, A. 2008. *Advantages and disadvantages of secondary research*. Accessed on 15 February 2018. Retrieved from http://prosandconsofsecondaryresearch.blogspot.fi

Rogers, L. K. 2011. *Equipment 101: sortation equipment*. Accessed on 12 November 2017. Retrieved from http://www.logisticsmgmt.com/article/equipment_101_sortation_equipment

Sherman, P. J. N.d. *Queuing theory and practice: a source of competitive advantage*. Accessed on 17 January 2018. Retrieved from https://www.isixsigma.com/industries/retail/queuing-theory-and-practice-source-competitive-advantage/

Stone, S. 2017. *The dock is your first line of customer service*. Accessed on 26 November 2017. Retrieved from http://www.cisco-eagle.com/blog/2017/01/10/the-dock-is-your-first-line-of-customer-service/

Sunol, H. 2017. *Warehouse operations: optimizing the put-away process*. Accessed on 27 September 2017. Retrieved from http://articles.cyzerg.com/warehouse-operations-optimizing-the-put-away-process

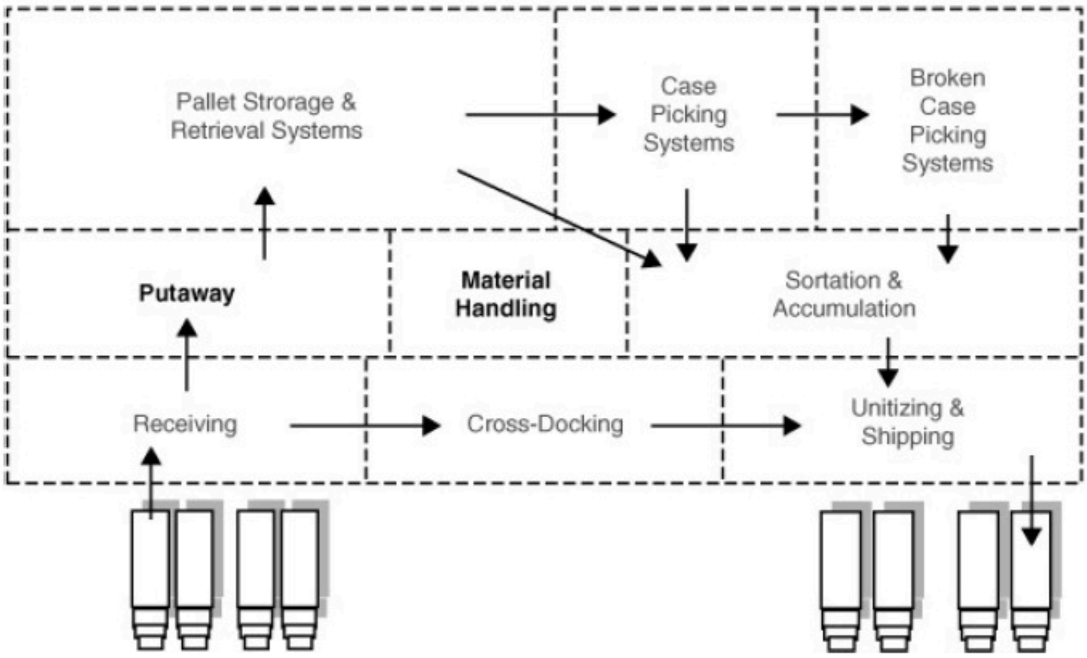
Travis, D. 2016. *Desk research: the what, why and how*. Accessed on 15 February 2018. Retrieved from https://www.userfocus.co.uk/articles/desk-research-the-what-why-and-how.html

Vitasek, K. 2007. *Best practices in material handling and put-away*. Accessed on 27 September 2017. Retrieved from http://multichannelmerchant.com/operations/best-practices-in-material-handling-and-put-away/

