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Abstract

This paper discusses methods to revise the numbers of e-KANBAN for parts procurement operations from supplier factories. Three policies, i.e. Fixed Interval Review (FIR) Policy, Demand Average-monitored Review (DAR) Policy and Demand Average & Variance-monitored Review (DAVR) Policy are proposed to absorb the fluctuation of parts consumption level, which is created by the downstream shop floor of the production line. The performance of each policy is evaluated by simulation experiments and quantitative trade-off relations between criteria, i.e. Ratio of Line Stops (RLS) and Frequency of e-KANBAN Resetting (FKR), are clarified. Obtained characteristics suggest that DAVR and DAR Policies dominate FIR Policy but each of the former two policies do not hold superiority from the other.

1. Introduction

These years, because of rapid progress of globalisation and information technology in every sector of industry, assets of operations management are transferred among companies without serious obstacles. The same phenomenon also happens in each business function such as in supply chain.

Looking at Just-In-Time technology born in a Japanese car manufacturer some decades ago, many competitors utilize this toolset as so-called lean technology. In addition, information infrastructure starts to absorb this engineering asset into its own domain and modifies it. An example of such diversification is electronic version of KANBAN system called e-KANBAN system. However, according to such a drastic change, traditional know-how becomes obsolete and necessity of new technological development emerges. In this paper, based on the above argument, a new problem on a powerful engineering tool for supply chain management, called KANBAN system, is focused to study.

A contemporary problem surrounds this technology is how to determine the numbers of KANBAN in the recent volatile demand environment. Generally, the numbers of KANBAN are quite sensitive for performance of production-logistics system, e.g. manufacturing system often stops if numbers of KANBAN are not enough, and contrary, work-in-progress inventory will exceed the capacity of buffer space if it is too much.

As both globalisation and information infrastructure are the major causes of demand instability, operations managers and researchers in this area have to cope with this problem. One effective way to overcome this difficulty is to revise the numbers of KANBAN more often than before. And, ironically, e-technology can contribute this subject as it provides quick repetitive response with low cost.

As a matter of research contribution, this paper discusses the way to revise the numbers of KANBAN for parts procurement operations from supplier factories and proposes some policies for reviewing the numbers of KANBAN to absorb the fluctuation of parts consumption level created by the downstream shop floor of the production line.

2. KANBAN System and Its e-version

The mechanism of typical KANBAN system between final assembly factory and parts supplier factory is illustrated in Figure 1. For simple explanation, let us suppose the lot size of parts transportation is one. Each part is transported from supplier factory with its KANBAN, which describes part specification, supplier site, frequency of transportation etc. Then this is qualified and accepted by quality assurance (QA) division of final assembly factory followed by transfer to line side. When each part is required by assembly line, the part and attached KANBAN are separated and assembly operation proceeds for the former.

