Department of Social Systems and Management

Discussion Paper Series

No. 1230

Impact of Integration of Manufacturaing Planning and Control Systems on Supply Chain Management

by

Ayako KAWAI and Ryo SATO

April 2009

UNIVERSITY OF TSUKUBA
Tsukuba, Ibaraki 305-8573
JAPAN

Abstract

Manufacturing planning and control systems (MPCSs, for short) are an essential element for supply chain processes today. However, there are few researches which include planning information systems in supply chain models and optimize the whole structure holistically in spite of the social importance of MPCSs for supply chain management. At present, we do not have any ideas even about process behavior when organizations which have MPCSs are linked in a supply chain. To clarify fundamental properties of supply chain structures including planning information systems are tasks of big challenges as well as pressing urgencies. While planning information systems and practical activities have been told individually in many researches, they should be dealt holistically as a system. This research aims at the ingegration of planning systems and practical activities to optimize whole supply chain structures. Actual supply chain processes have million considerable parameters, and they interact each other. It is too complex to deal, so we simplified supply chain processes focusing on interaction between material flow and information flow in this paper. Firstly we suggested the supply chain process model, and then dynamic properties of the process are shown. Analyses of the behavior implies management capability and limits of the MPCSs. Furthermore, a way of optimization for the supply chain structure and the effects are shown.

Keywords: *Supply Chain Management, Manufacturing Planning and Control Systems; Discrete Event System; Process Behavior; Structural Optimization; Inventory Allocation; Frequencies of Information Update*

1 Introduction

In the modern era of expanding globalization of markets, the role of manufacturing planning and control systems (MPCSs, for short) in supply chain management (SCM, for short) is becoming increasingly important for companies to survive. While product-life cycle is becoming shorter and high-mix low-volume production is increasing, consumer demands for schedule, cost and quality keep growing increasingly severe. Many companies in the world had been addressed these severe business environment with implementation of enterprise resource planning (ERP) systems to each company[15][16]. ERP systems are now commonly used by large companies to support decisions of MPCSs whose engine is material requirement planning (MRP)[15]. Many of the ERP systems were based on simple MRP logic, or ERP systems can be considered a direct extension of MRP[4][15]. ERP, or MPR systems had succeeded in the production management in each manufacturers[4][15][16]. However, now, they have not been able to respond to more increasingly compatition in the market with closed efforts of individual companies. They have to integrate individual own MPCSs to their supply chain processes. Therefore, MPCSs are an essential element for supply chain processes today.

However, it is not obvious how to integrate MPCSs in supply chain processes to gain great effects. Vollmann et al.(2004)[15] described that it is not easy to conduct internal and interfirm integration of MPCSs, because network structures of supply chain processes have complex interactions. Croom et al.(2000)[14], Tan(2001)[11], Huang(2003)[12], and Cutting-Decelle et al.(2006)[2] which are survey papers of SCM also similarly described that SCM is too difficult to capture the entire picture. Besides this, Vollmann et al.(2004)[15] emphasized the necessity of redesign MPCSs to suit each supply chain circumstance based on knowledge of new business process reengineering and new information system, and they showed some best-practices from various point of views in the book. However, so many companies actually believe that most important issue is introducing MPCSs for their supply chains borrow from the best-practices. This paper is what sounds a warning against such present trends.

Most researches considering information systems in SCM have been within the context of case studies or frameworks for system construction. Huang(2003)[12] as well as Vollmann et al.(2004)[12] also just mentioned that optimization of establishing information systems for SCM is a big challenge. To the best of our knowledge, there is no research with having a point of view that supply chain structures including information systems were holistically optimized. At present, we do not have any ideas even about process behavior when organizations which have MPCSs are linked in a supply chain. For this reason, to clarify fundamental properties of supply chain structures including planning information systems are tasks of a big challenge as well as pressing urgencies.

On the ohter hand, many researchers have insisted the importance of analyzing detailed models including bill of materials of products, information systems, capacity and so on in recent years. For example, Gunasekaran et al. (1997)[1] pointed out that information technology is a necessary element for smooth logistics in supply chain processes. Relph et al. (2003)[6] explained the importance of cycles of planning update. However, they did not suggest any concrete ways of implementation. Cases which the ERP system plays a significant role in supply chains are studied by Himoto et al.(2004)[7] and Berchet et al. (2005)[3]. Himoto et al. (2004) referred to the gap between traditional inventory management theories and MRP implementation. Though they proposed a solution to fill the gaps in an actual manufacturing system, they did not consider network structure of supply chain process. In Venkatswaran et al. (2004)[8], bill of materials and planning information systems in a supply chain process was modeled in detail. They analyzed impacts of some models, and then, insisted on the importance of model accuracy in the supply chain disciplines. They also insisted on the importance of including planning information systems in supply chain models. However, the major point of the paper is impact of model accuracy. They did not consider structual optimization in the paper.

