Integrated Set Parts Supply system in a mixed-model assembly line

Suhartini Mohd Jainury, Rizauddin Ramli, Mohd Nizam Ab Rahman, Azhari Omar

Abstract

The mixed-model assembly line (MMAL) is a type of assembly line in which a variety of product models are assembled on the same line. The use of highly variant parts on the assembly line need to be considered carefully to enable satisfactory material flow control and allow for smooth production. To increase the quality of parts supply and parts assembly in MMAL, Toyota has introduced an innovation system known as Set Parts Supply (SPS). In this paper, we investigate the parts supply issues in SPS implementation using a case study in the automotive industry. The linkage of parts supply strategies with Manufacturing Execution System (MES) is introduced to improve the SPS implementation which are (i) synchronized parts supply, (ii) e-kanban system and (iii) Synchronized Supply Sheet. From the research findings, the integration with MES has contributed to the Just In Time in parts supply at the supermarket area and assembly line.

1. Introduction

The growth of global demand in the automotive industry has rapidly increased and as a result, the industry has become more flexible and responsive to market change. Diversified customer requirements are among the largest challenges that every manufacturer has been forced to meet by increasing the variety of cars manufactured within a short lead time by implementing the mixed-model assembly line (MMAL) (Tamura, Long, & Ohno, 1999). The MMAL is implemented in many manufacturing industries as one type of assembly line with different models and their variants present at each workstation (Boysen, Scholl, & Wopperer, 2012). It is the practice of assembling products without changeovers on the same line. As a component of the Just In Time (JIT) practice, the objectives of MMAL is to deliver the products at a constant rate of part usage, to smooth the overall production and to balance the workload at each workstation (Lovgren & Racer, 2000).

The complex environment of a MMAL requires that thousands of parts for different model variants be assembled on the same line. Goltz, Gujula, Günther, Rindner, and Ziegler (2012) addressed five main problems that exist in the automotive industry with the high level of model variants on a MMAL: line balancing, master production scheduling, production sequencing, material flow control and resequencing. The high level of variants also significantly impacts the performance of the assembly line and parts supply (Fisher & Ittner, 1999). Cheldelin and Ishii (2004) discussed the most general issues that arise when highly variant parts were placed on the assembly line: omission, incorrect installation, wrong part installation and ‘other’ incorrect operations, such as keying in the wrong serial number and wrong product code.

To improve the material flow control and to adapt the JIT parts supply, Toyota Motor Corporation implemented a new system known as the Set Parts Supply (SPS), which has been adopted in Toyota Tsutsumi (Noguchi, 2005). The main concept of the system is that the selection and assembly of parts are carried out in different areas and the parts are subsequently supplied in a complete set as a unit load to the assembly line. The SPS was introduced because the assembly operators were expected to assemble a variety of parts for different models while simultaneously they need to remember the correct parts, searching for parts, picking parts and installing the parts on the car body (Nomura, 2008). This situation causes the assembly operator's to forget the information and means they are unable to complete the process within the task time (Monden, 2011).

According to Monden (2011), although SPS is similar to kitting in certain aspects the differences have not been clearly defined. The SPS has been recognized as a system that addresses quality, cognitive and flexibility needs, while kitting which has been widely practiced by the Swedish automobile companies is considered...
primarily as a method for solving problems of available space (Corakci, 2008). A considerable amount of research has been published on kitting with different strategies related to the implementation, design and performance of such systems (Bozer & McGinnis, 1992; Brynzér & Johansson, 1995; Caputo & Pelagagge, 2011; Hanson & Medbo, 2011; Limère, Landeghem, Goetschalckx, Aghezzaf, & McGinnis, 2011; Medbo, 2003). However, research on the SPS is rather limited. Therefore, it is important to close this research gap and explore how the SPS is defined as well as the problems arising from its implementation.

For these reasons, in this work we investigate the parts supply problems that arise in SPS implementation and determine strategies that could be implemented to solve the problems. The remainder of the paper is organized as follows. In Section 2, we provide a review of the SPS implementation. Section 3 describes the case study and Section 4 explained the detail framework of SPS integration system. The research findings are presented in Section 5. We concluded the paper in Section 6 with the suggestions for future research.

