Purchasing and raw materials management in science-based industries

Einkauf und Rohmaterial Management in wissenschaftsabhängigen Industriebereichen

Achat et gestion des matières premières dans les industries à base scientifique

研究開発産業における仕入・原材料管理

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Abstract: 'Just in Time' (JIT) methods have recently been receiving extensive publicity and acclaim as one of the major factors in Japan's industrial success. However, the effort of corporate and plant managers throughout the rest of the industrialized world to adopt and imitate the JIT policy, setting goals of reaching the Japanese inventory levels as closely as possible for work in process and raw materials, have been less than successful. Sometimes, as in the Science-Based Industries, adoption of JIT as a purchasing policy does not yield an optimal solution. The paper distinguishes between 'Big JIT' – the philosophy and strategy of the JIT methods, which can be applied to all types of industries, and the 'Small JIT', the scheduling mechanism – namely the Kanban, which cannot be applied to Science-Based Industry. The paper focuses on purchasing policy in Science-Based Industries, where caution must be exercised in cutting raw materials inventory levels. An analytical model is applied to meet with the requirements of Science-Based Industry.

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Keywords: Inventory management, science based industry, Just in Time, purchasing policy.

Zusammenfassung: Die 'Just-in-Time' (JIT) Methoden haben in der jungsten Vergangenheit große Publizität und Bestätigung, einer der Hauptfaktoren des japanischen Industrieerfolges zu sein, erfahren. Die Bemühungen der Konzern- und Betriebsmanager der restlichen industrialisierten Welt bei der Adoption und Imitation der JIT-Politik, der Zielsetzung, die japanische Art der Lagerhaltung in Bezug auf Fertigung und Rohmaterialien so eng als möglich zu kopieren, müssen als wenig erfolgreich angesehen werden. In wissenschaftsunterstützten Industriezweigen erweist sich die JIT-Einkaufspolitik als nicht-optimale Lösung. In diesem Beitrag wird zwischen 'Big JIT' – die Philosophie und Strategie der JIT-Methoden, welche auf alle Arten von Industrieformen angewendet werden kann – und 'Small JIT' – jenem, Kanban genannten Terminhaltungsmechanismus, welcher nicht auf die wissenschaftsunterstützten Industriebereiche angewendet werden kann – unterschieden. Der Beitrag konzentriert sich auf die Einkaufspolitik wissenschaftsunterstützter Industrien, wo Kürzungen in der Rohmateriallagerhaltung nur mit Vorsicht durchgeführt werden können. Ein analytisches Modell wird eingesetzt, um den Anforderungen der wissenschaftsunterstützten Industrien gerecht zu werden.

Sachwörter: Lagerhaltung, wissenschaftsunterstützte Industrien, Just-in-Time, Einkaufspolitik.

Résumé: Les méthodes 'juste à temps' (JAT) ont récemment suscité un intérêt considérable et ont été identifiées comme un des facteurs principaux du succès industriel du Japon. Toutefois, les efforts des dirigeants de sociétés ou des directeurs d'usine dans le reste du monde industrialisé pour adopter et imiter la politique du JAT avec comme objectif d'approcher autant que possible les niveaux des stocks de matières premières et de produits intermédiaires japonais n'ont pas eu le succès escompté. Par exemple dans les industries à base scientifique, l'adoption d'une politique d'achat de JAT ne constitue parfois pas la solution optimale. L'article fait une distinction entre le 'grand JAT' dont les concepts et la stratégie peuvent s'appliquer à n'importe quelle industrie et le 'petit JAT', mécanisme de programmation dénommé Kanban, qui ne peut être appliqué à des industries à base scientifique, où il faut se montrer prudent lorsqu'on diminue le niveau des stocks des matières premières. Un modèle analytique est proposé pour répondre aux besoins des industries à base scientifique.

Mots-clés: Gestion de stocks, industrie à base scientifique, juste à temps, politique d'achat.