As mentioned above, establishing a methodology for designing and analyzing MPCSs in SCM have been required. While planning information systems and practical activities have been told individually in many researches, they should be dealt holistically as a system. This research aims at the ingegration of planning systems and practical activities to optimize whole supply chain structures. In this paper, we show firstly dynamic properties of a supply chain controlled by MPCSs, and then, management capability and limits of the MPCSs. Furthermore, a way of optimization for the supply chain structure and the effects are shown.

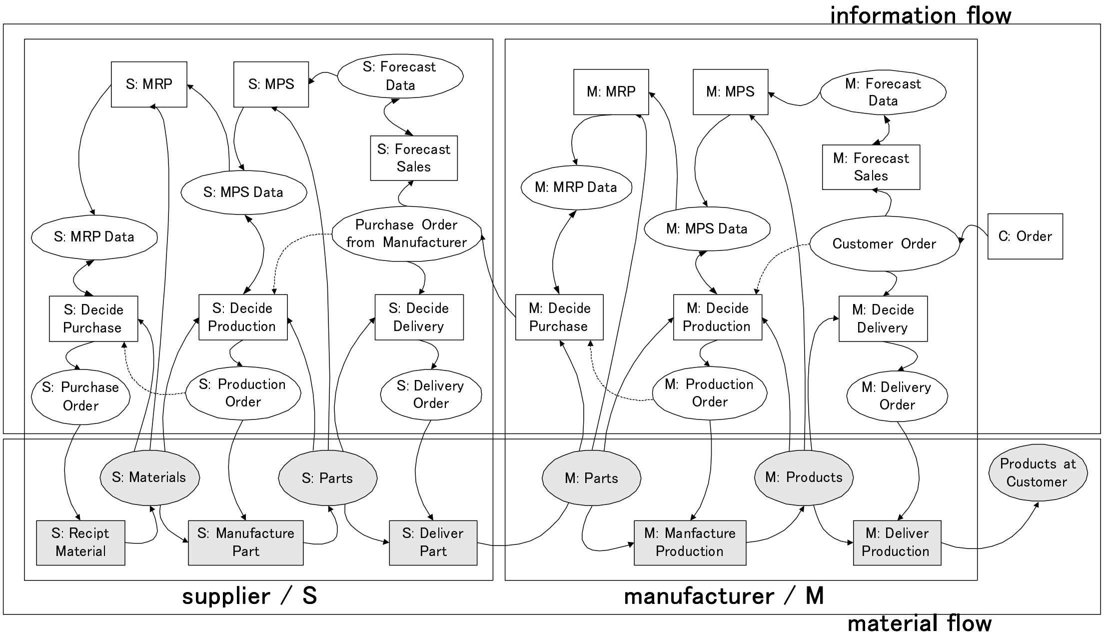
In section 2, a supply chain process model considered in this paper will be explained. In section 3, capability and limits of the MPCSs to manage the supply chain processes will be shown through analyzing the behavior of the model. In section 4, a way of optimization for the supply chain process will be suggested. And effects of the optimization will be shown. And finally, conclusions will be presented in section 5.

2 Sypply chain process model

In this paper, we apply a conceptual framework called *business transaction systems*[13] to construct supply chain process model. The static structure of business transaction systems are represented by *activity interaction diagrams*[13], and its dynamic structure is modeled as a discrete event systems. Activity interaction diagrams consist of diagrams of activities, queues, and arrows such like Figure 1. In Figure 1, rectangles represent activities, and ellipses represent queues. And arrows represent object flow. Arrows from an activity to a queue represent adding flow that an object is added into the queue when the activity completes. On the contrary, arrows from a queue to an activity represent subtracting flow that an object is subtracted from the queue when the activity starts. In the Figure 1, in the material flow, objects mean physical goods such as materials, parts and products, and in the information flow, they means data. The supply chain process model considered in this paper has MPCSs explicitly. Its experimental model is realized in Java. By identifying the state transition table of the experimental results as that of the theoretical business transaction system, it is ensured that the program behaves without errors.

2.1 model overview

The model considered in this paper is a two-stage serial supply chain process represented in Figure 1. The lower side of the figure represents material flow. Materials are handed from the supplier to the market through manufacturing and delivery processes of the supplier and the manufacturer. The upper side of the figure represents information flow. The manufacturer receives customer order data, and the data is transformed from the manufacturer's forecast to the supplier's purchase order through various information processes such as master production schedule (MPS, for short), material requirements planning (MRP, for short) and so on. In Figure 1, "S:" means "supplier's" and "M:" means "manufacturer's." For example, "M:Product" represents the manufacturer's product. Assumptions of the supply chain process model are as follows:



MPS: master production schedule, MRP: material requirements planning

Figure 1: supply chain process model

- Bill of materials of the manufacturer's product is M:Product - M:Part - S:Material, and each component consists one respectively. That is, one product consists of one part, and the part consists of one material. In fact, "M:Parts" is identical to "S:Parts" while their inventory locations are different.
- Each lead time is shown in Table 1, and information processes complete at once.
- Capacities are infinite to simplify the model. In other words, capacities are enough to produce, deliver, and store.
- Sales forecast is based on exponential smoothing[4]. And the smoothing constant is set to 0.2. Production planning is developed on the basis of the sales forecast, and purchase order planning is developed on the basis of the production planning.
- Customer orders arrive every day.
- The manufacturer receives customer orders at the every end of a day. And the orders are shipped at the end of the next day. The supplier receives the manufacturer's orders at the end of a day. And the orders are shipped at the beginning of the next day.
- Both production and purchase orders are released every day.