2. Set Parts Supply

The SPS system has been successfully implemented by Toyota as a modified version of a production system that caters to the high variants of parts in a MMAL (Marukawa, 2011). According to Nomura (2008), two main tasks are contained in the SPS system. An operator known as the shopping man performs the first task in the supermarket area and the second task is carried out by the assembly operator on the assembly line.

Previously, both tasks were carried out by only one operator specifically the assembly operator. However, in the SPS system, the assembly operator is able to focus solely on assembling the parts in the correct manner. The shopping man can also concentrates on searching to provide a set of parts to the assembly operator according to the sequence of the vehicle on the assembly line. In the supermarket area, the shopping man selects all of the required parts in and places the parts in the ‘set boxes’. After the ‘set boxes’ are completed with all required parts, they are transferred to the assembly line. The assembly operators take the parts one after another from the ‘set box’. The assembly operators subsequently assemble the parts on the car body.

The benefits of implementing the SPS in mixed-model production have been reported in several studies. According to Nomura (2008) the flow racks at the line side assembly line were eliminated by separating the supermarket area and assembly line. Smalley (2009) identified that the existence of SPS provides a major advantage to the manufacturer in improving the quality of the product through error avoidance. By implementing the SPS, Wang, Wang, Xu, and Yang (2010) found that the space required on the shop floor was decreased and the manpower allocation at the work stations was reduced. This system also assists in decreasing the workload of the senior operator (Monden, 2011) and it is easy for new workers or unskilled workers to adapt to the SPS (Marukawa, 2011).

SPS also requires an additional strategy to cater the parts supply issue specifically for searching and selection of the required parts. Deechongkit and Srinon (2009) found that the development of a system called the Digital Picking System (DPS) in the SPS implementation helped to reduce the time spent searching for parts. The DPS turns on a light for the required parts after a signal is sent to the supermarket area and the light signal subsequently guides the shopping man to select the correct parts. However, the development cost of DPS can be very expensive. Therefore, there is a need to study another strategy to support the selection task in the SPS implementation. Furthermore, the consideration of parts supply issue is very important as the highest priority area to improve productivity (de Koster, Le-Duc, & Roodbergen, 2007).

3. Data collection

To obtain a complete picture of the SPS implementation and parts supply issue, a case study was conducted in a mixed model assembly line of a Malaysian automobile manufacture. One of the authors was attached to the Industrial Engineering Department for 6 months for the purpose of this study. The data were collected through participation in meetings and discussions with personnel in the Information and Computer Technology Department and the Production Control Department. Semi-structured interviews were used to obtain the information from individuals and observations were carried out to understand the production process flow. The official documents collected include official records, minutes of meetings, technical drawings and other related items.

3.1. Case study

The study was conducted in an automotive plant that produces a variety of car models on the same line. The production capacity is approximately 150,000 units per year and the plant is fully equipped with automatic line control from the body shop, paint shop, trim and final shop. The plant allows for greater production flexibility in which three different platforms can assemble mixed model cars on each line with the lot size one. The continuous improvement in activities has facilitated waste reduction, improved product quality and provided greater inventory control throughout the manufacturing process.

The SPS was implemented in the trim and final shop. The door-sub assembly line was chosen due to the complexity of both parts and process as shown in Fig. 1. There were about 195 types of parts used in one model with 33 variants at the door-sub assembly line. There were four models with different number of variants in this case study. The door-sub assembly line has 12 workstations with assembly processes at each right and left side. Every assembly operator will do the different process starting from the first workstation. At the line side assembly line is supermarket area where the containers were placed on the flow racks. Most of the flow racks were unmovable and had different size of racks.

The system begins after receiving parts from supplier in the containers at the receiving area which also called temporary storage area. The manpower at the receiving area will arrange the containers at the flow racks. When the signal order received, the parts will be supplied to the supermarket area next to the assembly line.

