Implementation of Just-In-Time Policies in Supply Chain Management

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Abstract: This Paper focuses on the implementation of Just-In-Time (JIT) in Supply Chain Management (SCM) context. Three Pull Control Policies (PCPs), developed for controlling the inventory level, are discussed. Kanban, ConWIP, and a hybrid PCP, are recognized for implementation in multi-echelon, multi-stage, and multi-product supply chains. The performance of each policy is measured through three measurement criteria. Considering the uncertainty, the performances of policies are evaluated via a Fuzzy AHP method. For, identification, performance measurement, and evaluation of PCPs the study proposes an integrated approach. The approach explains the PCPs mechanisms, measurement criteria formulations, and multi criteria decision making methods. Finally, the solution approach is examined through a case study.

Keywords: Just-In-Time, Supply Chain Management, Pull Control Policy, Kanban, ConWIP, Analytical Hierarchy Process, Fuzzy, Multi Criteria Decision Making

1 Introduction

Introduction of strict governmental regulations and the fast changing demand trends require the organizations to implement competitive strategies [1]. However, excessive inventories limit the capability of producers to modify their products in response to change. Blocked by a high level of inventory in the network of a supply chain system, a new product is to wait behind the existing stock before being introduced to the market. JIT is an ideology first developed to control the inventory level in manufacturing systems. Investigating this ideology in a greater context of SCS – which includes manufacturers, suppliers and distributers – is the focus of this study. The purpose of this study is to implement, compare and evaluate the JIT policies in a greater context of Supply Chain Management (SCM). Kanban and ConWIP are the two major pull control policies (PCPs) that were first developed for controlling the production level in manufacturing systems [2]. Both policies use Kanban cards that circulate in loops and authorize transactions. The transaction can be a production, assembly, or transportation. The difference between Kanban and ConWIP system is in designing the loops in which the kanban authorizations circulate. If every two neighbouring station have a designated loop of kanban sets the system is Kanabn, and If the entire network shares one loop of kanbans the system is ConWIP. Combining the two systems various hybrid pull policies can be developed. This study considers the hybrid systems that are defined based on designing Kanban-ConWIP loops in a network. The procedure to combine the policies and produce hybrid systems is further explained in Section 3.1.

This research translates the implementation PCPs from the context of manufacturing to SCM. The recent studies on SCMs emphasize the requirement of supply chain members to effectively communicate between each other [3]. Controlling the inventory level through local communications between suppliers, manufacturers, distributors, and sale points is therefore a significant issue. PCPs are by definition the local communication of supply chain members to control the supply chain inventory via authorization kanbans. However, certain specifications of supply chains require the network to be tailored accordingly. This study proposes an approach to implement PCPs in a multi-product, multi-echelon, and multi layer network. Such a network is considered to represent a common supply chain network consisting of entities such as suppliers, manufacturers, distributors and sales points. A description of the studied supply chain network is available in Section 4.2.

The questions in this field are not limited to what policies enable the controlling and how the policies are reflected in SCM context. But this study also seeks to answer that which of the policies is more efficient. Therefore, three objectives are designed for this study:

- To identify the JIT strategies for controlling the excessive inventory and improving the response to actual demand
- To measure the performance of PCPs in multi-product multi-echelon, and multi layer supply chain networks
- To evaluate the PCP alternatives based on designated criteria with respect to uncertainty

The implementation of PCPs is reported in various industries. Continues popularity of pull strategies among industry practitioners is apparent from the cases. The literature shows the adaptability PCPs in industries with different environments [4]. Section 2 reviews the literature on PCPs implementation in manufacturing context. A review on JIT implementation in SCMs is also presented. The results show that despite extensive studies investigating the PCPs in manufacturing context, the research on PCPs implementation is supply chain is limited. This study addresses the gap by proposing an approach to identify JIT policies for SCM, implement, and evaluate the alternatives.