- If there is not enough stock to satisfy requirements, they ship maximum quantities as possible as they can.

Table 1: assumptions on lead times

	process	lead time
supplier	material procurement (S: Recipt Material)	2 days
	part production (S: Manufacture Part)	15 days
	part delivery (S: Deliver Part) = part procurement of manufacturer	3 days
manufacturer	product production (M: Manufacture Production)	with in a day
	product delivery (M: Deliver Production)	2days

2.2 information process structure

In this subsection, we describe more detail assumptions in the information flow.

In this supply chain process, weekly sales forecast is developed based on exponential smoothing. And daily forecast data is obtained simply by dividing the weekly forecast by 5, which is number of days in a week. MRP is developed on the basis of the daily forecast. The daily forecast data is a input data of gross requirements of MPS. In MPS, net requirements are calculated based on the gross requirements as follows. Firstly, amount of stock on the end of each day is calculated based on the gross requirements, planned receipts, and planned on hand inventories. Next, the defference between the amount of stock and the target inventory level is set to net requirements. And then, this quantity of the net requirements is backed off over the lead time as planned production orders.

The planned production orders calculated in the MPS are input data of gross requirements of MRP. In MRP, planned purchase orders are also calculated in a similar manner to the MPS. That is, roughly summarized, weekly forecast is transformed from daily production planning into purchase planning in the supply chain process. And developed forecast and planned order are updated regularly. Daily manufacturing and purchasing process are operated based on the planning and actual on hand inventories.

This information structure in planning is practical, because basic structure of planning system in Figure 1 is quite similar to that of a Japanese manufacturer[9].

3 Capability and Limits of MPCS for SCM

In this section, we show a typical behavior of the Figure 1 model, that is, a model of supply chain process controlled by MPCSs. And then, structural parameters which should be considered are extracted from the model.

3.1 behavior of the supply chain process model

New products are released to a market, and they are well-received by the market. After that, they disappear from the market yet through stable spread period. The demand graph is constructed of four phases; "new product development", "ramp-up", "continuous improvement" and "ramp-down"[15]. The demand shape can be approximated in a trapezoidal shape. Results of preliminary experiment show that the supply chain process has complex behavior in the phase of ramp-up. For this reason, we focus on the ramp-up phase. Demand graph of ramp-up phase can be approximated by collinear of $y = x + 30$(y :order quantities, x :days).

A supply chain structure which target inventory level at each stock point is same as each process lead time, and forecasting and planning data are updated once a month can be considered simple and natural (Table 2). In what follows, we show that even such a simple supply chain process with MPCSs has complex and undesirable behavior beyond expectation.

Table 2: a natural supply chain structure

target inventory level in day's supply			
supplier		manufacturer	
S:Materials	S:Parts	M:Parts	M:Products
2 day's	15 day's	3 day's	0 day's

frequency of information update		
forecast	MPS	MRP
once a month	once a month	once a month

Figure 2 shows transitions of forecasting and demand under these conditions. The supplier's demand is part purchase order from the manufacturer. This is represented with dots which pop up like needles. And the manufacturer's demand, forecasting and the supplier's forecasting also are plotted on the figure. These increase almost in parallel with the line of $y = x + 30$ of the manufacturer's demand.