要約　近年，「かんばん」（ＪＩＴ）方式が，日本企業の大きな成功要因の一つとして，広く宣伝されてきた。他の先進工業国の企業や工場においても，この「かんばん方式」を採り入れたり模倣して，工程中在庫や原材料在庫のレベルを目標である日本のレベルに何とか到達させようと努力しているが，まだとても成功しているとは言えない。研究開発産業の場合，仕入管理に「かんばん方式」を取り入れても，最善の解決策とはならないことがある。本稿では，「かんばん方式」を「大きなかんばん方式」と「小さなかんばん方式」に区別している。「大きなかんばん方式」とは，「かんばん方式」の原理・原則で，どの企業にも適用できるもの，「小さなかんばん方式」とは，工程管理のメカニズム，いわゆる「かんばん」で，研究開発産業には適用できないものをいう。本稿は，研究開発産業における仕入管理に焦点を当て，原材料の在庫レベルを切り下げるについては注意を要すると論じている。また，研究開発産業の要件を満たす分析モデルを紹介している。

キーワード　在庫管理，研究開発産業，かんばん，仕入管理

1 Introduction

Acknowledging inventory management as one of the main contributors to success, Western manufacturing companies have taken with great enthusiasm to imitating the Just in Time (JIT) methods employed with such telling effect in Japan. In adopting JIT, however, Western corporate and plant managers have focused attention on reaching as closely as possible the Japanese inventory levels, often in total disregard of the quite different nature of the business in which their companies engage.

Most of the JIT literature discusses the benefits to be gained by implementing these methods (Schonberger, 1982, 1986). The main focus is on substantial reduction of WIP (Work in Process), shortening of lead times and improvement of quality. Very little attention is given to raw materials management in research and development (R&D) organizations and the job-shop environment. Other studies compare JIT to the traditional MRP systems or the OPT concepts (see, for example, Fox, 1983a, 1983b; and Plenert and Best, 1986). No alternative models have been suggested for Science-Based Industry (SBI). The purpose of this paper is to create such a model.

This paper discusses the nature and problems of high-tech, R&D, job-shop oriented industry, designated here as SBI. The paper differentiates between 'Big JIT' – the philosophy and strategy, and 'Small JIT' – the scheduling technique, namely, the 'Kanban' pull system. As will be shown in the coming sections, Big JIT concepts and techniques can be adapted to most environments and industries, while Small JIT techniques are limited to repetitive lines, and their use in the SBI is not optimal. Purchasing policy in SBIs needs a specific strategy designed to suit to the nature of these industries. Such a strategy is developed here, using a mathematical optimization model.

Section 2 of this paper defines and discusses the nature and behaviour of SBI. Section 3 specifies the characteristics of assembly-line industry, and shows why Small JIT methods adapt well to its processes. In Section 4 we demonstrate that Small JIT and JIT purchasing are not optimal for SBIs. We present and apply an alternative model for purchasing items in SBIs, giving examples of the model's application and a sensitivity analysis. Section 5 summarizes the conclusions that may be drawn.

2 Science-Based Industry

In order to clarify the term Science-Based Industry it is important to characterize and define its major distinguishing attributes.

The first and probably most important characteristic of this industry is the high R&D content of its product line. Products are often sold on the basis of innovation and superior performance, rather than pure price competition. This in turn adds uncertainty to the system. Examples of SBIs are aerospace industries, industrial and professional electronics, and the high end of the computer industry.

The second important characteristic is the extreme sensitivity of the industry to the timely availability of its products. 'Time to market' is a crucial element and failure to meet the appropriate R&D production cycle time can result in large penalties to the company, and may even put its survival in question. Another potential threat is the ongoing pressure for shorter cycle times in the R&D stage as well as during production (Goldratt and Fox, 1986).

A third major characteristic of SBI is that technology is used as a strategic weapon in the organization. Thus there is more and more pressure for more innovation, the use of new technologies and building an environment that can cope with a high level of uncertainty.

SBI, then, usually employs a substantial proportion of highly qualified people, most of whom hold academic degrees and have a high level of technical expertise. This contributes to the high labour content of the total product cost.

With respect to the purchased parts and materials, the following characteristics are typical of SBI:

(a) In the development stage, which may be seen as an effort at technology improvement, the percentage of components and other raw materials in the total development cost is relatively low (usually less than 15%). At the same time, technological risks, uncertainties arising from knowledge gaps, and rapid changes generated by the suppliers, the engineers and the clients, all need to be managed.