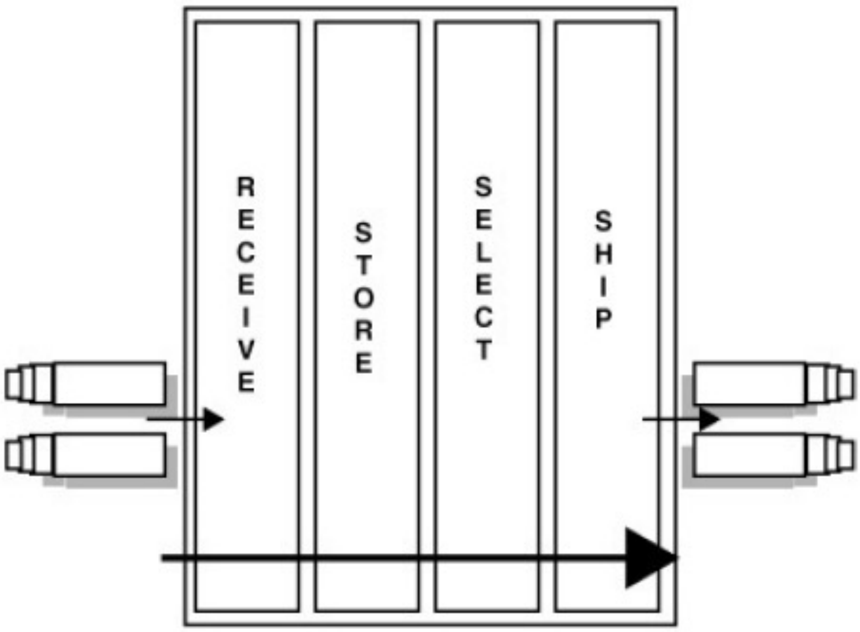
Woollard, D. 2015. *Could your warehouse loading bay be more efficient*. Accessed on 26 November 2017. Retrieved from https://www.dmg-freight.com/could-your-warehouse-loading-bay-be-more-efficient/

Appendices

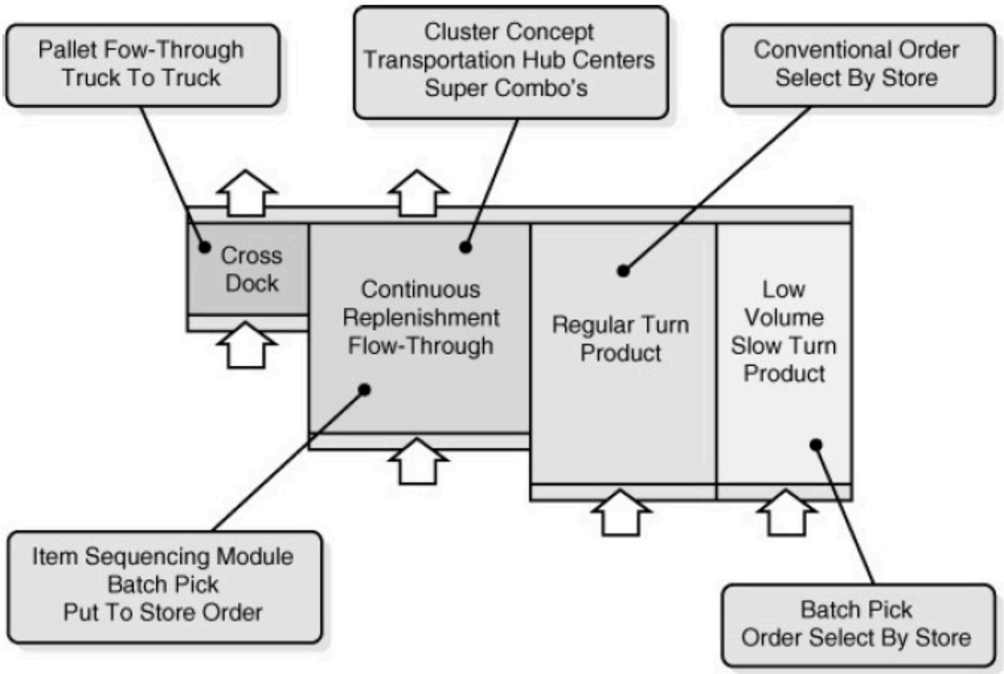
Appendix 1. U-shape layout (adapted from Frazelle 2002, 187)



