INTEGRATION IN THE SUPPLY CHAIN THROUGH THE APPLICATION OF AN EXTERNAL KANBAN SYSTEM

Paulo Corrêa Lima
Campinas State University - Faculty of Mechanical Engineering
Caixa Postal 6122
CEP 13083-970, Cidade Universitária Zeferino Vaz
Campinas, SP, Brazil
plima@fem.unicamp.br

Cleber Favaro
Campinas State University - Faculty of Mechanical Engineering
Caixa Postal 6122
CEP 13083-970, Cidade Universitária Zeferino Vaz
Campinas, SP, Brazil
cfavaro@uol.com.br

Abstract. *Companies are optimizing their supply chain using different tools. In spite of having an impressive progress in materials flow, when we look at the information flow, the evolution is questionable. Information is not so easy to follow and besides trying to improve the level and the quality of communication, companies had created high tech approaches. In many times the consequences are information delay and erratic demand. The solution that Toyota developed to address this requirement is a leveled pull between facilities supported by an external kanban system. The paper objectifies to propose a method to integrate the supply base through the implementation of the just-in-time system, coordinated by an external kanban system. Starting with a review of the concepts of lean, the purposed framework is supported by the literature review of Toyota's model. Withdrawal and Production kanban application in the supply chain are presented and an example with two future states is developed in order to illustrate the method. Finally, we conclude that a simple tool, based on visual control, can establish a robust and efficient solution to communicate the demand, reducing demand amplification and orders delay and therefore reducing the inventory.*

Keywords*. External Kanban, Lean Manufacturing, Supply Chain Management*

1. Introduction

In March 1990 the Brazilian automotive market was opened to imports and in the following years the investments had increased deeply. Autoparts and automakers installed their operations in the country, and new models of production system as industrial parks and modular consortium started to change the relationship standards among customers and suppliers (Salermo & Dias, 2002).

The presence of new members in the automotive supply chain collaborated to increase the mix of vehicles available to final customer, who is looking closely for high quality and short response time. In order to achieve superior operational efficiency in those complex environments, companies are applying the concepts and tool pioneered by Toyota Motor Company named lean manufacturing or Toyota Production System (TPS). Lean's goal consists in cutting waste along the value stream of each product family and thus reducing lead time from order to delivery.

The contribution of purchased material is increasing and Dyer (2002) emphasizes that it represents from 50 to 60% of total cost. Thus, the unit of competition had changed from single and isolated companies to extended value streams. The approach to design materials and information flow under lean principles should be also extended to the supplying base to maximize overall gains instead of local ones.

In spite of trying to improve the level and the quality of communication that is usually poor, companies had made large investments to created high tech approaches. Moreover, those IT solutions have different interfaces to communicate to each other, increasing the number of constraint to the flow. The consequences are information delay and erratic demand. To achieve a shorter time line that is the fundamental objective of an enterprise, it is necessary to let the information flow, to schedule from a single point and to pull the upstream members. The solution that Toyota developed to address this requirement is a leveled pull between facilities supported by an external kanban system. The centralized computational systems in not used anymore to calculate daily orders, the supply of parts is performed by a new and simply replenishment model based on real demand.

The objective of the paper is to propose a complete method to integrate the supply base through the implementation of the Just-In-Time system, coordinated by an external kanban system. Starting with a basic review of the concepts and principles of lean, the purposed framework is supported by the literature review of Toyota's lean supply chain model. One example is used to clarify how to apply in two steps the external system.

2. Lean Thinking and Supply Chain

There is a growing attention on TPS since the beginning of the ninities when Womack et all (1990) released the book *The Machine that Changed the World*. The book is based on a five years benchmark of auto-industry that reported the several contracts among Japanese automakers and their rival including productivity 50% high and a half of the defects detected per vehicle. The term lean was coined to make reference to this production system that uses less efforts and delivery better quality than traditional mass production, and offers a higher diversity (Womack and Jones, 1994).

Taiichi Ohno, one of the founders of TPS, states the fundamental principle of the system that supports the company's strategy: to remove waste in order to shorten the lead time from customers ordering to cash (Ohno, 1990). The point is reaffirmed by Monden (1997) who argues that the main requirement of a production system should be increase the profit through the elimination of cost caused by waste.