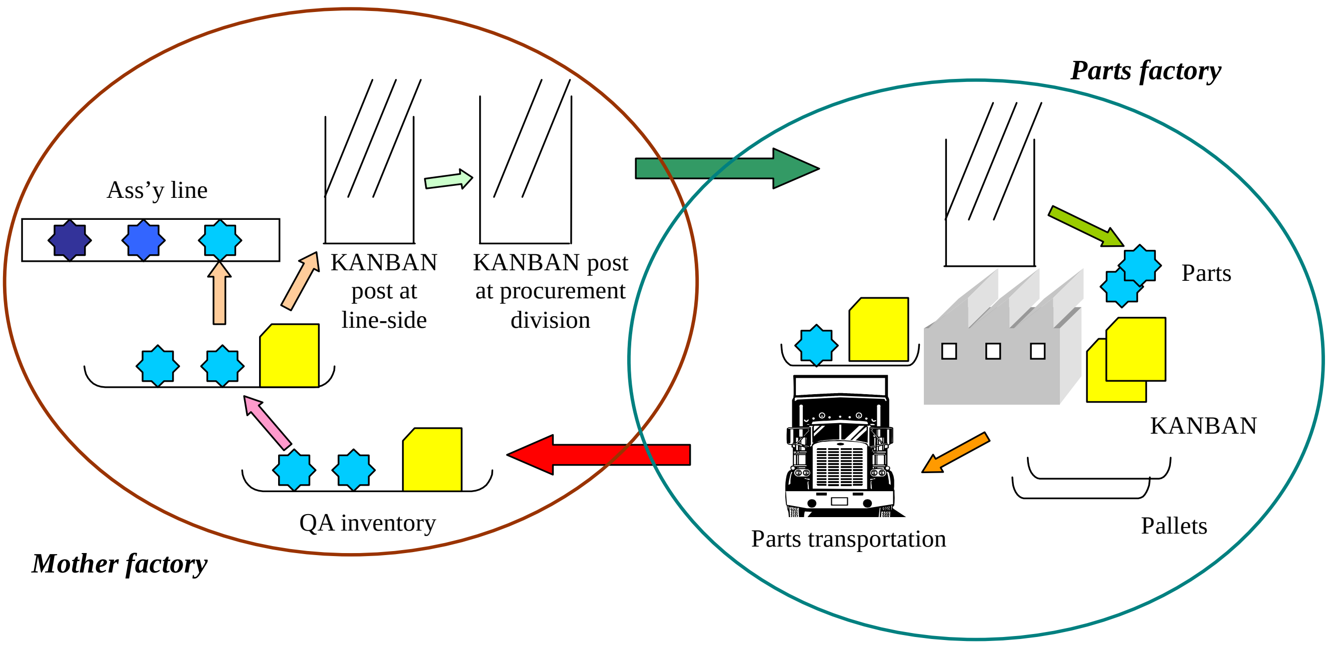

Figure 1. Mechanism of KANBAN system

The latter is threw in KANBAN post at line-side and assorted into every supplier sites to prepare procurement operation at the division in charge.

KANBANs in the KANBAN post at procurement division are periodically transferred to appropriate suppliers and attached to the parts ready to deliver at supplier factories. Then, these are transported to QA division of assembly factory again through periodic delivery operation.

During the entire operation cycle, quick response or lead-time reduction is one of the key subjects for better performance of the production logistics system and substantial efforts have been made on this matter by launching continuous improvement activities as well as information technology implementation.

Typical example of the latter activities is electronisation of KANBAN system called e-KANBAN that is quite simple and natural attempt. Essential idea is to realise zero transfer lead-time of KANBANs in every operation phase such as their separation from parts at line-side, assortment, transfer to suppliers and coupling with deliverable parts. Concerned technologies for actualise this idea include parts database system, low cost peripheral facilities for data capturing in each phase of operation, infrastructure for data transfer such as web-based systems, monitoring and analysing systems of demand or requirement data from downstream function (assembly line in this case) etc.

Some of these technical issues have been developed, revised and implemented in some extent by the companies operated based on KANBAN systems and all of these attempts indicated that information technologies were relevant for KANBAN system refinement.

Recognising the above fact, in this paper, the last issue is focused to discuss in terms of consideration of way to revise the numbers of KANBAN.

3. Related Research and Consideration

Traditional way to determine the numbers of KANBAN is described by formula (1) [2].

$$N_t = [(\mu_t^D L + K\sqrt{L}\sigma_t^D)/M] \qquad (1)$$

Where,

- N_t : The numbers of KANBAN determined at the end of *t*-th day
- μ_t^D : The average demand quantity per day estimated at the end of *t*-th day
- L : Lead time of parts procurement (days)
- K : Parameter of safety inventory
- σ_t^D : The standard deviation of demand quantity per day estimated at the end of *t*-th day
- M : Capacity of pallet (Numbers of KANBAN to be installed on it)

The essential idea of this expression is that KANBAN must care entire demand quantity and additional quantity due to its fluctuation during procurement lead-time. For the latter issue, policy of 3-sigma guarantee is quite usual and, therefore, K =3 might be very agreeable. The most important point here is that numbers of KANBAN derived by this way strongly affect the performance of entire system.

It is obviously noticed from this method that numbers of KANBAN depend on every variables and parameters defined above. Parameters, i.e. parts procurement lead-time, safety inventory parameter and pallet capacity, are controllable in some extent by KANBAN system manager and they made efforts to determine or improve these values properly for many years. Especially, procurement lead-time consists of parts transportation and/or transfer time and KANBAN management time, and substantial contribution to eliminate the latter portion of lead-time have been realised through e-KANBAN implementation.