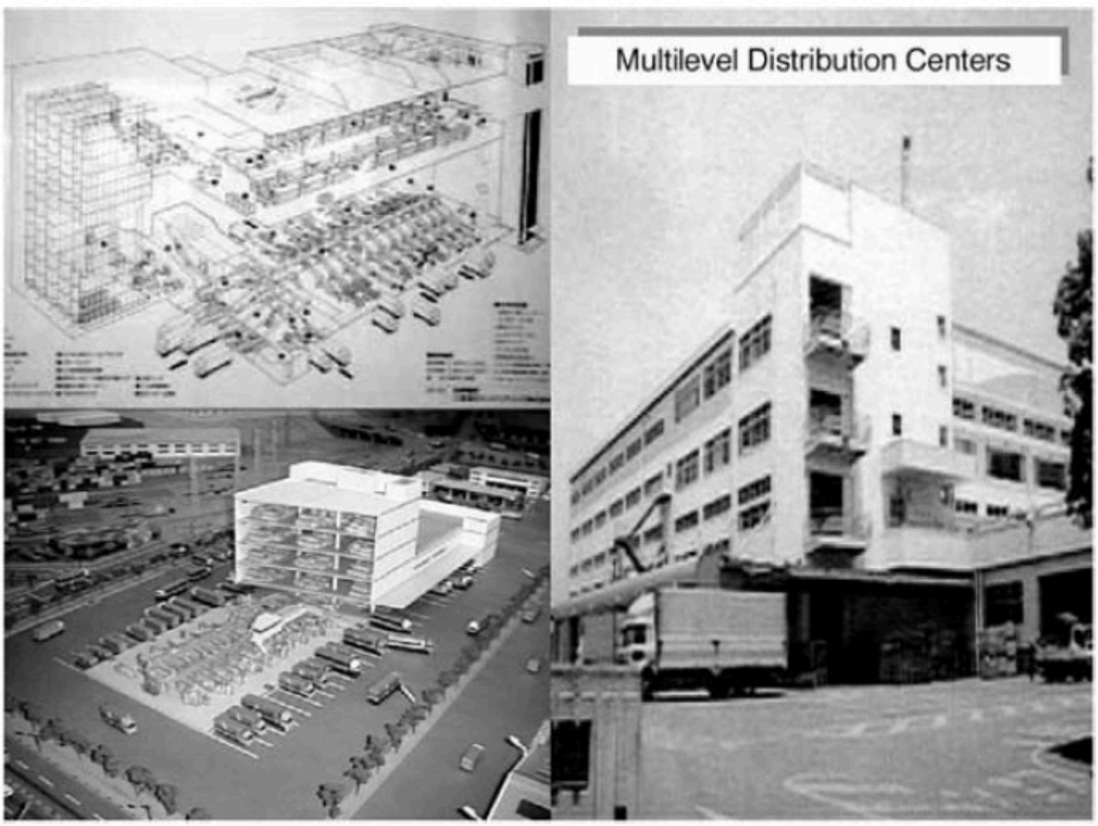
Appendix 2. Straight-thru layout (adapted from Frazelle 2002, 188)