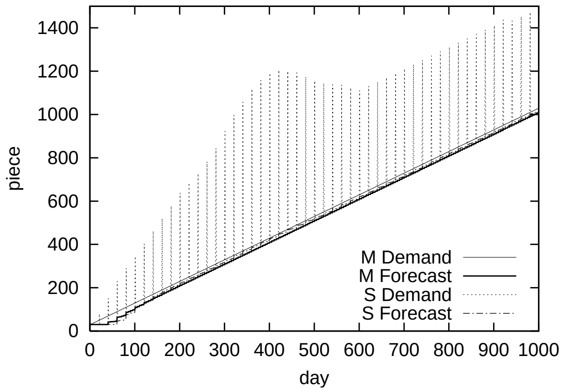


Figure 2: transitions of forecast and demand

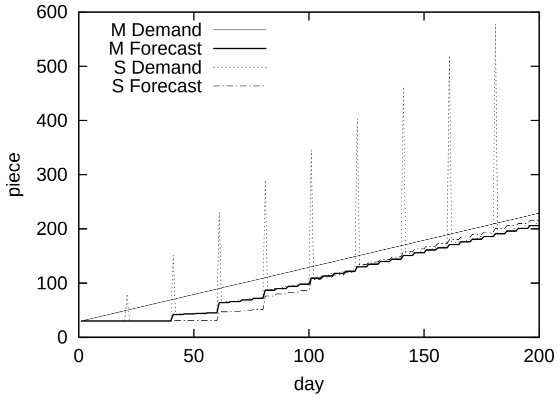


Figure 3: close up of Figure 2

Since exponential smoothing can easily follow linear trend, the manufacturer's demand forecast follows their actual demand in a short period. On the contrary, the supplier's demand is jumping up at the end of every month. The supplier updates its sales forecast, MPS and MRP at that time. In the supply chain process, enough order quantities to satisfy the target inventory level at the end of a day are planned in advance based on the sales forecast. The supplier and the manufacturer update their planning data periodically, and the most recent status of the process including sales forecast, actual demand, inventories and work in processes is reflected in the up-to-date planning at that timing. In this case, the manufacturer's forecasting is constantly below actual demand as can be seen in Figure 3. Accumulation of the forecat-demand gap is reflected in planning at a time when forecast is updated at the end of a month. Furthermore, planning is also updated once a month. For these two reasons, order quantities increase at once in order to fill the gap. Although this may be too extreme case, amount of logistics actually increases on 5th, 10th, 15th, 20th, 25th and the end of month in Japan. This phenomenon allows us to realize that the experimental result is not just an empty figment.

3.2 capability and limits of the MPCSs

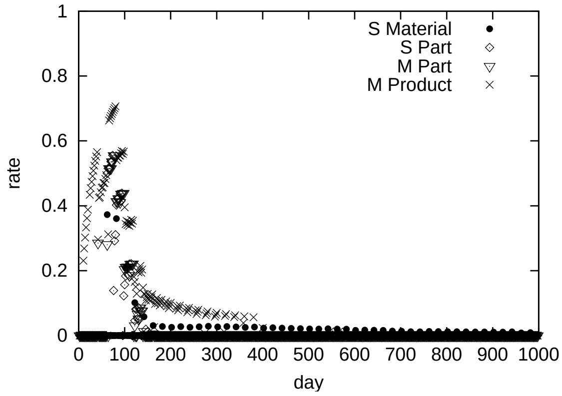


Figure 4: case1:transitions of shortage rate

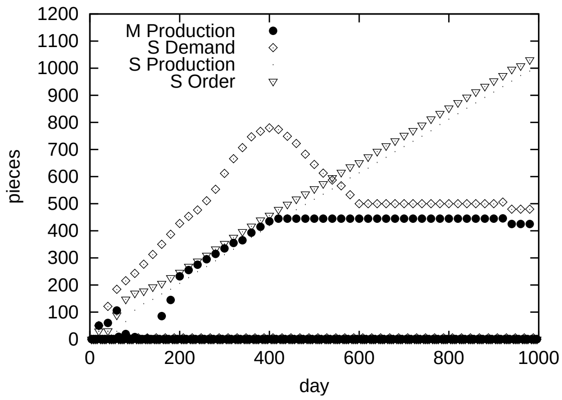


Figure 5: case1:transitions of order fluctuation

Figure 4 shows transitions of shortage rate behind Figure 2. In Figure 4, values of shortage rate are plotted on the graph. Shortage rate is defined as the rate of the quantities of shortage to the requirements. Figure 4 shows transitions of shortage rate of "S:Materials", "S:Parts", "M:Parts" and "M:Products" in Figure 1. Figure 4 indicates that stockout continuously occurs at all the processes. This result shows that the planning function of the MPCSs does not work well. On the other hand, all the values of shortage rate converge on 0 in the late of the period. The MPCSs feeds back actual-planning gap and process status to up-to-date planning. Since the purpose of the system is to satisfy the market requirement with perfect service rate, it can be said that the MPCSs adapts the planning to the supply chain circumstances in the long run to achieve the intended purpose. This can be recognized as a capability of the MPCSs.

Figure 5 indicates more serious issues than Figure 2. Figure 5 shows transitions of order fluctuations of "M:Production Order", "Purchase Order from Manufacturer", "S:Production Order" and "S:Purchase Order" in the model of Figure 1. That of "Customer Order" is omitted because the manufacturer's demand constantly increments by one per day. There are much more uncontrollable problems in the internal behavior of this supply chain process. On the graph, absolute values of the difference between the order quantities for a day and the previous day are plotted. Black dots show the manufacturer's production order fluctuations, dots and triangles show the supplier's production and purchase order fluctuation respectively and diamonds show the supplier's delivery order fluctuations. Again, it is noticed that order quantities significantly fluctuate at the end of a month which is the timing of forecasting and planning update.

Figure 5 as well as Figure 2 also indicates that the MPCSs do not work well. The MPCSs should adapt the supply chain process to the market and stabilize the process as a whole. On the contrary, it causes confusion in this case. Especially for the supplier, order fluctuations of production and purchase processes keep increasing even in the late of the experimental period. In the supply chain process, only one product, and its bill of materials contains only one part, flows in the chain and market demand increases deterministically. While the process has such a simple logistics structure, the process has such unreasonable behavior. This shows that the control function of the MPCSs does not behave successfully without parameter adjustment of the supply chain structure. Even such a simple two-stage supply chain process behaves much unstable despite the purpose of MPCSs. This result implies that it is not easy to manage for actual supply chain processes with MPCSs. Supply chain performance cannot be improved simply by introducing MPCSs.