(b) The raw materials cost increases during production (though usually to no more than 40%). The number of components, which are purchased from many suppliers all over the world, reaches thousands of items and sometimes tens of thousands.
(c) Since the competitive race forces engineering to use state-of-the-art components and to change standards of items frequently, the technological life cycle of some of the components is relatively short.
(d) The lead time of the non-standard, state-of-the-art components, which must be used to maintain a competitive edge, is long, uncertain, and may vary from item to item and with time. Since many of the items are relatively new, it is difficult to reduce the lead time or its variance. Part of the lead time and its variance are caused by technological uncertainties.

To summarize, the need to achieve state-of-the-art performance requires the frequent use of non-standard, state-of-the-art components, which increases overall uncertainty because of doubt concerning their availability in time.

The availability of purchased components is one of SBI's constraints. To illustrate, imagine a multimillion dollar communication satellite program, containing thousands of different purchased items. Some of these items are state-of-the-art, special components, often available from a small number of vendors. The lack of one item, which may cost say a few hundred dollars may cause serious delays of the program. In the meantime, excess cost is accumulated on manpower and other expenses leading to significant cost overruns. Adding more uncertainty (due to lead time of purchased items) to the built-in stochastic R&D environment can result in bad due-date performance and high penalties.

3 Repetitive assembly-line processes

The traditional classification divides industrial processes into four major categories: project, continuous processes, repetitive processes, and intermittent processes (Chase and Aquilano, 1985). The term project refers to a one-time mission divided into defined tasks, having a managerial and/or technology network. Continuous processes are exemplified in process industries such as steel, plastics, and chemicals. In repetitive processes, items are produced in large production lots, following the same series of operations as the previous ones. These are exemplified in the mass production of, for example, the automotive and appliance industries.

Intermittent processes are those in which items are processed in small lots or batches, often to customer's specifications. These are typical of job shops, which characteristically turn out individual orders, taking different workflow patterns through the plant and requiring frequent starting and stopping. Usually, the SBI has a job-shop/intermittent process nature.

For better understanding, a clear distinction should be made between JIT as a managerial philosophy (Big JIT), and the JIT scheduler (Small JIT). Big JIT consists of three main parts Total Quality Control (TQC), Total Preventive Maintenance (TPM), and Just-in-Time production. The philosophy and techniques of Big JIT have been widely discussed in the literature (Schonberger, 1982, 1986). Its concepts of avoiding waste, improving quality, and working on small lots are valid for all types of processes and industries.

Small JIT deals with the scheduling of operations and purchased items. The idea is to have the parts just in time, exactly at the time they are needed, and the main scheduling mechanism is a 'Pull' system, or 'Kanban' (see Schonberger (1982)).

Manufacturing parts and assemblies using the JIT scheduler results in minimal inventory (raw materials, work in process and finished goods).

While TQC and TPM can be applied to all types of production processes, Small JIT can be applied only to repetitive assembly lines (Goldratt, 1988). In our opinion, any attempt to schedule all the items 'Just in Time' will not necessarily fit the nature of SBI. Scheduling operations within the plant in a JIT manner is done to avoid waste and reduce WIP. Unfortunately, however, many companies try to reduce the raw materials and purchased items inventory at any cost, and doing this may sometimes reduce the system's throughput and cause reduction in profits. The model shown in the next section demonstrates and explains this issue.

4 A model for scheduling purchased items

This section briefly reviews a purchased items scheduling model which may be applied and modified for use in the SBI. For further details the reader is referred to Ronen and Trietsch (1986).

First we shall introduce the one-item model, and show a heuristic solution for the n-components model. Then, we shall modify the model and apply it in our case.

By way of introduction, let us consider the following special case. A project requires one purchased component, which must be on hand at a specific time, t^*. If the item is received earlier, the project will be completed in time, i.e. without penalties, but an inventory-holding (carrying) cost C will be incurred for each time unit the item is held in inventory after arrival and until t^*. On the other hand, if the component is late, a penalty P is incurred for each time unit of delay, since the whole project will consequently be delayed. In SBI the penalty has a tangible component (legal dues for late delivery) and many intangibles: loss of goodwill, ill-conceived and hasty attempts to catch up by avoiding good engineering rules, and so on.

Assume now that the lead time of the component has a given stochastic distribution, and the project manager has to decide when to place the order in such a manner that the total expected cost of the inventory holding cost and the delay penalty will be minimized.

We assume that the project manager is responsible for all the costs associated with the purchasing decision. Therefore, it is in his or her interest and power to minimize the expected total costs. We also assume that the component's lead time is a stationary stochastic variable with a given distribution. We wish to optimize the scheduling of the order placement, which is the decision variable under the project manager's control.