On the other hand, variables, i.e. demand average and variance must be the target variables to estimate because these concern uncontrollable business environment issue. A traditional way adopted in some factories is periodic consideration on whether numbers of KANBAN should be changed or not. For instance, some factory in Toyota Motor Co. used to consider its modification by monthly basis. The mind behind such policy is that demand statistics, e.g. average and variance, are basically stable and downstream activities such as sales division make efforts to guarantee this steadiness. And if it does work successfully, efforts on demand monitoring can be minimised as a by-product of this attitude.

However, as the business situation has been getting volatile gradually during this decade, the above argument became tough to emphasize for many companies. And consideration on how to monitor, estimate the demand statistics and feedback such information to revision of numbers of KANBAN become an emerging subject to cope with.

As a related study on this subject, Katayama et al [1] considered two types of revision models of numbers of KANBAN described below and analysed their performance under auto-correlated demand arrivals from downstream function.

1) FIR (Fixed Interval Review) Policy: This policy performs reviewing procedure every predetermined interval. Key parameter of this method is length of interval (days).
2) AR (Adaptive Review) Policy: This policy launches reviewing procedure based on the following flow chart (Figure 2), which includes statistical test procedure for detecting the change of demand average.

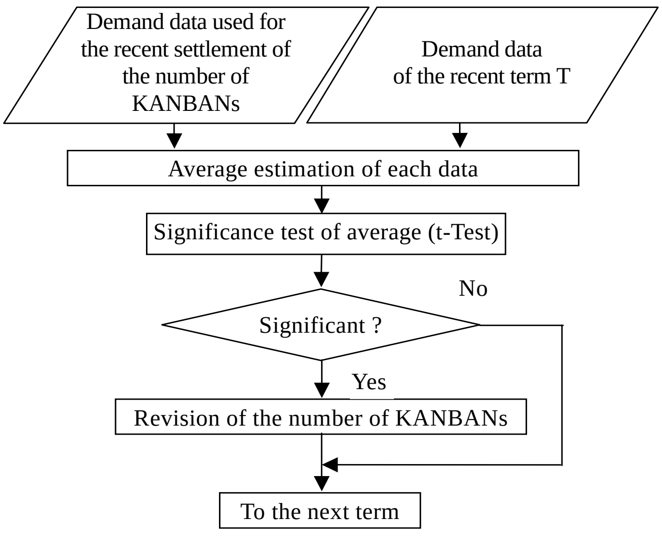

Figure 2. Flowchart of AR Policy

However, considered situations in simulation-based experiment in this study were quite limited, i.e. drastic change of average demand such as step function model and/or change of demand variance was not treated. Study on such more complicated cases is remained for further research.

4. Model Construction

Based on the arguments described in the former sections, analytical model is constructed in this section, where demand model, and some policies for revising the numbers of KANBAN and performance criteria are proposed.

4.1. Demand Arrival Model

First order autoregressive model described in formula (2) is adopted as demand arrival model.

$$D_t = \lambda D_{t-1} + (1-\lambda) X_t \qquad (2)$$

Where,

- D_t : Interval of the t-th and t-1-th demand arrival
- X_t : Statistically independent element of interval of demand arrival D_t. Its probability density function is supposed to be a Normal Distribution $N(\mu_t, \sigma_t^2)$.
- λ : Autocorrelation coefficient of adjacent interval data of demand arrival, i.e. D_t and D_{t-1}.

From this expression, it is noticed that mean and variance of D_t are μ_t and $\frac{1-\lambda}{1+\lambda}\sigma_t^2$ respectively. The cases to analyse include changes of mean and variance of D_t by step functions.

4.2. Structure of Lead-time

As mentioned in section 3, structure of lead-time is very important in KANBAN system, which consists of parts transportation and/or transfer time and KANBAN management time.