Ohno (1997) purposes that the only way to achieve continuous improvement is to design a system free of seven wastes: overproduction, waiting on machines, inventory, defects, motion, transport and unnecessary process.

Many tools are designed to fight waste, but Shook (2002) highlights that the misunderstanding of real functional requirements of each shop floor environment results in inconsistent application of them.

Objectifying to create a roadmap to lean, Womack and Jones (1996), based on successful implementations of TPS, define the five following principles of lean thinking:

- Define value from the customer point of view;
- Map each value stream;
- Create flow along them;
- Pull where flow ends;
- Pursue perfection.

When the supply chain is analyzed, overproduction is the most usual waste that can be found (Jones & Womack, 2002). The information flow is erratic and the forecast are distant of real demand. Lee et all (1997) purposes that problems to keep the demand information updated are one of the main causes of high level of inventory.

Fine (1998) defines the supply chain design as being the ultimate competitive advantage and its conception should be done concurrently with the process and the product. He states that Toyota is the company that performs three dimensional concurrent engineering the best. Favaro (2003), Dyer (2001) and Hines et all (2000) creating different models to represent the lean supply chain, but all of them consider the just-in-time, supported by the kanban tool, as a key to Toyota's operational excellence.

The advantages of using a pull system to coordinate the material flow are listed below:

- Transfer the real demand of the client to its supplying base;
- To operate with standard inventory;
- Reducing the bullwhip effect;
- Low cost approach;
- Avoiding supplying disruptions through visual control.

The next topic will provide an overall view of how do define the amount of inventory that should be carried.

3. Sizing the Kanban Inventory

Kanban, the Japanese word that means card, is the visual tool developed by Toyota to achieve pull system. Monden (1997) defines two types of kanban that are mainly used: withdrawal and production kanban. The production kanban authorizes the upstream process to produce replenishing the consumed inventory, while the withdrawal kanban authorizes the downstream process to get material from the supermarket. Ohno (1997) sets the seven kanban rules:

- Move a product only when it is going to be consumed;

- Do not move a product without a kanban;
- The number of parts issued to the subsequent process must be the exact number of specified by the kanbans ;
- A kanban should always be attached to the physical parts;
- The preceding process should always produce parts in the quantities withdrawn by the subsequent process;
- It is not allowed to storage defective parts in the supermarket;
- Process the kanban at every work center in order in which they arrive at the work center.

The maximum inventory is determined by the number of kanban cards, allowing inventory standardization. The cards must be placed at the item at the supermarket or at the kanban board. When the material is consumed, the card goes back from the supermarket to the kanban board. It indicates the decrease of the inventory level.

The kanban board is usually associated with colored zones (green, yellow and red) to improve visual control (Peinado, 2000; Tardin, 2001 and Favaro, 2003). When a card arrives in the board, the operator put it from green to the red zone. The green zone means that the level of inventory is satisfactory and it is not necessary to produce. When a card is placed in the yellow zone, the operators are authorized to make the changeover and replenish the amount of card that the find at the board. The red indicates inventory is running low and there is an eminent risk of a shortage.

A methodology to calculate numbers of card in each zone that will be shown on the next topics, covering the production and withdrawal kanban types.

3.1. Production Kanban

Peinado (2000) and Tardin (2001) focused on internal production kanban system. The kanban zones represent the lot size, lead time and safety stock. The first step is to calculate the effective time of work (EWT), discounting breaks and lunch and the time needed to produce (TNP) as show Equations (1) and (2).

EWT = day of work per month x shifts per day x net hours per shift (1)

TNP = S (cycle time x monthly demand) (2)

The sum presented in Equation (2) is from the all parts related to analyzed equipment. Assuming that the equipment supports the demand, the difference between the EWT and TNP is the time left for changeover (TLFC).

TLFC = EWT – TNP (3)

The TFLC should be distributed among the parts that run in the equipment. The projected time for changeovers (TFC) must be inferior to the TFLC and is defined as being:

TFC = S (changeover time x total of changeovers performed monthly) (4)

The total of changeovers performed monthly measures the leveling capacity of the equipment. The interval measures the time between two changeovers to produce the same item. If you say that the equipment can make changeovers and runs the product every day, we can say that you get every part every (EPE) interval of one day. Thus the lot size (LS) is defined as one day. So, the LS is defined as:

LS = (monthly demand / days of work per month) x EPE (5)

EPE = days of work per month / total of changeovers performed monthly (6)

The LS is associated with the green zone of the kanban board.