The objective function is

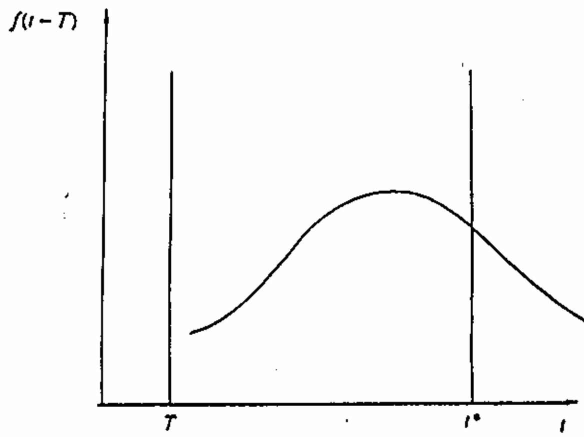
$$\underset{T}{\text{MIN}} \; [E(\text{Penalty Cost}) + E(\text{Holding Cost})] \qquad (1)$$

where T is the time the order is placed. Figure 1 illustrates the relationship between t^*, T and the lead time distribution. Note that the distribution 'starts' at T (the item cannot arrive before it is ordered), and consequently the area to the right of t^*, i.e. the penalty probability, increases with T, as expected. Expanding the objective function (1), we may write:

$$\underset{T}{\text{MIN}} \; [C \int_T^{t^*} F(t - T)\,dt + P \int_{t^*}^{\infty} [1 - F(t - T)]\,dt] \qquad (2)$$

where: t is the current time; $F(\,)$ is the CDF of the lead time; C is the holding cost per period; and P is the penalty cost per period.

Figure 1 The relationship between t^*, T and the lead time distribution



Note that these costs are assumed to be linear. The lead time distribution $F(\,)$ in the SBI has a much larger standard deviation than in the repetitive assembly lines.

Solving equation (2) yields an optimal order point T^*, satisfying

$$F(t^* - T^*) = P/(P + C) \tag{3}$$

Let us modify this result now for the special case of science-based projects:
Let α be the proportion of the purchased items out of the project cost. This ratio is about 10% to 20% in many science-based projects.
Let C_t be the total project cost.
Let C_h be the holding cost proportion of the total cost. This proportion is normally between 20% and 30%.
Let C_p be the penalty cost proportion of the total cost. This is a difficult proportion to determine, since many intangible penalties are involved. Thus,

$$C = C_t * C_h * \alpha \tag{4}$$

$$P = C_t * C_p \tag{5}$$

Incorporating equation (3) into equations (4) and (5) yields

$$F(t^* - T^*) = C_p/(C_p + C_h * \alpha) \quad \text{or,} \tag{6}$$
$$F(t^* - T^*) = 1/(1 + C_h * \alpha/C_p) \tag{7}$$

4.1 Sensitivity analysis

Now, let us carry out a sensitivity analysis of this result:

(A) Sensitivity analysis for α

α is the ratio between the purchased items and the overall project cost. In projects where α is small, the purchase order release will approach zero.

$$\text{If } \alpha \to 0 \text{ then } F(t^* - T^*) \to 1$$

This usually yields a trend toward $T^* = 0$, a result that reflects the tendency of many project managers to release purchase orders at the first possible opportunity. Moreover, in certain cases $\alpha \to 0$ may even yield a negative T^*. In real-life situations it is common for project managers to feel that they should have released the orders 'yesterday'. Thus, the impulse to implement JIT purchasing of raw materials should be carefully checked. As shown here, in certain cases of SBI projects, the opposite attitude is to be preferred. Now,

$$\text{If } \alpha \to 1 \quad \text{then} \quad F(t^* - T^*) \to 1/(1 + C_h/C_p)$$

In this case, the ratio between the holding costs and the penalty cost will result in optimal timing.

(B) Sensitivity analysis for C_h and C_p
If $C_h \gg C_p$ then $F(t^* - T^*) \to 0$. This means that better results will be obtained if the purchase orders are released at the last possible opportunity. This is the usual case of JIT purchasing policy being applied in repetitive assembly lines. In these cases, where the product is standard and treated as a commodity, the penalty is considered less than the holding costs, which can reach an annual high of 40%. Consider, for example, a VCR manufacturer. It is not conceivable to accept late delivery as 40% of the price of one VCR.