Based on some case investigation of car factory that operates under e-KANBAN system, certain fixed lead-time is assumed for the former portion, i.e. physical transportation lead-time of parts. For the latter portion, i.e. KANBAN management time, the ultimate ideal case, i.e. zero lead-time, is supposed because of e-KANBAN.

4.3. System Criteria

Two criteria, i.e. RLS (Ratio of Line Stops) and FKR (Frequency of the numbers of e-KANBAN Revisions) are considered as key performance indicators, which were also examined in the past study [1]. Namely, the first criterion RLS is a reliability measure of the system that evaluates risks of line stoppage or malfunction. On the other hand, the second one, i.e. FKR, is an efficiency measure that evaluates necessary operational efforts to manage KANBAN system. Where, some man-hours for indirect work such as redefinition of e-KANBANs have to be consumed if revision is launched.

$$RLS = \frac{Overall \quad line \quad stoppage \quad time}{Overall \quad available \quad time \quad of \quad the \quad line} \times 100(\%) \qquad (3)$$

$$FKR = \frac{Number \quad of \quad revisions \quad of \quad number\ of \quad e-KANBAN}{Total \quad production \quad terms} \quad \text{(Times/Term)} \qquad (4)$$

4.4. Proposal of Revision Policies of The Numbers of KANBAN

In the past research discussed about AR Policy [1], only demand average was focused to estimate and its variance was ignored despite of the σ_t^D in expression (1). This means that AR Policy cannot adapt the structural change of demand fluctuation, which tends to become large due to volatility increase of the market.

Therefore, as a new revision policy of the numbers of KANBAN, variance test procedure for detecting the change of demand variance is added to the flowchart given in Figure 2. Detail of this logic named Demand Average & Variance-monitored Review (DAVR) Policy is described in Figure 3.

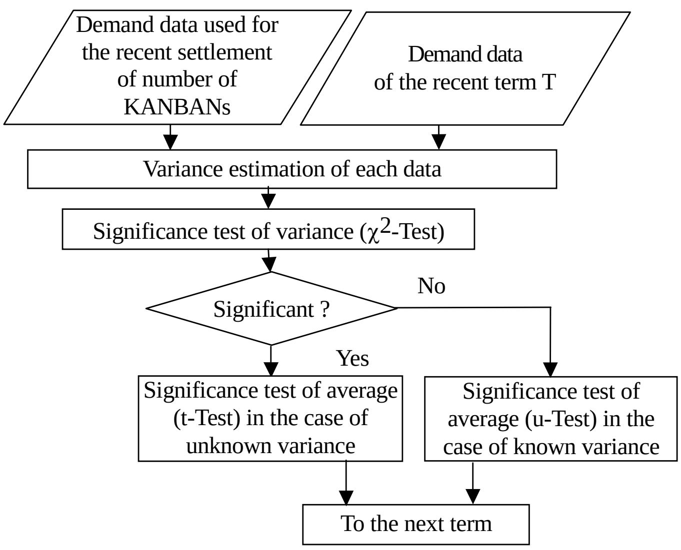

Figure 3. Flowchart of DAVR Policy

Based on demand arrival data, i.e. interval of the adjacent demand arrivals, used for setting current numbers of KANBAN and that of recent term T, e.g. interval data of demands in recent 10 days, each variance is evaluated by using the formula of definition of variance. From this procedure, their point estimates are obtained.

Then, these point estimates are examined whether these are significantly different or not. The logic of the significant test of variance, which is performed in terms of χ2-Test, is applied for this procedure.

If the result is significant, demand average is checked whether it changed or not. This procedure, the followed step of variance test, can be performed by t-Test of average as same as Figure 2 because this is the case of unknown variance. On the other hand, if the result is not significant, checking procedure of demand average is performed by ordinary u-Test of average because this is the case of known variance.

When entire procedure is executed, the same procedure is iterated again after the shift of unit time.

As the summary of this section, following three revision policies are considered to examine in this paper. Where, FIR Policy and DAR Policy is the same policy as the policies in the former research) [1]. Especially, DAR Policy is the same policy as AR Policy (See Figure 2) and is renamed for easier distinction from DAVR, the proposed policy.

1) Fixed Interval Review (FIR) Policy
2) Demand Average-monitored Review (DAR) Policy
3) Demand Average & Variance-monitored Review (DAVR) Policy

5. Performance Analysis by Simulation

The mission of this section is to analyse the chain relation between accuracy of demand monitoring, revision policy of numbers of KANBAN and system performance. This analysis is performed through simulation experiment in which simulator developed by C^{++} language is used. Summary of some relevant characteristics is also given based on the obtained result.

5.1. Simulation Condition

Some assumed conditions for simulation experiment are summarised as follows.

1) Simulation horizon: 150 days
2) Working hours of production line: 16 hours/day
3) Parts procurement lead-time L : 0.125 day
4) Parameter of safety inventory K : 3.0
5) Capacity of pallet M: 1
6) Autocorrelation coefficient of adjacent interval data of demand arrival λ : 0.8
7) Cases of demand parameters: Following five cases are considered.
   a) μ_t ; 12→8, σ_t^2 ; 1
   b) μ_t ; 12→8, σ_t^2 ; 2.5
   c) μ_t ; 12, σ_t^2 ; 1→2.5
   d) μ_t ; 8, σ_t^2 ; 1→2.5
   e) μ_t ; 12→8, σ_t^2 ; 1→2.5

   For instance, case a) means that μ_t changes 12 to 8 by step function. Where, timing of parameter change is determined randomly and total numbers of simulation for each case are 148 patterns. On the other hand, σ_t^2 is fixed to 1

8) Revision interval of the numbers of KANBAN R for FIR Policy: 29 cases, i.e. 2～30 days
9) Length of the term T for statistics calculation regarding DAR and DAVR Policies: Three cases, i.e. 3, 5 and 10 days
10) Necessary time to remove or attach KANBAN from or to appropriate parts: Immediate (zero)
11) Time interval of collection of KANBANs from KANBAN posts: Immediate (zero)
12) Revision point of the numbers of KANBAN: KANBAN post. This means that necessary numbers of KANBAN are added to KANBAN post when revised numbers are bigger than the current amount. Otherwise, appropriate numbers of KANBAN are removed from there. If there are not enough KANBANs in the post, KANBANs are waited to arrive to remove.

5.2. Results and Consideration

Obtained results through simulation experiment are summarised in Figure 4 and 5. These figures represent the relationship between two criteria, i.e. Average RLS and Average FKR, in terms of trade-off charts, which are obtained by 148 iterations of simulation.

Figure 4 illustrates comparative performance of three revision policies considered in this paper, i.e. FIR, DAR and DAVR, for specified parameter conditions. Where, μ_t changes from 12 to 8 and σ_t^2 is stable as 1.

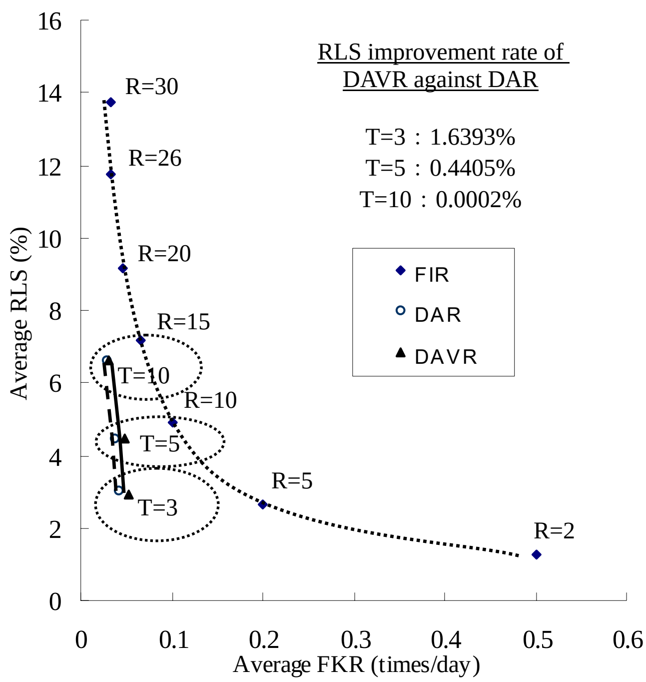

Figure 4. Performance comparison of three policies (in the case that μ_t; 12→8, σ_t^2; 1)