Green Zone = LS / number of parts per package (7)

The next step is to calculate the lead time (LT), or yellow zone. The LT is the interval between you decided to produce one item and to get one package of it available to downstream process. It writes:

LT = changeover + (pitch - cycle time) + queue + transportation + interval between deliveries (8)

Yellow Zone = LT x demand / number of parts per package (9)

If the client pulls an amount that is smaller than the green zone, the operators are not authorized to produce more. If the sum of yellow and red positions is smaller than one lot, at the next withdrawal, the system will not be able to support it. So, it is important in those cases to leave a lot in the yellow to assure no shortages. It explains why the interval between deliveries (or one lot) appears in Equation (8)

The last zone to be calculated is the red that is called safety sock (SS). It represents the amount of material needed to avoid supplying disruptions. It should be able to protect against machine's downtime, quality problems and other sources of variation.

SS = safety stock in days x (monthly demand / days of work per moth) (10)

Red Zone = SS / number of parts per package (11)

Calculated the kanban's zones, the standard work-in-process is stated. The association of the zones and the parameters (LS, LT, SS) presented above is similar to Tardin's (2001) proposal. In spite of applying the same equations to define the parameters, Peinado (2000) suggests associating the red zone with the LT and the yellow with the SS. Favaro (2003) based on empirical conclusion purposes that the LT and SS should be compared. The biggest zone should be the red and the smaller the yellow. He explains that if the number of kanbans in red zone is bigger it will increase the sense of priority in the operators.

3.2. Withdrawal Kanban

The concept of withdrawal is very close to the production kanban, but a capacity analysis is not necessary. It is substituted by a choice between transportation cost versus inventory carrying cost. Milk-run delivery system should is used to increase the number of deliveries, keeping the transportation cost equal, problem that Moura (2000) analyzes carefully.

Favaro (2003) presents a comprehensive methodology to define the external withdrawal kanban and the following equations cover the usual cases.

The green zone also represents the LS, but the EPE is related to the delivery. So, LS for withdrawal is shown in Equation (12). The green zone is defined using Equation (7)

LS = monthly demand / deliveries in the month (12)

The purchasing lead time (PLT) corresponds to the yellow zone and it is defined as:

PLT = Administrative + Production + Transit + Inspection (12)

Some of the factor involved in PLT may be or almost be null. Exemplifying, if the supplier has products with assured quality, the inspection when the shipment is received is zero. It is import to keep on mind that when the production kanban is applied to external kanban the LT defined by Equation (8) may not be used. It assumes that a single pack will be able to supply the client, what is not true. So, the correct choice is to apply Equation (12).

The Equation (13) shows the yellow zone:

Yellow Zone = PLT x demand / number of parts per package (13)

The concept of the red zone is exactly the same of the production kanban and corresponds to Equations (10) and (11).

Favaro (2003) explains that in many cases the implementation of external kanban may help cost in two aspects. By creating a material replenishment system that reacts automatically to variations in the demand, it eliminates forecasting error and stabilizes delivery time and quantity. Thus it is possible to achieve inventory reduction and simultaneously non standard transportation cost reduction.

In order to clarify how production and withdrawal kanban can be used as a tool support supply chain improvements, an example will be shown in the topic 4, including two different ways of operating that allows a gradual inventory reduction.

4. Example of External Kanban Application

The example here presented will embrace the supplying of climate control system from a first tier to the automaker. The client buys three different models of climate control: ventilation (H), heating and ventilation (HV) and heating, ventilation and air conditioning (HVAC) that are delivered in similar racks. The following table shows the demand and the number of parts per rack for each model.

Table 1. List of products, demand and parts per rack.

Products	Demand (parts/month)	Package (parts/rack)	Demand (racks/month)
V	3000	10	300
HV	5400	10	540
HVAC	3350	10	335

The operation pattern of the client and the supplier is same: 22 days per month and 2 shifts per day. The net time available in each shift is 7,33 hours, resulting 322,5 hours per month.

