Abstract: The actual socio-economic dynamics and the aggressive competition on a global scale lead companies to frequent revision of their organizational structure, strategic objectives and decision-making processes. Organizations need, therefore, some methods that can provide for an innovative approach to their investigations to business problems. Even if the publishing storm around JIT may have subsided to a certain degree in recent years and many analytical methods have been published for its analysis, most of the academic papers concerning pull production suggest Discrete Event Simulation (DES) for systems management. Only little attention has been paid to System Dynamics (SD) applications. In this paper a SD model for a Single-Stage Multi-Product Kanban system will be proposed and tested under different demand patterns.

Key-Words: System Dynamics, Pull Production, Kanban, Simulation

1 Introduction

The actual socio-economic dynamics, the aggressive competition on a global scale, more educated and demanding customers and a rapid pace of change in process technology, lead companies to frequent revision of their organizational structure, strategic objectives and decision-making processes [1, 15]. This essentially means that companies have to show great ability in adapting to changes imposed by their own target market [16, 17]. Organizations need, therefore, some methods that can provide for an innovative approach to their investigations to business problems in order to [2]:

- identify the main cause-effect relations which characterize the environment in which they operate;
- find new approaches allowing for better control on production systems and more effective use of the enterprise resources.

In this regard, System Dynamics (SD) provides a useful interpretation of business contexts, analyzing how policies and decisions affects the structure of companies and the dynamics of the available resources [13].

Even if the publishing storm around JIT may have subsided to a certain degree in recent years [11] and many analytical methods have been published for its analysis [10, 3], the kanban system is still a subject of active research and its potential for significant improvements of operations is documented by several studies [12, 5]. Particularly, in this paper a SD model for a Single-Stage Multi-Product Kanban system will be proposed and tested under different demand patterns.

2 Problem Formulation

As is well known, in pull systems the customer acts as the only trigger for movement. Demand is transferred down through the stages of production from the order placed by customers, achieving a continuous flow at the production system. However, where this is not possible, according with lean production principles, a kanban pull supermarket will decouple processes, avoiding stocks increase: the supplier workstation will produce output only on the instructions of the customer workstation (kanban production), providing for what have been consumed.

Generally speaking, each item picked-up from the store determines a replenishment signal: a production card is collected in a special board that displays items consumption and then used to start production according to the sequencing rules of the upstream section (Fig. 1).

Fig. 1 - Kanban supermarket management system
Thus the upstream production will be “pulled” by the items requested in the supermarket, where the continuous flow is broken, and the lot production process is implemented, aiming at minimizing setup and change over time. It is noticeable that determining the exact quantity of each product code to be stored in the supermarket is essential for the efficiency of the system. Particularly, they must be considered:

- daily output of each product line;
- number of items stored in each bin;
- daily "milkrun" frequency (replenishment rate);
- safety stocks or buffers.

In this paper the effects of the dynamic behavior of a Single-Stage Multi-Product Kanban system on the suitable size of its supermarket will be analyzed. The system consists of one production unit in which three different products are made, one supermarket and one kanban board to collect and manage work orders according to a pull logic.

3 Literature Review

System Dynamics is an approach that combines theory, methods and philosophy for complex systems study. Particularly, concepts drawn from the field of feedback control are used to analyze policies, decision-making processes and time delays effects on system behavior [4]. The logic is extremely pragmatic and it’s based on System Thinking where different building blocks (elementary circuits) are put together to generate representations of more complex systems [13].

Six basic steps can be identified and summarized as follows (Fig. 2):

1. Identification and description of the system to be analyzed;
2. Analytical description of the system in terms of key variables and equations to be considered. The dynamic formulation of the hypotheses aims at explaining the basic structure of causalities among the investigated variables (System Dynamics Tools);
3. Developing of a formal simulation model and its implementation;
4. Alternative policies analysis and model deepening/review;
5. Results discussion and implementation planning;

It must be specified that these steps may be modified as appropriate and that one can go back to a previous step so to improve the understanding of the system. Most of the academic papers concerning pull production suggest Discrete Event Simulation (DES) for systems management and control [7, 14] and only little attention has been paid to SD application in this field. In [9] SD principles are used to build a simulation model of a Multi-Stage Kanban system. To check model consistency, several simulation have been carried out. The real aim of the simulations was experimenting system flexibility in terms of capacity to adapt to sudden changes. Simulations were also useful to analyze different management policies and system behaviors in case of unpredictable situations. In particular, the response of the production system to specific, little variations was examined (such as small changes in demand). Even if the model is rather straightforward, the main objective was to show SD effectiveness in JIT Kanban system modeling.

3.2 Model structure

A deep insight into the considered system and the hypothesis on which the model is based can be found in [8]. Powersim Studio® (vs. 2005) was adopted to formalize the model. Three Stocks (level variables) were used to represent:

- the supermarket;
- the green-white zone of the kanban board;
- the red zone of the kanban board;

while Flows were used to represent:

- the production rate;
- the demand rate;
- the inflow rate of kanbans into the green (red) zone;
• the outflow rate of kanbans from the green (red) zone.

Particularly, a specific product is assembled (determining an outflow from the supermarket) only when it is requested from the customer. In turn, the picking from the supermarket determines production orders that will replenish the store (Fig. 3 - The Supermarket logic Fig. 3).