In case of FIR Policy, FKR becomes small whereas RLS gets large according to longer revision interval and it is observed there is an inverse proportion between two measures. Looking at the performance of DAR and DAVR Policies, both show quite superior performance to FIR Policy and do not hold superiority from the counterpart. Namely, both of these policies have quite close but different trade-off characteristics. According to decrease of T, i.e. length of the term for statistics calculation, RLS values of both policies are improved substantially but FKR values are not sacrificed very much. In comparison with DAR Policy, DAVR Policy indicates its strength on reduction of RLS whereas weakness on FKR. Improvement rates of average RLS of DAVR from that of DAR are positive and smaller T values create better improvement. These might be because of the effect of its variance test procedure.

In case that both of demand parameters are changed, i.e. μ_t change from 12 to 8 and σ_t^2 change from 1 to 2.5 by step function, characteristics illustrated in Figure 5 was obtained. This figure just focuses on the performance of DAR and DAVR Policies and illustrates that superiority of DAVR Policy against DAR Policy becomes bigger for small T, which is the same trend as Figure 4. However, the improvement rates indicate better scores. This feature is quite reasonable as DAVR Policy tries to detect the change of variance σ_t^2 in the supposed situation. On the other hand, FKR measure gets worse as DAVR tries to revise the numbers of KANBAN more frequently in this case.

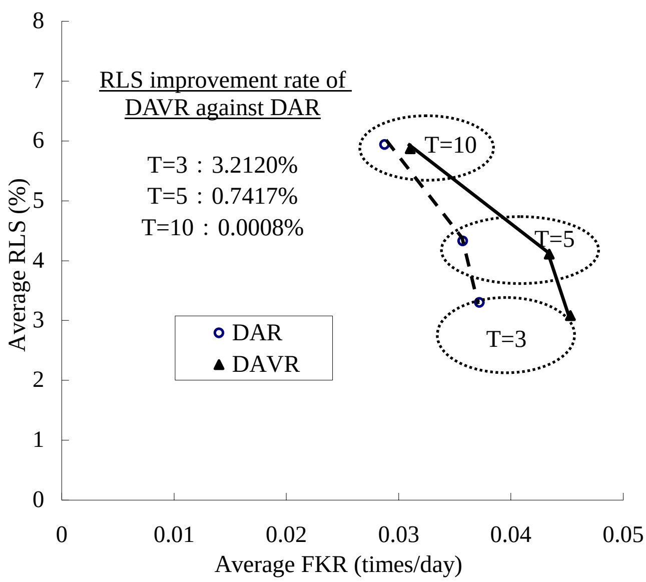

Figure 5. Performance comparison of DAR and DAVR policies (in the case that μ_t; 12→8, σ_t^2; 1→2.5)

For more detail in the case of μ_t; 12→8 and σ_t^2; 1, Table 1 summarises the joint characteristics of both FKR and RLS measures of FIR and DAVR Policies. Here, average FKR values are the points read from each performance graphs that attain the same RLS performance.

It is noticed from this Table that DAVR Policy provides smaller average and variance of RLS than FIR Policy. That is, DAVR adaptive estimate/control offers more servile characteristics than static FIR Policy.

Table 1. RLS performance comparison of FIR Policy and DAVR Policy (μ_t ; 12→8, σ_t^2 ; 1)

Average FKR	Policy	Average RLS	Variance of RLS
0.051 or 0.053	FIR	7.169	5.443
	DAVR	2.933	0.451
0.046 or 0.047	FIR	9.169	13.43
	DAVR	4.459	1.203
0.031 or 0.033	FIR	11.74	21.62
	DAVR	6.601	4.069

6. Concluding Remarks

This paper argued about three revision methods of the numbers of KANBAN for robust and efficient parts procurement operations in some volatile demand environments. The performance of each policy is evaluated by simulation experiments and quantitative trade-off relations between considered criteria are obtained. These characteristics indicate that proposed policy in this paper (DAVR) dominate traditional simple method (FIR) in terms of both criteria and provide more reliable feature than the other semi-advanced method (DAR).

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