The shopping man at the supermarket area received the Assembly Instruction Sheet (AIS); which contains the car sequence number and information for the assembly operator from the Manufacturing Execution System (MES). The shopping man reviews the information on the AIS which is printed at printer A. Next, the shopping man searches and picks the required parts from the flow racks at the supermarket area. The parts are placed on the SPS trolley until the trolley contains a full set of parts. The trolley is subsequently pushed to the first workstation on the assembly line. The trolley is placed between the workstation and is tied at the conveyor hanger. All of the trolleys carrying a set of parts follow the door sequence or in this paper it is called as Work In Process (WIP) and are synchronized with the assembly line. Finally, the shopping man pulls the empty trolley from the last workstation back to the supermarket area and the process of selection and picking repeats.

On the assembly line, the assembly operator at each work station will review the information in the AIS hanging on the conveyor hanger to confirm the variants and model. Next, the operator picks up the required parts from the SPS trolley. After completing the assembly process at the workstation, the trolley is pushed to the next workstation in sequence until the last workstation is reached and the process is repeated.
However from observation, certain problems occurred with the SPS implementation. The information required for ordering and supplying parts was only available in the filing system. The person in charge had to trigger the vehicle information manually from the MES on an hourly basis. The shopping man in the supermarket area also had to order parts using a form as a kanban signal. In this scenario, human error frequently occurred, monitoring of parts ordering was difficult and the quantities were not always accurate. The shopping man was also confronted by a large number of parts required for variants that did not correlate with the AIS provided. The excessive number of parts on the racks appeared congested and messy. This situation further raises the difficulty for the task of the shopping man.

On the assembly line, the assembly operator found that the wrong parts had been put on the SPS trolley when the parts arrived at the workstation and therefore, the assembly operator had to wait for replacement parts. Parts shortage may occur due to a late delivery from the suppliers.

According to this situation, several conditions must be considered to solve the problem. We used the Five Why Analysis approach to determine the root cause of the problems as presented in Table 1:

Consequently, depending on the analysis, it is important to structure an efficient parts supply in the supermarket area with the correct information. A discussion was held with other departments to establish the best strategies for overcoming the issues of parts supply. Three improvements were selected to solve the problems that arise in the supermarket area: (1) synchronized parts supply (2) e-kanban system and (3) Synchronized Supply Sheet (SSS) for the door assembly line. Section 4 discusses the improvements in further detail.

4. Improvements of parts supply

4.1. Synchronized parts supply

For this case, the manufacturer created 49 racks in which to place the synchronized parts supply. The racks were designed to hold the parts as a unit load without the need for a container, with the parts either hanging using a hook or laying on the racks and using the element of poka-yoke to avoid mistakes and encourage the First In First Out (FIFO) concepts.

Fig. 2 shows the process flow for the synchronized parts supply from the local suppliers to the manufacturer. The suppliers receive the information for the WIP sequence from production planning through the line status monitoring at the MES portal. Next, the parts are prepared in the racking based on the sequence which means that when the parts arrive at the receiving area in the man-

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Five Why Analysis for parts supply problems in SPS implementation.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problems</td>
<td>The assembly operator had to wait for replacement of parts</td>
</tr>
<tr>
<td>Why?</td>
<td>Because the wrong parts were supplied to the assembly line on the SPS trolley</td>
</tr>
<tr>
<td>Why?</td>
<td>Because the wrong parts were put on the SPS trolley by the shopping man</td>
</tr>
<tr>
<td>Why?</td>
<td>Because the wrong parts were selected by the shopping man</td>
</tr>
<tr>
<td>Why?</td>
<td>Because the shopping man could not remember all of the variants of parts in the sequence</td>
</tr>
<tr>
<td>Why?</td>
<td>Because the parts supplied from the supplier were not arranged in sequence</td>
</tr>
<tr>
<td>Problems</td>
<td>The shopping man had to wait for parts replenishment or parts shortage</td>
</tr>
<tr>
<td>Why?</td>
<td>Because of late delivery from suppliers</td>
</tr>
<tr>
<td>Why?</td>
<td>Because the wrong signal or wrong information was received from the suppliers</td>
</tr>
<tr>
<td>Why?</td>
<td>Because of the wrong information from the manufacturer</td>
</tr>
<tr>
<td>Why?</td>
<td>Because the wrong information/signal was provided from the shopping man</td>
</tr>
<tr>
<td>Problems</td>
<td>The shopping man had to take time for the selection task</td>
</tr>
<tr>
<td>Why?</td>
<td>Because the shopping man could not remember the information in the AIS</td>
</tr>
<tr>
<td>Why?</td>
<td>Because the AIS contained work instructions that were suitable for the assembly operator</td>
</tr>
<tr>
<td>Why?</td>
<td>Because there was no sheet that contained the information concerning the parts required for each variant of car on a specific assembly line</td>
</tr>
</tbody>
</table>
4.2. e-kanban system