It should be noted that the green-white zone and the red one were separately modeled in order to identify involved variables and to better understand their patterns of operation.

Anyway, the green-white zone size (Green-White Zone Stock) increases at “Kanban In” rate, which represents production requests, and decreases at “Kanban Out” rate, which represents assembly requests. Really, there’s a kanban inflow in the green-white zone only if (Fig. 5):

\[ \text{Diff } 1 = \text{Green-White Zone} - \text{Threshold Limit} > 0 \]

that is only if there’s still some space in the kanban board column associated with the considered product. The auxiliary variable:

\[ \text{GAP} = \text{Threshold Limit} - \text{Green Zone Queue} \]

determines what kind of product will have higher priority hold as proportional to the probability of entering the red zone.

The size of the green-white kanban zone and the red zone one are upper bounded by two auxiliary variables which, in turn, work like inputs for the supermarket. This is because before processing any request form the customer some safety stocks are needed for each specific product. Therefore, the initial size of the supermarket was set for each product \( i \) as:

\[ \text{Supermarket Initial Size}_i = \text{Threshold Limit}_i + \text{Red Zone Size}_i \]

This initial stock level in the supermarket, however, does not exceed the maximum size of each column in the kanban board.

As previously mentioned, when items are picked from the supermarket to perform the assembly, a certain number of production kanbans will enter the green zone of the kanban board (or at worst the red zone).

The green-white zone of the kanban board is depicted in Fig. 4.

The red zone of the kanban board is depicted in Fig. 6.

The sub-model operates as the one discussed above and the priority assessment model showed in Fig. 5 applies in the same way too: the “Red Zone GAP” variable defines the
“Red Priority” variable that in turn determines which of the three products has the higher production priority. Finally the “Priority” variable, combining “Green Priority” and “Red Priority” variables, determines which kanban has to be processed. In this way production can replenish the supermarket once production capacity is assessed (Fig. 7).

Fig. 7 - Pull production flow

5 Results and discussion

Simulations were carried out to test the model in two scenarios characterized by different demand trends. Furthermore, it will be assumed:

- \( \text{Threshold Limit} = [6; 7; 9] \);
- \( \text{Red Zone Size} = [3; 5; 7] \).

These hypothesis result in the initialization of the Supermarket on \([9; 12; 16]\).

5.1 Case 1 – Results under constant demand

Considered demand patterns are shown in Fig. 8. It must be noticed that it was assumed:

\[
\text{Demand}_{P1} = \text{Demand}_{P2} = 5 \text{ pcs/day}
\]

The Green-White Zone size of each item initially increases according to demand patterns and required production times (Fig. 9)

Fig. 9 - Green-White Zone Size

However, when the Threshold Limit is reached a further request of the item determines the entry of the same one in the red zone and, hence, an increase of the Red Zone size (Fig. 10).

Fig. 10 - Red Zone Size

This size begins decreasing as soon as the system starts producing the items corresponding to the red kanbans, consistently with their priorities. At the same time, while Supermarket size exhibit a maximum 43% decrease for Product 1, there’s a maximum 25% decrease for Product 2 and a maximum 33% decrease (22% increase) for Product 3 (Errore. L’origine riferimento non è stata trovata.). Supermarket size varies until a dynamic equilibrium is reached between production flow and assembly flow.
5.2 Case 2 – Results under variable demand

Considered demand patterns are shown in Fig. 12.

With regard to the Green-White Zone size, the initial trends are quite similar to those showed in the previous case, since demand is steady up to period 4 (Fig. 13). When demand goes down, the zone size (whichever the product) decreases too and levels off when demand is zero.

Similarly, the Red Zone size for Product 3 initially increases but quickly falls as no more requests have to be met (Fig. 14). As it concerns Product 1 and Product 2, assumed demand trends (and priorities achieved) are not enough for Red Zone size to increase. This last consideration affects Supermarket size too: there’s no further slope growth in Product 1 and Product 2 trends (from period 4 to period 5). However, whichever the product, Supermarket size quickly increases after period 4 until it reaches stable values when items demand falls to zero.

6 Conclusions and future developments

The aggressive competition on a global scale lead companies to frequent revision of their organizational structure, strategic objectives and decision-making processes. Investigating these changes, learning how the elements and structure of a business process can bring about such changes and how the performance of the process changes over time is nowadays critical for companies to survive. The methods of Systems Thinking provide firms with tools for better understanding management problems, supporting,
at the same time, a pro-active behavior, allowing a quick and effective adaptation to changes. In this paper System Dynamics has been adopted to analyze the dynamic behavior of a Pull Kanban production system. Particularly, the kanban board has been modeled considering two stock variables, one for the green-white zone and another one for the red zone, while kanban flows are used to determine the supermarket size. Simulations were run under two different demand patterns. The dynamic evolution of the interest variables is quite consistent with what was expected in theory. This proves the reliability of the relations adopted in the model. However, model robustness might be further tested as:

- different production times;
- different level of service and safety stock policies;
- Multi-Stage Multi-Product Kanban production systems;

could be considered. In any case, the model could be useful when taking strategic decisions in unpredictable market conditions due to the increasing frequency of new products introduction, changes in parts for existing products or fluctuations in product demand and mix.

References: