Warehouse redesign to satisfy tight supply chain management constraints

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Abstract: - The picking process is a critical supply chain component for many companies. A proper warehouse configuration, storage policy, trays replenishment policy, and other factors are also important to reduce not only the delivery time, but also increase productivity while maintaining quality factors at competitive costs. This paper presents an integrated approach to tackle the complexity of warehouse redesign under several space and quality factor constraints. The proposed design methodology integrates warehouse layout configuration, storage policy, replenishment policy, picking policy, routing policy and also trays and shelves sizes design. As a result of the proposed strategy, considerable savings on resource costs (equipment and workers) can be achieved.

Key-Words: - Picking, warehouse, simulation, colored petri nets, logistics, supply chain.

1 Introduction

Due to market competitivity, continuous improvements in the design and operation of production and distribution networks are needed, affecting somehow to new challenges (i.e. lean management philosophies) into warehouse quality factors performance.

Traditionally, warehouse redesign used to solve several decision problems which were alternatively situated at a strategic, tactical or operational level [11]. Nowadays, due to fierce market competitivity, a proper coordination of all the decisions and activities is required because decisions at a certain level use to propagate to other levels and to affect other activities. In the warehouse design presented in this paper any decision at any level can affect the results of other decisions at upper and lower level due to tight constraints introduced by costs reduction competitivity. For example: usually, a new storage system (strategic decision) implies a new layout configuration and a new evaluation on the required human resources (tactical), constraining the assignment and scheduling of warehouse operations (operational). However, to give a proper answer to real warehouse productivity demands, new approaches that could support the analysis of the cause/effect relationship between all the decision variables considering also the one time cost (investments) versus recurrent costs (permanent) would avoid non-productivity operations that appear due to oversized infrastructure. It is easy to note that an operational decision, like the used picking policy, can imply changes at tactical level (storage dimension, layout configuration or number of employees) and even at strategic level (storage system). Industry lacks of innovative modelling approaches which could integrate all the decisions at the same level to be able to design a warehouse under certain tight constraints, balancing one time costs (investment) and recurrent costs (permanent).

A complete literature review on warehouse design can be found in [10,11,12]. It should be noted that most research works focus the interest in one of the warehouse activities: receiving, storage, picking or shipping operations; however, it should be considered that any of these operations can affect the others, so, improving the decision activity of any of these sections will imply new constraints in the other sections.

As Fig. 1 shows, due to the sequentially activities, a decision at picking can affect shipping as well as receiving and storage. For example, a replenishment policy to avoid empty trays in the storage subsystem can imply an increment on the recurrent costs due to the required human resources, and a decrease on the one time cost due to a decrease in the storage area requirements because of better occupation rate factors in the trays. On the other hand, a conservative replenishment policy usually leads to a decrease on the recurrent cost due to a decrease on the number of required employees, but increases the one time cost because more space for the storage subsystem is required due to a poor occupation rate factors in the trays.

To get into the warehouse design state of the art, papers regarding warehouse systems and its management [6], warehouse operation comparison and mixing [9], or warehouse layout design [17,20], can be consulted. Furthermore, despite several papers regarding the use of simulation as a tool in warehouse design have been written (models of order picking systems, cost models for inventory and inventory sizing models, models for warehouse capacity expansion [1,3,4]); and there are also papers regarding the use of mathematical methods to optimize warehouse sizing, satisfy time delivery constraints, and others [21,22,23]; neither integrated approach to tackle a warehouse redesign under strategic, tactical and operational tight constraints, nor integrated approach to tackle warehouse activities (receiving, storage, picking and shipping) all together has been published.

In particular, there are works regarding travel time analysis and estimation to improve the cost of picking process [7,13]; other papers are about picking strategies [14], where batch and zone order picking strategies are compared; a lot of papers treat the most studied picking decision which is the route for the pickers [15,16], which is considered a variation of the classical vehicle routing problem. Clustering techniques, for storage location assignment, are used in [8] to optimize picking process; class based storage location assignment are used in [18]; and zone storage location assignment in [19]. It is also possible to find papers about replenishment policies at particular cases [24].