On the other hand, the success of JIT implementation in supply chain depends on multiple factors. Achieving lower levels of inventory, together with minimum lost demands and lead time is important in evaluating the PCPs. In response to this significant issue, this study is focused on analysing and prioritizing the PCPs based on multiple objectives. The evaluation of measurement criteria, based on SCM expert's judgment, involves uncertainty. The proposed approach in section 4 responds to the ambiguity in linguistic expressions via implementing principals of fuzzy set theory. The approach is examined by conducting an experiment based on a real case study. The results from the case study contributively reflect the major evaluation priorities from a real supply chain perspective.

2 Literature review

Researchers argued that the better performance of JIT and pull systems is due to their responsiveness to the actual demand [5]. The performance of push type systems relies on the forecasting demand in which errors occur [6]. The amplification of forecasting error, especially in a broad network of supply chain members, negatively impacts the performance. This issue makes JIT a suitable methodology for SCM in comparison to forecast based systems. Takahashi and Nakamura compared the performance of pull and push systems and proposed a hybrid push-pull policy in SCM context [7]. Their study merely considered Kanban system as a representative for pull systems. Later, Takahashi, Myreshka, and Hirotani investigated three pull type systems in SCM context [8]. The comparison was conducted among ConWIP, synchronized ConWIP, and Kanban systems. One of the significant contributions of their research was prioritizing the inventory level in deferent stations. This issue is significant in the context of SCM as the cost of excessive inventory varies for each supply chain member. Yet, the level of inventory was the mere base of their comparison.

The study of Kojima, Nakashima, and Ohno included important measurement criteria other than inventory level. Their evaluation was based on inventory level, production quantities and total backlogged demand in stages [9]. However, their studied supply chain network was single layer which does not represent a common supply chain with multiple layers.

Other researchers developed the literature by recognizing common issues in SCM such as, reorders, returns, and risk [10,11]

Multi criteria decision making (MCDM) methods were used for JIT policy evaluation in manufacturing systems [12].
MCDMs are applied in studies that compare several PCPs with regards to multiple measurement criteria. Due to the uncertainty involved in measurement and comparison of criteria, which involves expert judgment, fuzzy set theory principles were combined with MCDM methods [13]. However, the application of such combinatory methods are applied in manufacturing systems and the studies that use such methods in JIT-SCM are rare.

3. Problem formulation

To identify, measure, and evaluate the PCPs in SCM, following the objectives of this research, this section presents suitable methods for each purpose. The identification of the PCPs in section 3.1 recognizes the JIT mechanisms to control the network. In section 3.2 the measurement criteria are explained and formulated. Section 3.3 describes the evaluation methodology to rank the best alternatives with regards to uncertainty.

3.1 PCP mechanisms

In Kanban control system, a permission signal/card called kanban is used to control and limit the release of orders to every member of supply chain. Different sets of kanbans circulate in between every immediate member. Members function when there is a kanban that authorizes the operation. Otherwise, it waits until a kanban is available. Every order that is under process has a kanban attached to it. After the processing, the order and the attached kanban card move to the proceeding member. When the proceeding member receives the order, the kanban returns to the previous station. This repeats until the product is complete at the final station.
A generalization of the kanban system, when there is only one set of kanbans circulating in the entire supply chain, is called ConWIP. Therefore, it can be regarded as a one-step kanban system. The ConWIP system operates am order arrives to the ConWIP line. The kanban at the upstream of the supply chain is added to the order. If no kanban is available, the order waits in the backlog, until a kanban becomes available. The order together with the kanban are conveyed through the supply chain. That allows the orders to be processed by members. When the job is processed at the last station, the card is removed and returned to the beginning of the line where it is connected to the next order waiting in the backlog. If there are no new orders backlogged, the kanban stays till a new order arrival. This repeats until all demands are satisfied [14]. In a multi- layer network the final members communicates with all preliminary members (usually suppliers) by transferring the authorization kanban to them all simultaneously. Considering that there is a member that multiple lines of members feed that specific member, we have a synchronizing point in the network. By assigning that member to be the begging point of a ConWIP loop set for the preceding members and the final point of a ConWIP loop set for the proceeding members, a hybrid system can be developed. The number of Kanabn loops is the highest in Kanban policy followed by hybrid and finally the ConWIP policy has only one loop.

