

Time-Based Conditions for Synchronized Procurement in *Douki Seisan*

Bautista J¹, Fortuny-Santos J²

Abstract This paper introduces the synchronous manufacturing philosophy (*douki seisan*) devised by Nissan, and relates it to “Just in Sequence”, a common technique in current automotive industry. Literature is full of case studies, and the advantages and drawbacks of JIS have been reported. However, no attempt to model the necessary relations to make this system work has been found. In this paper, the necessary conditions concerning the lead times and cycle times of the different activities are deduced, and even the moment when they should take place. They allow us to define a strongly synchronous system. For practitioners, each condition shows opportunities for process improvement. For researchers, lack of compliance with such conditions, gives rise to maximum satisfiability problems.

Keywords: lean manufacturing; mixed-model assembly line; just-in-sequence;

1 Introduction

The main pillar of the Nissan Production System (NPS) is *douki seisan* (DS) or synchronous manufacturing, a methodology that transfers customers’ orders to all processes at same time in order to achieve a continuous and smooth production

¹Joaquín Bautista Valhondo (e-mail: joaquin.bautista@upc.edu)
OPE Research Group (SGR 271). Dpto. de Organización de Empresas. Barcelona School of Industrial Engineering (ETSEIB). Polytechnic University of Catalonia (UPC). Avda. Diagonal 647, 08028 Barcelona.

²Jordi Fortuny Santos (✉e-mail: jordi.fortuny@upc.edu)
OPE Research Group (SGR 271). Dpto. de Organización de Empresas. Manresa Engineering School (EPSEM). Polytechnic University of Catalonia (UPC). Avda. Bases de Manresa 61, 08242 Manresa (Barcelona).

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flow. The requirements of DS for suppliers are similar to those of “Just-in-Sequence” (JIS) delivery: to deliver the required parts, in time, in the necessary quantity and in a pre-determined sequence. If “synchronicity” is about time, and all the necessary operations have a certain task time, JIS/DS procurement is only possible if certain time-related conditions are met. The understanding of the logic relations between the tasks implied in JIS procurement might help buyers and suppliers improve the way they work. In this paper we extend the existing literature by exploring and modelling such conditions. The following research questions are addressed: How can we model the JIS/DS relations? Under which time-related conditions synchronous manufacturing and delivery is possible? Which are the elements that allow/impede synchronous delivery.

2 Brief background

Literature has been reviewed to find previous research on JIT/DS concepts. Although the term JIS is clearly the name is inspired in “just-in-time”, the origin of the name is unknown and each company has a different name for it. In spite of earlier developments, it seems to have flourished maybe in the 1990s (Wagner and Silveira-Camargos, 2012) and specially at the beginning of the 21st century as a response to the pressure on carmakers related to mass customization of the final product (Sedliak and Šulgan, 2011). JIS has experienced great success amongst the premium German automakers who prefer build-to-order manufacturing to build-to-stock manufacturing. However, the importance of Just-in-Time and Just-in-Sequence procurement (as well as the fragile conditions it relied upon) had already been envisaged by Ford (1923). Although the advantages and drawbacks of JIS have been studied yet -see Thun et al. (2007)-, none of the reviewed papers analyses JIS/DS in quantitative terms.

In Nissan, *douki seisan* □ □ □ □ (synchronized flow) is a pillar of Nissan’s philosophy since 1960 (Sako, 2004). It describes an ideal state where all the processes get information from the customers at same time, in order to establish a continuous flow without changes in the scheduled sequence. When processes have advanced demand information, products can be scheduled and sequenced. Suppliers can be synchronized with the assembly line so they can deliver according to the schedule (Monden, 1998).

3 Moments, lead times and cycles: in search of synchronicity

The tasks that make synchronous manufacturing and delivery possible are shown in Figure 1. We assign a time variable to each task to represent its duration.

Let T_s be moment that an OEM (Original Equipment Manufacturer) -the car maker- sends a list with a sequence of T vehicles to a first-tier supplier. For reference purposes, T_c is the current date and time.

Following the notation in Boysen et al., (2009) the planning horizon is divided into T production cycles (with $t = 1; \dots; T$), with a cycle time c . We may introduce product variability by considering that our final product comes in several models $m \in M$ (where M is a set of models). The demand d_m at the end of the planning horizon is given and has to be met. Each one of the T vehicles in the sequence belongs to a certain model or type. This can be represented by binary variables x_{mt} . If model m is produced in cycle t $x_{mt} = 1$, otherwise $x_{mt} = 0$.

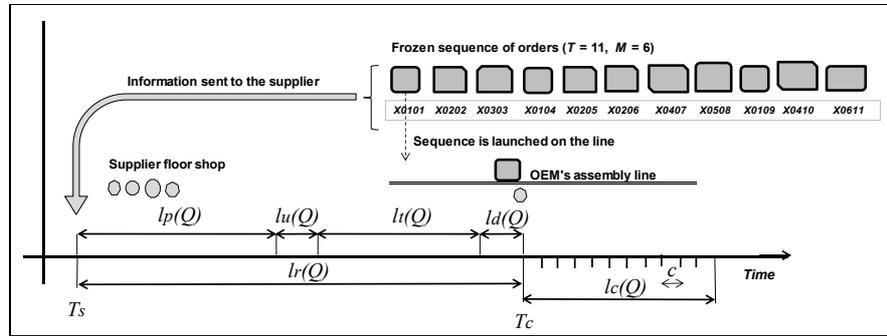


Fig. 1 Representation of the tasks involved in synchronous manufacturing and delivery (JIS/DS). For symbols, please refer to the text (Section 3)

As stated before, at T_s , a purchasing order (Q) of T sequenced units of a certain component Z is placed with a supplier. Because each model of final product needs a specific type of component Z , the purchasing order is the sequenced list of x_{mt} and the quantities demanded per type of component Z_m are exactly d_m .

This order must be ready at the border of the OEM's assembly line (BoL) after $l_r(Q)$ units of time -in consequence, the deadline is $T_s + l_r(Q)$ -. We call the supplier's maximum turnaround time (or order lead time) "reaction time" because it is the maximum time allowed to complete the necessary steps to deliver order Q . Nissan's maximum acceptable turnaround time is 6 days.

The supplier's manufacturing lead time $l_p(Q)$ includes setup time, run time and changeover time, which depend on the sequence and also on the production method.

The following step in our model is the order processing lead time $l_u(Q)$ or time necessary, after manufacturing, for order consolidation and time to load the vehicle (or transport system) that has to take the order to the customer. When the order has been loaded onto the vehicle, the order is taken to the customer. Transportation lead time is represented by $l_r(Q)$. Eventually, when the product arrives at the premises of the customer, an additional time $l_d(Q)$ is necessary to unload the vehicle, complete other inbound logistics work and take the sequenced units to

the border of the line. There, the T units of the different models of component Z are consumed in $l_c(Q)$ time units. This consumption time depends on T and c as shown in equation 1.

$$l_c(Q) = T \cdot c \quad (1)$$

Since these manufacturing and procurement activities are going to take place not once but on a repetitive way over time, we can consider their related cycle times. Thus, we define:

- $c_p(Q)$: Manufacturing cycle time for lot Q . The average time between two consecutive completed orders coming out the end of the manufacturing process under steady state.
- $p_u(Q)$: Vehicle load lead time. The time a vehicle remains parked at the loading dock of the supplier to enable the loading of an order Q .
- $c_u(Q)$: Order load cycle time. The interval of time elapsed between two consecutive lots are loaded in a vehicle. The time difference between two consecutive completions of loading tasks for two consecutive orders.
- $c_t(Q)$: Transfer cycle time. The interval of time elapsed between two consecutive lots are sent to the customer.
- $p_d(Q)$: Vehicle unload lead time. The time a vehicle remains at the dock of the customer to allowing the unloading of an order Q .
- $c_d(Q)$: Order unload cycle time. The interval of time elapsed between two consecutive lots unloaded from a vehicle.

The following conditions are necessary to establish JIS/DS delivery of lot Q :

Condition 1 (equation 2): The order lead time, made up of the time spent manufacturing parts $l_p(Q)$, processing the order and loading the truck $l_u(Q)$, transporting the order to the delivery point $l_t(Q)$, and unloading the truck and taking the order to the BoL $l_d(Q)$, must be shorter than, or equal to, the value of $l_r(Q)$ considered by the OEM, otherwise, the order will be late.

$$l_p(Q) + l_u(Q) + l_t(Q) + l_d(Q) \leq l_r(Q) \quad (2)$$

Condition 2 (equation 3): When components are supplied from a warehouse (manufacturing is not synchronous), order processing and truck loading $l_u(Q)$ plus transportation $l_t(Q)$ plus truck unloading and inbound logistics tasks $l_d(Q)$ must be shorter than, or equal to, the reaction time $l_r(Q)$. Condition 2 is dominated by condition 1, because if condition 1 is true, condition 2 is always true. For the OEM, equation 3 also gives the minimum anticipation required by the system to ensure that the requested sequence of components can be delivered on time. This

is the size of the period where no further modifications should be made to the schedule.

$$l_u(Q) + l_l(Q) + l_d(Q) \leq l_r(Q) \quad (3)$$

Condition 3 (equation 4): After the present sequence (which takes $l_c(Q)$), the OEM will assemble another sequence of T final products, also with cycle time c , which is the constant pace of the assembly line. A purchasing order Q' is sent to the supplier with the same anticipation $l_r(Q)$. The supplier will experience the beginning of two order cycles with a delay of $l_c(Q)$ time units. We can conclude that, being $l_u(Q)$, $l_l(Q)$ and $l_d(Q)$ constant, the time spent in manufacturing $l_p(Q)$ has to be equal to $l_c(Q)$. It means that the supplier is doing at any time what the OEM will be doing $l_r(Q)$ units of time later and so both companies are synchronized.

$$l_p(Q) = l_c(Q) \quad (4)$$

In steady state, and assuming perfect quality, if the supplier manufactures component Z in sequence according to the customer's order, the manufacturing cycle time (without setup or changeover) c_s is equal to the OEM's cycle time c (equation 5). If quality was not perfect and there was some idle time for setup and changeover, or different models had different cycle times, then c_s should be measured as the reciprocal of throughput (units per period of time) and would be an average value over lot Q .

$$l_p(Q) \leq l_c(Q) \Rightarrow T \cdot c_s \leq T \cdot c \quad (4')$$

$$c_s \leq c \quad (5)$$

Other necessary conditions are:

Condition 4: Manufacturing cycle time for lot Q must be shorter than or equal to the order load cycle time (equation 6). The opposite is impossible, because the second process depends on the first one. For example, if orders are finished every two hours, it is not possible to completely pack such orders and load them into trucks every hour, because there are no parts available. This phenomenon is known as process starvation (Bai and Gershwin,1995).

$$c_p(Q) \leq c_u(Q) \quad (6)$$

Condition 5: Vehicle load lead time must be shorter than or equal to the order load cycle time (equation 7).

$$p_u(Q) \leq c_u(Q) \quad (7)$$

If every $c_u(Q)$ time units an order has to depart, it is impossible to spend more than $c_u(Q)$ time units loading a vehicle. Otherwise, the next vehicle would have to wait. Equation 8, which is equivalent to Little's Law (Little, 1961), gives the average number of vehicles at the dock.

$$\text{Average number of vehicles at the supplier's dock} = p_u(Q) / c_u(Q) \quad (8)$$

Condition 6: The order load cycle time must be equal to the transfer cycle time (equation 9). This relation is clearer if frequencies are used instead of cycle times (cycle and frequency are reciprocal values): The number of trips per time unit must be equal to the number of vehicles that are loaded per time unit.

$$c_u(Q) = c_l(Q) \Leftrightarrow v_u(Q) = v_l(Q) \quad (9)$$

Condition 7: Vehicle unload lead time must be shorter than or equal to order unload cycle time (equation 10). For the same reason that explains condition 5. We can also compute the average number of vehicles at the customer's dock (equation 11).

$$p_d(Q) \leq c_d(Q) \quad (10)$$

$$\text{Average number of trucks at the customer's dock} = p_d(Q) / c_d(Q) \quad (11)$$

Condition 8: The transfer cycle time must be equal to the order unload cycle time. After conditions 6 and 8, we can write equation 12, expressing the continuity of the delivery cycle: in steady state, the number of vehicles that are loaded per time unit is the same that the number of vehicles that travel to the customer's premises and is the same that the number of vehicles that are loaded.