3.3 considerable structural parameters

In order to control supply chain processes by information systems, firstly, it is necessary to understand what characterizes the process behavior. And then, the whole structure should be synchronized appropriately.

Actual supply chain processes have million considerable parameters, and they interact each other. It is too complex to deal, so we simplified supply chain processes focusing on interaction between material flow and information flow as the model of Figure 1. In the Figure 1, there are six structural parameters - "demand", "forecasting", "MRP", "MPS", "activity" and "inventory". In the model, "demand" shape is supposed to be increasing deterministically. Lead time and capacity are important factor of "activity". Lead time is assumed to be fixed. And so prcesses is supposed to be enough flexible that capacity can be ignored. And though accuracy of "forecasting" can be regarded as a key factor of supply chain, in this model, we don't follow up on the accuracy more. Because it can be considered that exponential smoothing is already enough following. Under these conditions, next issue is follows; how can the supply chain process be optimized and how much does the peformance improve?

According to the analysis in this section, order quantities were jumping up at the timing of information update, and this disrupted the balance of the supply chain process. This derives from accumulation of the actual-planning gap. The gap has been accumulated during information update interval. These observations show that frequency of information update might be an element which has great impact on supply chain processes. Furthermore, inventory allocation is an important factor in supply chain processes[10]. Therefore, the supply chain performance might be improved throug adjusting frequencies of information update simultaneously with inventory allocation. In the next section, a method for structural optimization with this approach and its impacts will be shown.

4 Structural Adjustment for Supply Chain Optimization

In the previous section, capability and limits of the MPCSs were shown. Supply chain performance cannot be improved simply by introducing MPCSs. In order to control supply chain processes with MPCSs, parameters of the supply chain structure should be adapted to the circumstances.

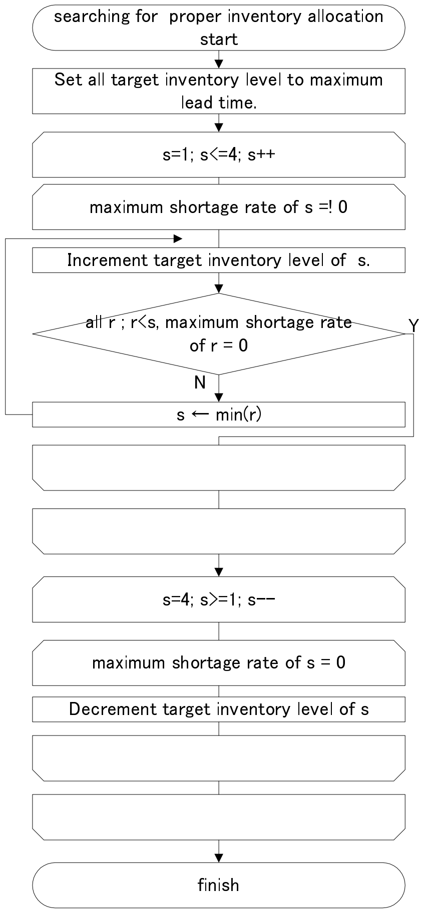
In this section, we suggest a method of optimization for the supply chain structure represented in Figure 1. And its impacts are shown.

4.1 performance evaluation

There exists trade-off between inventory volume and service rate in supply chain processes. If they have much amount of stock, then they can meet the requirements in a moment. However, processes with excess inventories cause much waste. Therefore, whole characteristics of the process cannot be evaluated from the perspective of either inventory volume or service rate. We observe balance of inventory, service rate and stability of the process to evaluate performance of the supply chain process.

Now, we define minimum combination of target inventory level which allows all processes to achieve strictly perfect service rate as *proper inventory allocation.* This can be searched in the manner of Figure 6. Service rate can be changed from 0%

to 100%. In this paper, it is fixed to 100%, because shortage is not acceptable in highly-competitive business environment today. Under the condition of fixed 100% service rate, the less inventory, the higher supply chain performance.



s=1:SMaterials, 2:SParts, 3:MParts, 4:MProducts

Figure 6: procedure of searching for *proper inventory allocation*

Further to inventory volume and service rate, process stability is important for supply chain management. If interfirm order fluctuations are huge and supply chain processes are unstable as Figure 5, companies must have a great stock to provide the order fluctuations. This opposes the common objective of SCM which is to reduce inventories by cooperative relationship. Furthermore, interfirm order fluctuations cause internal order fluctuations. It complicates their internal operations such as capacity planning, task planning, purchase planning and so on. Stable process behavior with small order fluctuations is an element essential for a sustainable supply chain relationship. For this reason, in this paper, supply chain stability is evaluated by average order fluctuations at each process as the following equation.

$$OF_j := \frac{1}{T}\sum_{i=1}^{T}\{\text{order quantity on } (i{+}1)\text{th day} - \text{order quantity on } i\text{th day}\}$$

OF_j represents period average of order fluctuations of process j. Experimental period T is set to 1,000 days to examine long term trend of the process behavior. The less OF_j, the higher the stability.