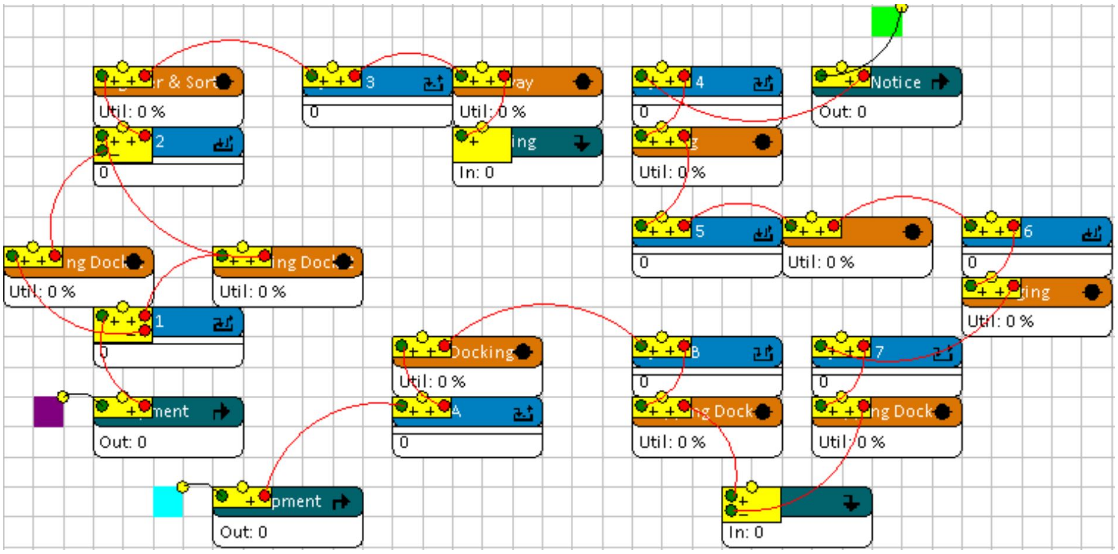
Appendix 3. Modular-spine layout (adapted from Frazelle 2002, 189)



Appendix 4. Multistory layout (adapted from Frazelle 2002, 190)



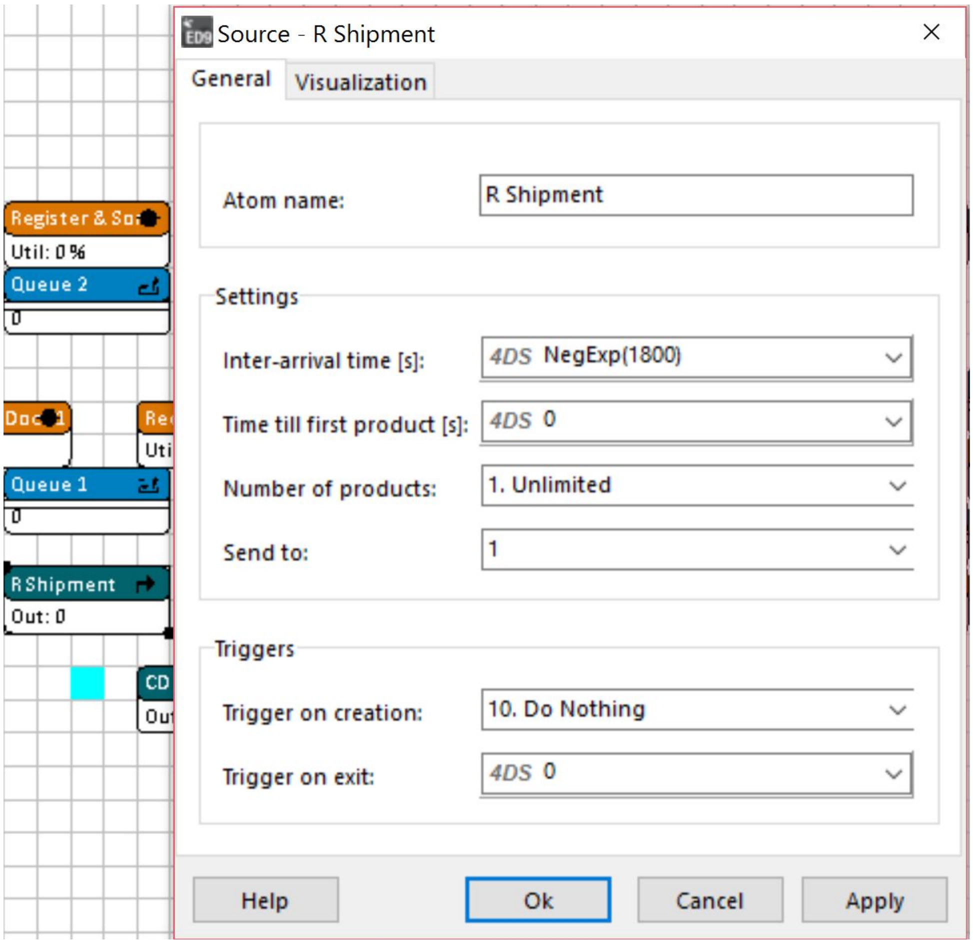
Appendix 5. Actual connections of objects in the programme