In this paper, a new approach using Coloured Petri Nets (CPN) and simulation techniques, integrating decisions on warehouse activities in general (receiving, storage, picking and shipping) at strategic, tactical and operational level all together is introduced. The particular case presented in this paper is a work made for an optical company with an expected increment of 72% in the number of points of sale (POS), under high warehouse space constraints and subject to really high service quality factors.

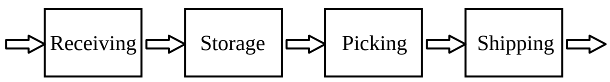

Fig.1: Warehouse operations

2 System Complexity Description

Unlike popular belief, every warehouse is not the same, it is important to understand the boundary conditions and the inner context interaction of each warehouse operation: receiving, storage, picking and shipping. In this paper a warehouse redesign proposal considering the following aspects will be properly described:

- Tight supply chain management constraints: highly complex material flow system for trays to support internal production demand and distribution demand.
- Tight space constraints: the company is located downtown, in a high populated city with no possibility to increase the size of the warehouse.
- Receiving uncertainty: perturbations appear in receiving operations and propagated to storage/picking/shipping operations due to unknown delivery delays from Asian suppliers (non control on providers: not in the amount neither on the delivery frequency).
- Shipping constraints: packaging operation from storage and production should be classified and finished every day before 4:00 pm independently of the amount of material to be shipped, and the all shipping demand of the day is obtained at 12:00 pm.
- Lack of information technologies (IT): due to manual manipulation and assembly of frames together with the historical cultural evolution of the company.
- Lack of turnover reference classification model: demand is highly dependent on the fashion at a certain unpredictable geographic area.
- Conservative picking and replenishment policies: due to the structure of the warehouse (shelves and trays), strict quality factors and a still preserved conservative picking procedure.

As mentioned in Section 1 there is a cause/effect relationship between the receiving, storage, picking and shipping operations that can affect the overall warehouse performance. In fact, when the warehouse system is ruled under tight resource constraints (i.e. equipment, space and human resources) its performance is highly sensible to a proper coordination of all the operations distributed into the four sections, because any perturbation/problem that appears in any section is propagated to the other section due to the difficulty to absorb the perturbation using the scarce resources available in just one section. The section where to start the redesign is critical because it will be the seed that will propagate constraint to the remaining sections. Unfortunately, there are no rules to decide the section where to star the redesign from. However, decisions at picking operation are the ones which more constraint the decisions at receiving, storage and shipping sections.

A local solution for this optical warehouse problem was introduced by the authors in [25]. They analysed the warehouse to determine the non productive operations of each section (i.e. non productive space area usability), and to evaluate how its modification would affect the other sections. Thus, they noticed that the occupation rate of the warehouse was 42% because of several causes, among which there was the free space inside master boxes and trays in the storage section (See Fig. 2). By reducing the free space (non productive volume) in the trays, master boxes and shelves, an occupation rate around 80-85% could be achieved. On the other hand, there was a 25% of expected increment of the material to be located and hard space constraints of the warehouse floor area (no possibility to increment the area). A new storage method should be designed avoiding an expansion of the storage floor area.

In this work, the redesign of the warehouse begins from picking operations; however, it is necessary to think about the four basic activities of the warehouse together to be able to deal with the best decision variable configuration. There is the need of developing a cause-effect relationship model (see Section 3) which helps the analysis of the constraint propagation between the different sections, which is highly correlated with the tight resource constraints imposed to each section.

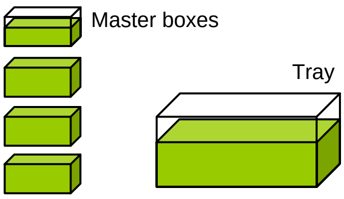

Fig.2: Free space in trays and boxes

2.1 Basic storage area characteristics

A trade off between non productive space usability and non productive operations was analyzed using a dynamic simulation model. One of the conclusions was, for example, large trays increase the used storage floor area and decrease the replenishment operations; and small trays decrease the used storage floor area but demand an intensive replenishment policy.