These measures for evaluation clearly shows that the process in the previous section is low-performance process. Proper inventory allocation of the process is 174 day's, 70 day's, 31 day's and 19 day's at each stock point of the supplier's materials, parts, the manufacturer's parts and products respectively. Too much inventories are required, even though the market demand increase only one per day. Process behavior of the process is shown in Figure 7.

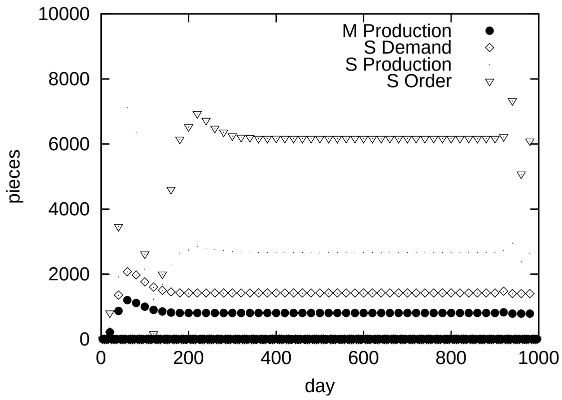


Figure 7: structure1:transition of order fluctuation

The behavior in Figure 7 seems to be more controllable than that in Figure 5. It can be said that proper inventory allocation has an effect on staility of the process. However, the fluctuation band is quite huge as can be seen. In fact, $OF_{\mathrm{S}Order} = 623.7, OF_{\mathrm{S}Production} = 268.5, OF_{\mathrm{S}Demand} = 142.6$ and $OF_{\mathrm{M}Production} = 81.0$ in spite of $OF_{\mathrm{M}Demand} = 1.0$ in this case. This result also indicates that it is not only inventory allocation that we need to consider for structural optimization for supply chain processes.

As we have seen in the previous section, frequencies of information update might be an important element which characterizes the supply chain process. And then, thesupply chain structure might be optimized through adjusting frequencies of information update simultaneously with inventory allocation.

In the next subsection, a method for optimization through the above approach, and its impacts will be shown.

4.2 Optimization for the supply chain structure

From combinations of frequencies of information update of view, following 5 samples of supply chain structures can be considered. 1: forecast/once a month - MPS and MRP/once a week, 2: forecast, MPS and MRP/once a week, 3: forecast/once a week - MPS and MRP/once a day, 4: forecast and MRP/ once a week - MPS/once a day, 5: forecast and MPS/once a week - MRP/once a day.

The proper inventory allocation of each structure is shown in Table 3. Target inventory level of 0 means that they do not have any safety stock of the item. For example, for the structure 3, the manufacture does not have product inventories. It means that the manufacturer starts their operation for a day's order at the beginning of the day, then can completes and ship on the same day. Table 4 shows order fluctuation of each structure. And Figure 8 is the cobweb chart of Table 4. Figure 8 shows effects of the optimization visually.

Table 3: comparison of proper inventory allocation among the structures

	Frequency of plan-update			Target inventory level(days)			
structure	forecast	MPS	MRP	S:Materials leadtime: 2 days	S:Parts 15 days	M:Parts 3 days	M:Products in a day
1	m	w	w	16	15	8	4
2	w	w	w	6	10	6	4
3	w	d	d	5	9	4	0
4	w	d	w	7	10	7	0
5	w	w	d	7	10	6	4
previous	*m*	*m*	*m*	*174*	*70*	*31*	*19*

m: once a month, **w**: once a week, **d**: once a day
MPS: master production schedule, MRP: material requirements planning

Table 4: comparison of order fluctuation amang the structures

structure	OF_j			
	S:Materials	S:Parts	M:Parts	M:Products
1	72.6	37.7	67.9	52.0
2	38.7	24.5	63.2	51.2
3	8.0	7.4	2.9	1.0
4	40.6	58.1	57.3	1.0
5	27.1	24.2	52.0	51.2
previous	*623.7*	*268.5*	*142.6*	*81*

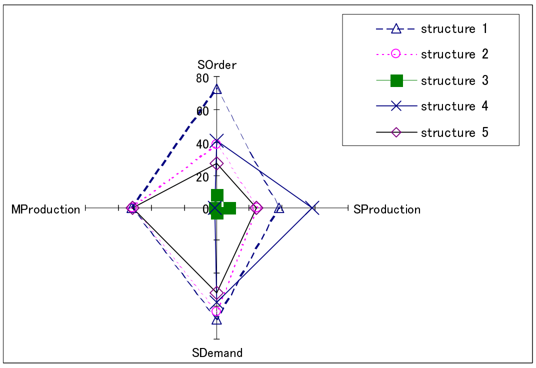


Figure 8: experimental results: effects of the optimization

These results shows following four insights. Firstly, adjusting frequencies of information update simultaneously with inventory allocation has great effect on the supply chain process model. As will be noted from Table 3, target inventory level of all the 5 structures is reduced drastically, compared with the structure in the previous section. And process stability of them is improved significantly. In addition, it can be seen that performance improvement becomes more pronounced toward upper processes. Why does the structural adjustment have such a significant impact on the supplier's processes? If information is updated by extremely low frequent, like previous, reliability of the information is to be also extremely low. Because forecasting accuracy is low and inventory status is outdated, actual-planning gap gets bigger and bigger. This has order fluctuation be significantly huge at the time of updating. And this fluctuation propagetes to the upper organization through the MPCSs along the supply chain process. This can be recognized as a kind of bullwhip effect. In this reason, after improving the reliability of the information, the performance of the supplier increases.

Secondly, they indecate that the structure 3 is the optimal structure among these

5 structures. The structure 3 can be achieved perfect service rate with the smallest stock, and the order fluctuation at all processes are also the smallest of the five. In the structure 3, all of forecating, MPS and MRP are updated most frequently. That is, order quantities of production and purchase are calculated and released every day judging by day-by-day circumstances. The supply chain process model of Figure 1 is examined on the assumptions that deterministic lead time as shown in Table 1, so much flexible capacities and deterministically increasing demand. Under the condition, it can be considered that high frequent information updating is suitable for the supply chain. As a result, inventories required from the process become small, and the process comes to be steady. Figure 9 represents transitions of order fluctuations of the structure 3. As shown in the figure, process behavior is very stable with small order fluctuation after around 200th day. Compared with Figure 5 and Figure 7, it obviously shows that the structure 3 has much stable behavior.

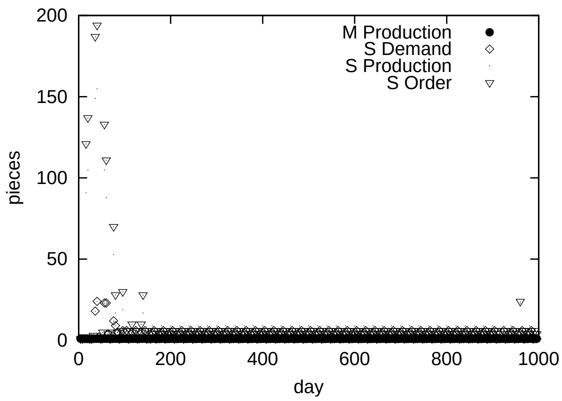


Figure 9: structure4:transition of order fluctuation

Thirdly, they show the importance of including MPCSs in supply chain models, and considering structural consistency as a whole. In the above, we described that high frequent information updating was suitable for the supply chain structure. However, the results of the structure 4 and 5 indicates that it is not always true. For examples, compared the structure 2 with the structure 4, the supplier's performance of the structure 2 is better than that of the structure 4 in spite of its MRP data updating frequency. More detail analysis shows that this is because of the forecasting trend and inventory volume. These results shows that various elements have complicated interaction each other in network of the supply chain process, and therefore, decisions by the MPCSs have immeasurable impacts on whole processes. This can lead to a completely different result despite their intention, or even if a result is desirable, the internal structure may have undesirable uncertainties like the structure 4 and 5. In such two cases, since the supply chain structure contains elements with uncertainty, its behavior becomes sensitive to environmental changes such as demand fluctuations, stock out or overstock, chage of plans and so on. Therefore, it is important to recognize whole structures of supply chain including MPCSs as a system. And structual parameters should be considered and designed from both dynamic and static point of views to establish a robust and stable supply chain structure.

Lastly, structural adjustment through the approach in this paper can reduce bullwhip effect without information sharing. As it is generally known, bullwhip effect can be reduced by sharing information among supply chain organizations[5]. However, results in this paper implies that optimization for supply chain structure through adjusting the parameters can be more effective than just sharing their information. Or, it might be able to be said that it is worthy not to share their information itself but to optimize the supply chain structure through information sharing. This is also an interesting result in this paper.

Through all the analysis above, performance of the process can be improved through structural optimization by adjusting frequencies of information update simultaneously with inventory allocation. This shows that frequencies of information update is an element which has great impact on the supply chain process. It must be recognized as an important element which characterizes the supply chain process. Additionally, proper inventory allocation of each structure seems to be related to the process lead time. Relatively much inventories seems to be required at stock points which need much time to obtain. Though we cannot calculate the volume at the present stage, developing calculational procedure will be worth a lot to design supply chain processes.

5 Conclusion

In this paper, we analyzed behavior of a supply chain process controlled by MPCSs. The supply chain process model considered in this paper is represented in Figure 1. The model has MPCSs whose structures and functions are expressly defined. With this model, capability and limits of the MPCSs were shown. And then, we suggested a way for optimizing the supply chain structure by focusing on frequencies of information update and inventory allocation. For this optimization, a procedure for searching proper inventory allocation was suggested in Figure 6. With this procedure, the minimum combination of target inventory level which allows all processes to achieve strictly perfect service rate can be obtained. And effects of the optimization were shown. The results are summarized as follows:

- Supply chain performance cannot be improved simply by introducing MPCSs. While the process has a simple logistics structure, the process can have unreasonable behavior. This shows that the control function of the MPCS does not behave successfully without parameter adjustment of the supply chain structure.

- Frequencies of information update is an element which has great impact on the supply chain process. It must be recognized as an important element which characterizes the supply chain process.

- The approach of optimization through adjusting frequencies of information update simultaneously with inventory allocation has great effect on the supply chain process model. With allocating proper inventory, process stability can be improved significantly. Furthermore, it can be seen that performance improvement becomes more pronounced toward upper processes. This can be recognized as a kind of bullwhip effect. After improving the reliability of the information through optimization for the supply chain structure, the performance of the supplier increases.

- The structure 3 in Table 3 is the optimal structure in this paper. Under the condition in this paper, it can be considered that high frequent information updating is suitable for the supply chain structure. As a result, inventories required from the process become small, and the process comes to be steady.

- It is important to include MPCSs in supply chain models, and consider structural consistency as a whole. Various elements have complicated influence each other in the network structures of the supply chain process, and therefore, decisions by the MPCS has immeasurable impacts on whole processes. This can lead to a completely different result despite their intention, or even if a result is desirable, the internal structure may have undesirable uncertainties. Therefore, it is important to recognize whole structures of supply chain including MPCSs as a system. And structual parameters should be considered and designed from both dynamic and static point of views to establish a robust and stable supply chain structure.

- Proper inventory allocation of each structure seems to be related to the process lead time. Relatively much inventories seems to be required at stock points which need much time to obtain.

- Though bullwhip effect can be reduced by sharing information among supply chain organizations, the approach in this paper can also reduce bullwhip effect without information sharing.

Since different structure of supply chain processes have different properties, there is no guarantee that different structure of supply chain can achieve similar results by the optimization approach. In this sense, this paper does not provide any solutions for general supply chain process. However, the results derived from such a simple supply chain model implies that it is not easy to manage with MPCSs, and provides some sort of suggestion to actual supply chain processes. Therefore, researching for supply chain structures including MPCSs is much valuable to both industrial and academic societies.

Further research on supply chain structural analysis should be required. Bill of materials, capacities, ways of information sharing and demand pattern shall be considered in the future. And developing calculational procedure will be our big challeng.

References

[1] Gunasekaran A and Nath B. The role of information technology in business process reengineering. *International Journal of Production Economics*, Vol. 50, pp. 91–104, 1997.

[2] Cutting-Decelle AF, Das BP, Young RI, Case K, Rahimifard S, Anumba CJ, and Bouchlaghem NM. Building supply chain communication systems: A review of methods and techniques. *Data Science Journal*, Vol. 5, No. 05, pp. 29–51, 6 2006.

[3] Berchet C and Habchi G. The implementation and deployment of an erp system: An industrial case study. *Computers in Industry*, Vol. 56, pp. 588–605, 2005.

[4] Silver EA, Pyke DF, and Peterson R. *Inventory management and production planning and scheduling,Third Edition*. Jhon Wiley, 1998.

[5] Chen F, Drezner Z, Ryan JK, and Simchi-Levi D. Quantifying the bullwhip effect in a simple supply chain: The impact of forecasting, lead time and information. *Management Science*, Vol. 46, No. 3, pp. 436–443, mar 2000.

[6] Rdlph G and Barrar P. Overage inventory-how does it occur and why is it important? *International Journal of Production Economics*, Vol. 81-82, pp. 163–171, 2003.

[7] Himoto Y, Saito A, and Matsui A. A case study on setting of safety stocks in scm/mrp. *Journal of Japan Industrial Management Association*, Vol. 55, pp. 51–58, 2004*(in Japanese)*.

[8] Venkateswaran J and Son YJ. Impact of modelling approximations in supply chain analysis - an experimental study. *International Journal of Production Research*, Vol. 42, No. 15, pp. 2971–2992, Aug 2004.

[9] Kato T. Approach of production at high cycle of daikin. *Communications of Japan Industrial Management Association*, Vol. 17, No. 4, pp. 279–283, 10 2007*(in Japanese)*.

[10] Kawai A and Sato R. On integration of manufacturing planning and control systems for supply chain management. *Journal of the Japan Society for Management Information*, Vol. 16, No. 2, pp. 21–44, 9 2007*(in Japanese)*.

[11] Tan KC. A framework of supply chain management literature. *European Journal of Purchasing and Supply Management*, Vol. 7, pp. 39–48, 2001.

[12] Huang QG, Lau SK J, and Mak KL. The impacts of sharing production information on supply chain dynamics: a review of literature. *International Journal of Production Research*, Vol. 41, No. 7, pp. 1483–1517, 2003.

[13] Sato R and Praehofer H. A discrete event model of business system - a systems theoretic for information systems analysis: Part 1. *IEEE Trans. Systems, Man, and Cybernetics*, Vol. 27, pp. 1–10, 1997.

[14] Croom S, Romano P, and Giannakis M. Supply chain management an analytical framework for critical literature review. *European Journal of Purchasing and Supply Management*, Vol. 6, pp. 67–83, 2000.

[15] Vollmann TE, Berry WL, Whybark DC, and Jacobs FR. *Manufacturing Planning and Control Systems for Supply Chain Management; 5th edition.* McgrawHill, 2004.

[16] Hopp WJ and Spearman ML. *Factory physics:foundations of manufacturing management.* Irwin/McGraw-Hill, 2001.