The automaker's run size is 1 part and it pulls modules from the climate control supplier daily. The method presented here will show a two steps implementation. The steps are characterized by:

- Two supermarkets, production and withdrawal kanban and a daily leveling load;
- Single supermarket, production kanban and shiftily leveling load.

The Figure (1) summarizes the future state one.

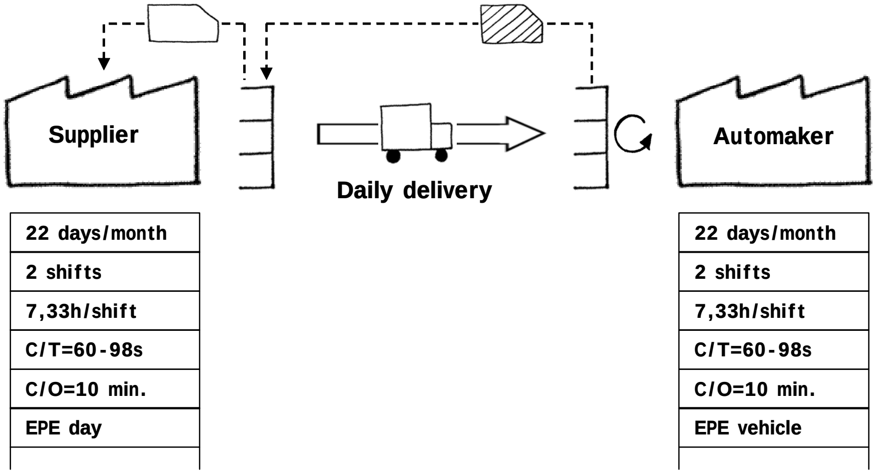

Figure 1. Future state one

The first supermarket that should be defined is the automaker's one. It is a typical withdrawal kanban and the equations suggested by Favaro (2003) should be applied. First the LS is calculated applying the Equation (12). It is also known that the PLT, from order to delivery, is about 7 hours. The number of cards in the yellow zone is defined by Equation (13). For this example, a safety stock of 1 day to avoid disruptions is adopted and Equation (11) is used to calculate the kanban card in the red.

The Table (2) is the result of client's supermarket sizing.

Table 2. Automaker’s supermarket in future state 1.

Products	Demand (racks/month)	Deliveries per day	Green: LS (cards)	PLT (h)	Yellow: PLT (cards)	SS (h)	Red: SS (cards)	Total of cards
V	300	1	14	7	7	7,33	7	28
HV	540	1	25	7	12	7,33	12	49
HVAC	335	1	15	7	7	7,33	8	30
								107

The maximum of inventory that will be finding in the client’s supermarket is 107 racks.

The nest step is calculating the kanban what will be implemented at supplier’s facility. As purposed by Tardin (2001), it is a production kanban and a capacity analysis is required. Climate control systems are assembled in a cell whose changeover time (C/O) and cycle time (C/T) are listed in the Table (3). Considering the demand presented at Table (1), the TNP is also calculated using Equation (2).

Table 3. Capacity analysis of the assembly line.

Products	Demand (racks/month)	C/O (minutes)	C/T (s)	TNP (h/month)	EPE (shifts)	TFC (h)
V	300	10	60	50,0	2	3,67
HV	540	10	75	112,5	2	3,67
HVAC	335	10	98	91,2	2	3,67
				253,7		11,0

The TNP is about 253,7 hours. Thus, the TLFC is 68,8 hours. The production lot ought to at least equal the withdrawal lot to support the pull. Then, the number of changeovers of each part needs to be the same of the number of days (delivery rate). The total of changeovers is denoted as being:

Total of Changeovers = 1delivery/day x 22 days/month x 3 products = 66 (14)

The TFC added to the TNP is 264,7 hours that results in a usage of 82%. It is possible to see that there is capacity enough to support a daily leveling load. After set the production interval, the inventory can be calculated. The safety stock is 1 shift of demand and the lead time may be determined applying the Equation (11). The size of the supermarket is shown in the table below.

Table 4. Supplier’s supermarket in future state 1.