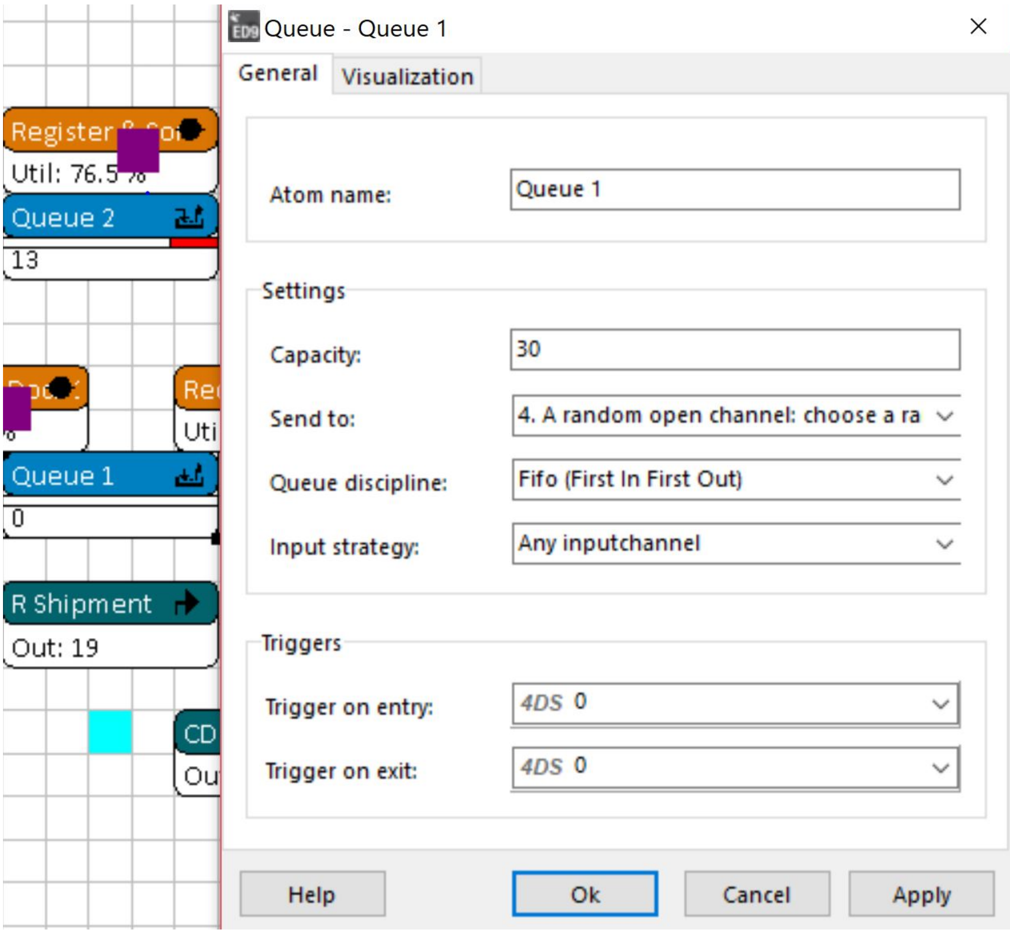
Appendix 6. Capacity of waiting lines

Queue	1	2	3	4	5	6	7	A	B
Capacity	30	60	30	150	50	50	50	15	15

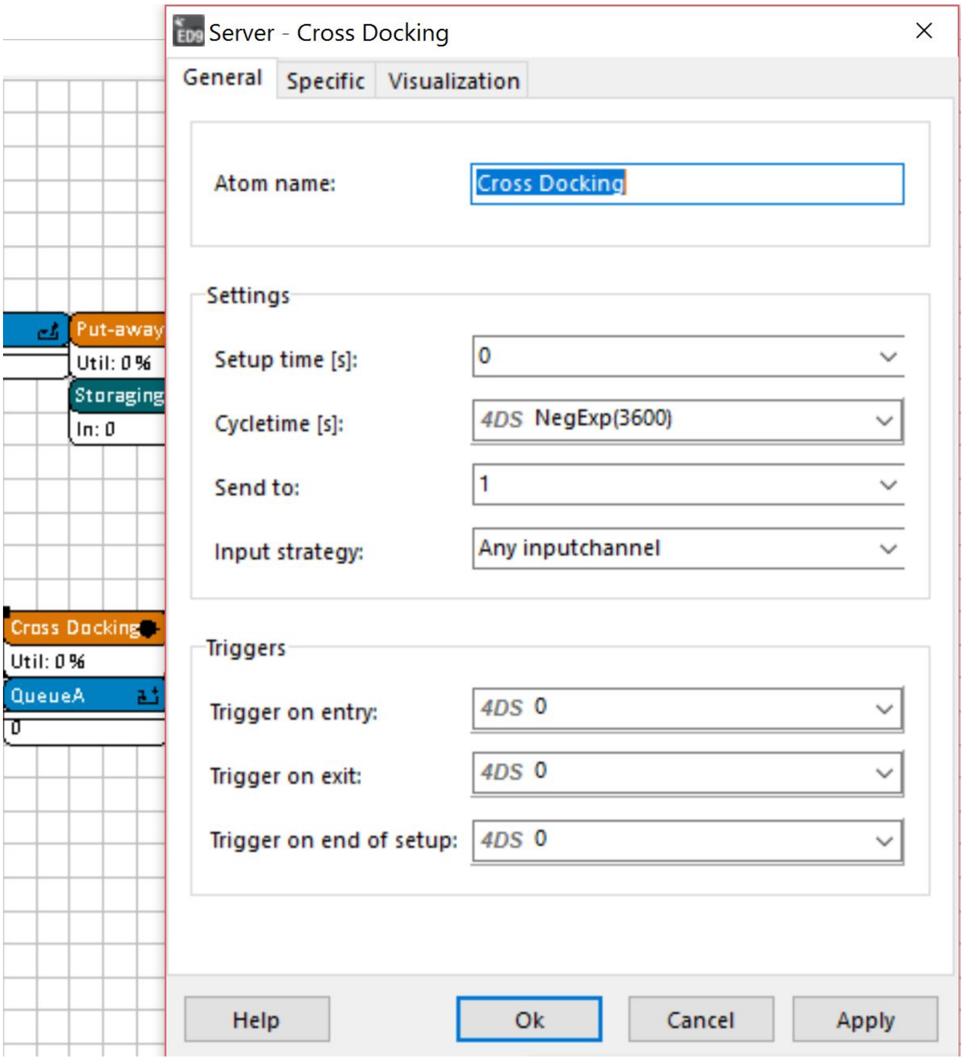
Appendix 7. Data-setup for the arriving of regular shipment



Appendix 8. Data-setup for receiving docks' queue



Appendix 9. Data-setup for cross-docking function



Appendix 10. Truck only depart after having 40 orders loaded