If $C_p \gg C_h$ then $F(t^* - T^*) \to 1$; in this case no late-delivery risk should be incurred, and the purchase orders should be released as soon as possible. This case is suitable for SBI. The penalty for late delivery of a unique product, especially in the prototype stage, including the intangible penalties of loss of goodwill and reputation, is, at times, much more than 5% per month.

Let us now investigate a special case. Suppose we have a high-material product (say $\alpha > 0.5$) and the penalty costs are a fraction of the product cost ($C_p < C_t$). If the holding costs are relatively high ($C_h > C_p$), then $F() \to 1$. This will lead to a policy of ordering parts 'Just In Time'. This case is appropriate for assembly-line manufacturing, as in the automotive industry, and thus the JIT policy is treated as a special case of our model.

For SBI the JIT approach to scheduling orders often yields losses and high penalties, because of the low α, high C_p and relatively low C_h.

4.2 Example

Let us assume that the component's lead time has an exponential distribution with parameter μ. The exponential distribution was chosen as an example because of the high standard

Table 1

α	T^*
0.1	−5.14
0.2	−2.49
0.3	−0.98
0.4	0.07
0.2	0.85
0.6	1.48
0.7	1.99
0.8	2.43
0.9	2.81
1.0	3.13

deviation characteristic of SBI. The more innovative the technology, the higher the expected μ.

Thus, $F(t) = 1 - e^{-t/\mu}$

Using the solution of equation (7) leads to equation (8).

$$T^* = t^* + \mu \ln [1/(1 + C_h * \alpha / C_p)] \quad (8)$$

Consider the following special case. We have to assemble a certain item 6 months from now. The item's lead time distribution is exponential, with an expected value of 4 months. The carrying cost of this item is 18% per year, and the penalty cost is 5% per month (60% annually). The purchased parts are 40% of the product cost. Thus,

t^* = 6 months
μ = 4 months
C_h = 18% per year
C_p = 60% per year
α = 0.4

and following equation (8) yields that $T^* = 0.07$ month.

Table 1 shows a sensitivity analysis of T^* as a function of α.

As α becomes larger, the delay in releasing the purchase order becomes longer. This might serve as an illustration of the fact that JIT methods are appropriate where the component costs are relatively high. In SBI, where generally α = 0.1 to 0.2, it will *not* be optimal to adopt these methods. Thus, we should be very cautious in applying JIT purchasing policy to this industry.

Solving the n-item model is much more complicated. Ronen and Trietsch (1986) suggested a good approximation for optimal scheduling by computing a simple lower bound. They achieved this by treating each item separately. Thus, if we have n items, T_i^* (the lower bound time to order item i) will be derived by solving the following equation, for $i = 1, \ldots, n$:

$$F_i(t_i^* - T_i^*) = 1 - C_i/S \quad (9)$$

where C_i is the holding cost for item i, and S is $P + \Sigma C_i$.

In other words, we calculate the T^* for each part independently. By using this policy, the expected penalty will never be greater than that derived by this bound. This may be perceived by managers as a 'conservative policy', because the penalty risks are less than under the optimal policy.

Using this method, we can easily calculate the desired time for releasing the purchase orders.

As n, the number of items in the product, increases, S increases and $F_i() \rightarrow 1$, meaning orders should be released as soon as possible. In the case of SBI, with its complex product comprising many items that need to be assembled, the optimal policy will be such that the JIT purchasing approach is inappropriate.

5 Conclusions

This paper deals with the problems of managing raw materials and purchasing in SBI. We first defined what is meant by the term SBI and described its attributes. Since innovation and shorter cycle time are of prime importance to achieving success in this industry, the penalty for late deliveries is relatively high. For this particular industry, a general model for scheduling purchased items was prescribed.

On the other hand, the assembly line/repetitive process industry has relatively high material content, and the Small JIT approach seems to work well. The confusion about whether or not JIT is appropriate for a given industry or process can be resolved with the aid of division of the concept into Big JIT and Small JIT.

An optimization model was used to solve the scheduling and timing for purchasing components in the SBI. Sensitivity analysis was carried out, and the JIT purchasing concept was reviewed as a special case of this model. It was also demonstrated that the JIT purchasing policy is not optimal for SBI.

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