Thus, a manual warehouse with new policies has been designed considering some automatic warehouse characteristics such us product to operator picking policy to avoid constraint propagation. Using a flat tray design, a considerable amount of references can be placed in front of the picker (see Fig. 3 left), and thus it is possible to minimize the picking travel time while increasing the replenishment tray operations. So, by using a cause-effect relationship model, it is possible to determine the best configuration were the increment on human resource at replenishment operations (receiving section) could be compensated by the benefits of optimizing picking operator travel time (picking section). At the same time, there is no increase, and even a decrease was achieved, of the storage floor area (optimal occupation rate factors into the trays).

Fig.3: Multi-Tray concept, ergonomic simulation image and designed shelf example

2.2 Storage structure design

To deal with the new storage policy, trays and shelves should be designed to fit as much SKUs (storage keeping units) as possible into as less shelves surface as possible. This kind of compacting approach requires the evaluation of the maximum number of pickings of the same SKU during a day to avoid constraint propagation between receiving-storage-picking sections due to a stock rupture of a certain SKU during the picking operation.

In this particular optical warehouse, two types of frames were considered for the new tray design, one for glasses and one for sunglasses. Once the trays were designed, it was necessary to design the shelves where the trays would be located.

Thus, a new model with the necessary volumetric characteristics must be developed to avoid again constraint propagation between sections. Since two types of trays were designed, two different shelves were also designed (see one of them in Fig. 3 right). To validate the proposal, an ergonomic model should also be formalized to determine if all the points were accessible for a human operator and evaluate the Methods-Time Measurement (MTM) times (see Fig. 3 middle).

In a similar way, the shipping policy should be adapted according to the cause-effect relationship with respect the models developed for the other sections, preserving certain quality factors inherent to the shipping section, which usually is to consolidate the POS travel trays before hard deadline delivery times.

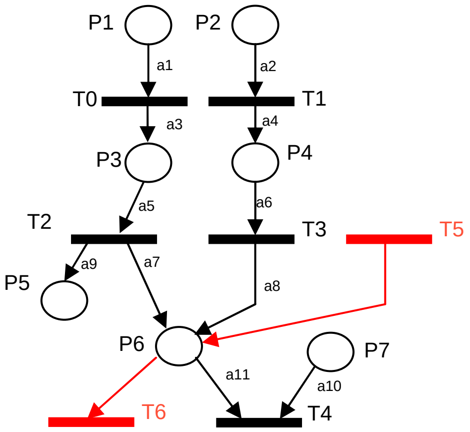

Fig.4: Material flow CPN model

3 Coloured Petri Nets Models

There are different modelling formalisms like flow chart and others which can be used to model a system; however, petri nets (PN) allows the engineers to develop a conceptual model of any system and to study the cause/effect relationships in it. A PN is a kind of bipartite and directed graph with two kinds of nodes [2]: places (represented by circles), and transitions (represented by rectangles), which are alternatively connected by arcs. Places can contain a non-negative number of tokens. Transitions represent events of the system, places represent cues and states and tokens represent the number of elements into the places. Coloured Petri Nets (CPN) [2,5] are a class of high level nets that extend the features of basic PN. The two most basic and important differences are that CPN use tokens which are arbitrarily complex data, and inscriptions on arcs (arc expressions) and transitions (guard functions). These characteristics make the CPN a powerful modelling tool to describe the material flow and the cause/effect relationships in most logistic systems.

Fig. 4, Table 1 and Table 2 illustrate the CPN developed to describe the basic material flow into the warehouse, from the frames arrival (represented by transitions T0 and T1) until the frames dispatching (represented by T4 and T6). There are two types of flow, new collection frames and frames for replenishment. The major part of the new collection frames goes directly to the POS and some of them go to the storage area (P6). The replenishment frames go to the storage area. The model also includes the reverse material flow from the POS to the warehouse. Part of these returned frames are sent to the suppliers because they are expired (no more in fashion). The others are sent to POS where they can be sold.