$$c_u(Q) = c_l(Q) = c_d(Q) \Leftrightarrow v_u(Q) = v_l(Q) = v_d(Q) \quad (12)$$

Condition 9: The order unload cycle time must be shorter than or equal to the time in which lot Q is consumed by the customer $l_c(Q)$ (equation 13). If $c_d(Q) = l_c(Q)$, there is a container or truckload for each sequenced order, although this equation alone does not explain whether the order is on time or it is late. The delivery is late if $c_d(Q) > l_c(Q)$. Following Little's law once more, the relationship between $l_c(Q)$ and $c_d(Q)$ gives the average number of orders of component Z, at the customer's, being unloaded from trucks and taken to the BoL during the assembly process (equation 14).

$$c_d(Q) \leq l_c(Q) \quad (13)$$

$$\text{Average number of orders BoL per sequence} = l_c(Q) / c_d(Q) \quad (14)$$

If we consider previous equations together, we connect the supplier with the OEM (equation 15).

$$c_p(Q) \leq c_u(Q) = c_t(Q) = c_d(Q) \leq l_c(Q) = T \cdot c \quad (15)$$

Finally, if $c_p(Q) = l_p(Q)$, which means that only one order is processed at a time, we get equation 16.

$$l_p(Q) = c_p(Q) \leq c_u(Q) = c_t(Q) = c_d(Q) \leq l_c(Q) = T \cdot c \quad (16)$$

Definition.

A manufacturing and delivery system is said to be strongly synchronous (equation 17) when the supplier's manufacturing cycle time of an order coincides with the order load cycle (which in turn coincides with transfer cycle time and order unload cycle time) and the supplier's manufacturing lead time and the time the customer needs to incorporate the supplies in its final products.

$$l_p(Q) = c_p(Q) = c_u(Q) = c_t(Q) = c_d(Q) = l_c(Q) = T \cdot c \quad (17)$$

Equation 17 describes the ideal state where idle times and wait times have been removed from the system and therefore it achieves its maximum efficiency. In practice, all deviations from this ideal state -*DS*- mean that the system only reaches a certain degree of synchronicity. Previous conditions offer directions for system improvement: practitioners have to act upon the elements (i.e. material, machines, technology, methods, information...) that lie behind each one of the terms that have been mentioned in conditions 1 to 9.

Condition 10: The amount of transportation units $u_t(Q)$ (vehicles such as trucks or autonomous automatic guided vehicles AGVs, slots in a conveyor belt, and so on, depending on the environment of each case) necessary to accomplish the deliverance process is related to the following concepts: vehicle load lead time $p_u(Q)$, transportation lead time $l_t(Q)$, vehicle unload lead time $p_d(Q)$ and transfer cycle time $c_t(Q)$ as shown in equation 18, where $\lceil \cdot \rceil$ is the ceiling function.

$$\lceil (p_u(Q) + 2 \cdot l_t(Q) + p_d(Q)) / c_t(Q) \rceil \leq u_t(Q) \quad u_t(Q) \in \mathbb{Z} \quad (18)$$

4 Conclusions

JIS has been developed as an answer to the variability of parts caused by the increasing customization of vehicles. Nissan Production System has always been based on synchronicity and therefore Nissan tries to extend its synchronous manufacturing and delivery strategy (*douki seisan*) to selected suppliers, facing the same situation that other companies that have implemented JIS lately.

In this paper, the synchronous manufacturing and delivery system between an OEM and a supplier has been modelled and up to 18 equations and 10 conditions have been developed to show necessary relations among the moments when some events take place, the amount of time spent in certain tasks and the cycle time of repetitive processes. Lack of compliance with such equations results in failure of the system. Research findings can help practitioners reduce the amount of time spent in a task or develop a more robust system. They should consider the agents and elements involved in each magnitude (E.g. time spent in order consolidation after manufacturing) and act upon them. However, investment in resources should take into account the relationships between processes shown in the proposed equations because otherwise improving a certain task might not lead to the desired improvement in the performance of the system. When the system reaches the condition described in equation 17, with no delays, no idle time and no late deliveries, the system is strongly synchronous.

Some directions for further research: (i) A synchronicity measurement index (SMI) should be developed to measure the situation of a company in the maturity path towards DS. (ii) Conditions given in this paper describe a set of constraints necessary to achieve synchronicity. Companies may have to choose to satisfy as many constraints as possible, taking into account the economic implications of doing so. This would be modelled as a maximum satisfiability (MAX-SAT) problem.

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