3.2 Measurement criteria formulations

The three measurement criteria considered by this study to find the performance of PCPs is the average inventory level (I), the number of backlogged orders (B), and waiting time (W). Following formula is modified for measuring the average inventory level:

$$I = \frac{\sum_{i=1}^{n}\sum_{t=1}^{t_{max}} I_i(t)}{t_{max}} \quad (1)$$

Where *t* and *n* are the indexes of time and members respectively
To calculate the $I_i(t)$ the following formula is used [8]:

$$I_i(t) = I_i(t-1) + P_i(t-L_i) - P_i(t) \quad (2)$$

Where L_i is the lead time for member *i* and $P_i(t)$ is the production quantity of member *i* started at *t* and completed after the lead time. Refer to "Comparing CONWIP, synchronized CONWIP, and Kanban in complex supply chains" [8] for further explanation.
Every time that an order arrives and is not satisfied immediately a backlogged order is counted.

$$B = \frac{\sum_{t=1}^{t_{max}} B(t)}{t_{max}} \quad (3)$$

Where $B(t)$ is the number of counted backlogged orders from *t* until *t+1*.

The time that orders wait to be satisfied is the third measuring criteria.

3.3 Evaluation methods

A popular approach to solve MCDM problems is Analytical Hierarchy Process (AHP) [15]. A systematic framework is provided by this approach to consider multiple evaluation criteria. The capability of AHP to include qualitative measures and combine them with quantitative values is advantageous. However the pair-wise comparisons can only be based on crisp values. This shortage is addressed by researchers through introducing the principals of fuzzy set theory to deal with the ambiguity in linguistic expressions. The approach proposed by Chang combines fuzzy set theory with AHP method [16]. Among several Fuzzy AHP methods proposed by researchers, this study applies extent analysis approach of Chang [17] due to its convenience and examined practicality in industrial cases. let X = $\{x_1, x_2, . . . , x_n\}$ and U = $\{u_1, u_2, . . . , u_m\}$ be the object and the goal set. Therefore for every objective *m* extent analysis (M) based on each goal can be conducted:

$$M_{gi}^1,\ M_{gi}^2, \ldots\ldots M_{gi}^m, \quad i = 1,2,\ldots\ldots,n \qquad (4)$$

Where M is a triangular fuzzy number.

The calculations based on Chang's extent method are provided bellow. For further explanation please refer to "Applications of the extent analysis method on fuzzy AHP" [16]

The fuzzy synthetic extent with respect to the *i*th object is obtained as follows:

$$S_i = \sum_{j=1}^{m} M_{gi}^j * \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^j\right]^{-1} \qquad (5)$$

Then the degree of possibility of $M_2 = (l_2,m_2,u_2) \geq (l_1,m_1,u_1)$ is calculated:

$$V(M_2 \geq M_1) = \sup\left[\min(\mu_{M1}(x), \mu_{M2}(y))\right] \qquad (6)$$

And can be equivalently expressed as follows:

$$V(M_2 \geq M_1) = \text{hgt}(M_1 \cap M_2)$$

$$= \mu_{M2}(d) = \begin{cases} 1, & if\ m_2 \geq m_1 \\ 0, & if\ \ l_1 \geq m_2 \\ \frac{u_2 - l_1}{(m_2 - m_1) - (u_2 - l_1)}, & otherwise \end{cases} \qquad (7)$$

Where d is the ordinate of the highest intersection point *D* between μ_{M1} and μ_{M2}.

To calculate the degree of possibility for a convex fuzzy number to be greater than *k* convex fuzzy numbers M_i ($i = 1,2,. . . ,k$) the following formula is used according to Chang

$$V(M \geq M_1, M_2, \ldots\ldots M_k) = V[(M \geq M_1) \text{ and } (M \geq M_2) \text{ and } \ldots..(M \geq M_k)] = \min V(M \geq M_i),\ i=1,2,\ldots.,k. \qquad (8)$$

And finally the normalized weight vectors are:

$$W = \left(d\ (A_1),\ d\ (A_2), \ldots\ldots\ldots d\ (A_n)\right)^T \qquad (9)$$

Where W is a non-fuzzy number.