This model and historic data obtained from the company were used to study the evolution of the amount of material and references in the warehouse and to estimate the maximum volume that could be absorbed by the storage subsystem.

Once the needs for shelves and trays were determined, it is necessary to develop a CPN for each section to describe all its operations. Due to the "bottom-up" characteristic of the CPN formalism a complete cause-effect of all the events in the warehouse can be achieved. All these conceptual models are used to develop a 3D operational model of the system and use simulation to determine an acceptable layout configuration under different policies for the different operations, the number of employees and equipment needed to satisfy both: production demands at a particular rate and distribution demands to POS under a time window constraint.

Places definition	
P1	Supplier frames for replenishment according to a file
P2	Supplier frames for new collection according to a file
P3	New collection frames at the supplier reception area
P4	Replenishment frames at the supplier reception area
P5	New collection to be dispatched
P6	Warehouse storage area
P7	Frames to be dispatched according to a file

Table 1: CPN model specification - Places

Transitions definition	
T0	Arrival of new collection frames at reception supplier area
T1	Arrival of replenishment frames at reception supplier area
T2	New collection frames carried to the dispatched area or to the warehouse
T3	Replenishment frames carried to the warehouse
T4	Warehouse frames carried to the dispatched area
T5	Frames from points of sale
T6	Old frames returned to suppliers

Table 2: CPN model specification – Transitions

4 Simulation Results

The simulation model is based on the CPN models and it is implemented using QUEST, a complete 3D discrete event simulation package that is designed for simulating manufacturing processes [26].

Different experiments confirmed that the new layout configuration could support the 25% increase of frames to be stored due to the 57% increase of POS, and the new design permits to save 80 m^2 in the storage area (shelves and trays) which can be used to absorb the lack of control on the suppliers. However, they also confirm the need of: new storage policy, new combined picking policy, new tray replenishment policy and new transportation/routing policy, which were also determined. Furthermore, experimentation with the model under different scenarios, leads a decrement of 2 employees (in comparison with the company estimation) to support all the picking operations.

The main benefit of the developed cause-effect simulation model is the possibility to guide the redesign experiments to deal with a recurrent cost lower than the one estimated by the company, and with a really low one time cost.

4.1 New Policies

Storage policy: The lack of space force the location of master boxes using all the possible space of the shelves to get an 80-85% of occupation rate. This type of storing can be chaotic, therefore radio frequency (RF) is introduced to know where is located a master box of some particular reference, how many master boxes are in the warehouse, how many frames are into each master box and into each tray.

Picking method: An approximation of the product to operator method will be use for the supplying of graduate glasses and sunglasses to the production line thanks to the trays and shelves design. However, the warehouse is also used for distribution of non graduated sunglasses to the costumers; therefore operator to product method must be used for this job. Picking lines should be ordered by SKU in just one list for all the costumers and the order of the SKU's (frames) will be as the order of the SKU's in the warehouse, minimizing the travel time of the pickers.

Tray replenishment policy: It is necessary to use a new policy to guarantee no empty trays during the picking process. Using historic data and the experiments results it was possible to evaluate the number of trays to be replenished every day; and using the RF technology and a new replenishment algorithm less employees are needed for this operation. It is easy to know that a proper identification of the tray to replenish and the master boxes from which it will be replenished decrease the operator travel time.

Routing policy: A better human-task assignation has been evaluated according to the simulation model in such a way that the picker focuses his work just in the picking process avoiding constant perturbations as transport operations to fit production subsystems. These operations which perturb the picker have been assigned to other employees.

5 Conclusions

Simulation has been used to design a warehouse under several tight constraints. It has been done making decisions at strategic, tactical and operational level together and treating the different four warehouse section operations as only one activity integrating all of them.

This paper has illustrated by means of a real case study, a new approach to integrate warehouse layout configuration, storage policy design, replenishment policy design, picking policy design, routing policy and also trays and shelves sizes design with the minimum number of employees taking into account different aspects which act as constraints, while balancing and decreasing as much as possible the one time cost and the recurrent cost.

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