Products	Demand (racks/month)	Green: LS (racks)	LT (h)	Yellow: LT (racks)	SS (h)	Red: SS (racks)	Total of cards
V	300	14	15,0	14	7,33	7	35
HV	540	25	15,3	25	7,33	12	62
HVAC	335	15	15,1	16	7,33	8	39
							136

The maximum of rack in the supplier’s supermarket is 136, totalizing a maximum overall inventory in the facilities of 243 racks.

In the future state 2, the kanban placed in the supplier is no more necessary. A single supermarket at the client’s plant triggers the supplier to replenish the inventory. Basically the system is a production kanban, in which the lead time is equal the purchasing lead time that now includes the time to produce the lot requested.

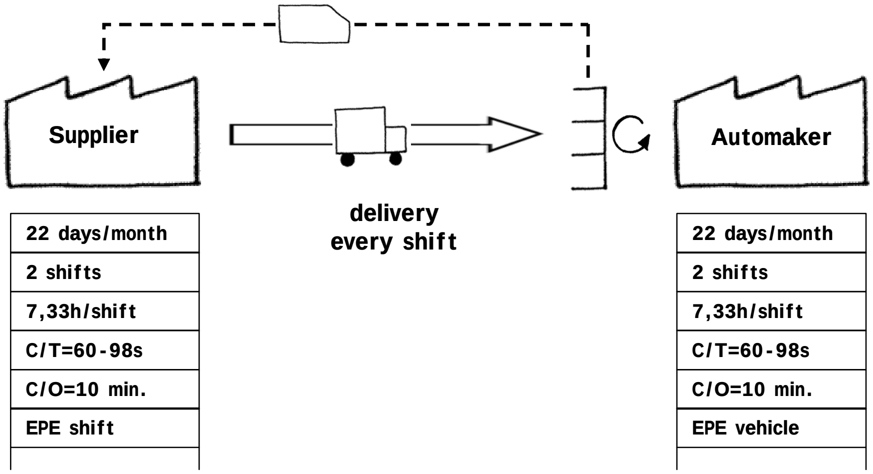

Figure 2. Future state 2

Here, the automaker pulls twice a day, reducing the withdrawal lot. So, it is necessary to check if there is capacity enough to increase the number of changeovers as much as the deliveries. By duplicating the numbers of changeovers, the TFC will also be doubled becoming 21,9 hours. The TNP remains the same (253,7 hours) and the usage increases to 85%. Then, we can conclude that the assembly line supports small lots. For this example, PLT reduces to:

$$\text{PLT} = \text{Admistrative} + \text{Transit} + \text{LS} \times \text{C/T} \qquad (15)$$

The Table (5) shows the new lot size and the calculation of the lead time. It is assumed that the safety stock for the state future 2 is going to be the sum of future state 1's, what means 2 shifts.

Table 5. Client's supermarket in future state 2.

Products	Demand (racks/month)	Green: Lot Size (racks)	Administrative + Transit Time (h)	LS x C/T (h)	PLT (h)	Yellow: Lead Time (racks)	Safety Stock (h)	Red: Safety Stock (racks)	Total of Card
V	300	7	7	1,3	8,3	8	14,66	14	29
HV	540	21	7	2,7	9,7	16	14,66	25	53
HVAC	335	8	7	2,3	9,3	10	14,66	15	33
									115

In this second case, the maximum inventory is designed to be 115 racks. The points that explain the reduction of inventory are listed below:

- Reduction of the duplicity of lots in two supermarkets (-54 racks);
- Leveling withdrawals and production (-35 racks);
- Elimination of lot (interval between deliveries) used in the yellow in the supplier's supermarket (-39 racks).

The reduction of inventory is about 50% from the future state 1 to future state 2 and 38% of the result may be achieved just by the adoption of a single kanban.

5. Conclusions

This paper presented a complete method to define the amount of inventory that an external pull system should hold. An example of application is developed including a two steps implementation. It starts with a withdrawal and production kanbans and migrating to a solution where a single production kanban trigs the whole value stream.

It is conclude that a simple and low cost tool, based on visual control, can establish a robust and efficient solution to communicate the demand throughout the supply chain, reducing demand amplification, orders delay and therefore cutting the amount of inventory carried by supplier and client and also improving the response time of the extended value stream to the end customer.

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