4 Proposed approach

The proposed approach of this study provides a framework for recognizing, measuring the performance, and evaluating the JIT PCPs in SCM context (Section 4.1). The solution provided in this study is examined through a case study in section 4.2

4.1 Solution steps

Identifying the criteria and alternatives is the first step in this approach. To build the MCDM problem the measurement criteria described in the previous section is considered as the problem criteria and the alternatives are the PCPs. The design of PCPs is based on the case. Setting the kanban loops between suppliers, manufacturers, distributors and warehouse creates the alternatives.

The next step is structuring the model in a hierarchical format. This is a necessity for applying AHP solution. Therefore to achieve the objective of higher efficiency, the measurement criteria are laid out horizontally. The last layer is the alternatives. Kanban, ConWIP and the hybrid PCP are set as the alternatives. In this structure each alternative is connected to all three criteria. The last step is building the pair-wise comparison matrices between criteria and alternatives. Since the measurement criteria are varying in nature and have different values based on every case, a weight is assigned to the criteria. The Fuzzy AHP technique is applied to find the weights for criteria. Triangular fuzzy numbers presented in Table 1 are used to convey the linguistic expression of supply chain experts. The linguistic terms for this purpose are expressed to determine the level of importance

Similarly a pair-wise comparison of alternatives with respect to each criterion is conducted. The linguistic expressions reflect the level of efficiency.

Table 1. Linguistic scales for importance and efficiency [18]

Linguistic scale for importance	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Absolutely equal (A)	(1, 1, 1)	(1, 1, 1)
Equally Important/efficient (E)	(1/2, 1, 3/2)	(2/3, 1, 2)
slightly more Important/ efficient (SM)	(1, 3/2, 2)	(1/2, 2/3, 1)
moderately more Important/ efficient (MM)	(3/2, 2, 5/2)	(2/5,1/2, 2/3)
strongly more Important/ efficient (TM)	(2, 5/2, 3)	(1/3, 2/5, 1/2)
extremely more Important/ efficient (EM)	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)

4.2 Experimenting the approach

To inspect the validly of the proposed approach the implementation of the Kanban, ConWIP and hybrid PCP is examined for a real case. ImantakCo. supply chain that produces electro-mechanical parts for a car manufacturer is selected for this study. The company's supply chain applied Lean techniques to eliminating the wasteful steps in production distribution.

The supply chain includes two parallel layers, each including a supplier and a manufacturer. Then an assembly plant is the synchronizing member that is fed by the two lines. A distributer is located after the plant and finally a warehouse where the final product is stored for customer demand. To implement Kanban policy in proposed model, for each neighbouring station exclusive kanbans are designated. kanbans are only circulating within the assigned work station. For the suggested production and assembly line 6 sets of kanban loops are considered.

For the ConWIP implementation there is only one group of kanbans that circulate in between all members. Once a part reaches the end of the supply chain the kanban travels back to the suppliers.

For hybrid system there are three sets of kanbans. The first set circulates between the warehouse and the synchronizing member which is the plant. This loop creates a three stage ConWIP sub-system. The other two loops are set between the plant and each supplier. Similarly they each create a three stage ConWIP sub-system.

Measuring the criteria is conducted through 1000 runs of discrete event computer simulation with 100 warm up rounds. The evaluation of results via AHP technique is presented in Table 2. The results show that the three ConWip loop hybrid system has the best ranking for the studied case.

Table 2. PCPs ranking

PCPs	Weight	Rank
Kanban	0.264	3
ConWIP	0.352	2
Hybrid	0.384	1

6 Conclusions

JIT is practiced widely to minimize the costs and improve the production performance. Reserving minimum work in process is aimed by JIT system. This Paper shows how Kanban and ConWIP and hybrid PCPs can be implemented in the context of SCM. The comparison PCPs based on the proposed approach using computer simulation proved the superiority of a proposed hybrid system in supply chain. Besides the level of inventory two other performance measurements are presented. The proposed approach comparison considers a multi-level network. This research introduces a systematic method to design, perform and evaluate the systems. The excessive inventory, as a source of cost in SCM, can be limited by appropriate selection of PCP.

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