The e-kanban system was developed as a strategy to solve the problem. This web-based system obtains real-time body data from the MES. The system functions specifically as an interface with the ERP and MES to calculate the sub-daily requirements as shown in Fig. 3. The MES receives the scheduling information for production planning through the ERP system and the MES provides the quantity of real-time online bodies or WIP to the e-kanban system. The rapid information flow is fully visible from forecast to the MES. The automatic data transfer to the e-kanban system also ensures the accuracy of the data. No manual data maintenance is required in e-kanban which reduces human errors and avoids manipulation. The latest WIP sequence from the MES will enable suppliers and third party logistics (3PL) to supply parts on a Just In Time basis.

Figs. 4 and 5 present an overview of the e-kanban system and the e-kanban operational flow respectively. The e-kanban system links to the Bill Of Material (BOM) from the ERP. The combination of information from the e-kanban database and the BOM (i.e. basic information, packaging information, logistics information and order information) are used to convert the body data into a part-by-part format. If there are any additional orders, the user will fill up the order form in the e-kanban system. The quantity of parts usage per car and the quantity of parts per packaging process are also provided.

The system will calculate the required quantities of parts and the quantities of parts for order. The information for the required quantity of parts will appear in the supply form via the web portal such that the Production Control Department in the temporary storage area can supply parts to the supermarket area at the specific time at the right place with the required quantity. In the ordering flow, after the system generates the fixed delivery time and estimates the time arrival for each part, the system will order a specific time and submit the information to the suppliers or 3PL by uploading the ordering format to the ERP. The suppliers view the order on the web and print the order form as shown in Fig. 5. The supplier will deliver the parts to the manufacturer according to the quantity ordered at a specific time.

Many benefits are provided by the e-kanban system. Accurate information can be obtained by avoiding the manual part ordering operations that lead to human error. The information is also applied as a web-based system with real-time data which makes it simpler for the manufacturer and suppliers to monitor the parts ordering and delivery processes. The system also reduces the job scope for the shopping man and eliminates forms that must be filled out.

4.3. Synchronized Supply Sheet (SSS)

The SSS is a sheet that contains information concerning the production order and information pertaining to the product specification from the MES. It contains data with additional details relevant to the specification of the vehicle including the number of sequences, body number, model code, option and various parts required for the right hand side (RH) and left hand side (LH). The manufacturer’s plant, the parts are already in sequence and are synchronized with the assembly line.

![Fig. 2. Process flow of the synchronized parts supply.](image1)

![Fig. 3. Data flow of e-kanban system integrated with MES.](image2)
previous AIS contained detailed data for the entire assembly line which makes the shopping man confuse. The information in the SSS which was created for specific workstation is much easier for the shopping man to read and relates the parts information from the suppliers. The MES sends the data to the SSS printer when the car body enters the trim and final shop from the painted body storage (PBS) area. The SSS printer is located in the supermarket area which is easy reach for the shopping man.

4.4. Integration with MES and ERP

The three improvements were integrated with MES to increase the production efficiency. MES is an information technology system for managing manufacturing operations and monitoring WIP on the shop floor. A large collection of real-time data and feedback from production status results in the MES were used for improvement analysis to increase the enterprise’s production control, management capacity, reduce product cycles with minimum cost and increase the productivity (Luo, 2010).

The MES plays an important role in communicating across the business systems at the ERP level and the control system on the shop floor, as shown in Fig. 6. The ERP provides a shared database from various applications inside the organization such as finance, materials management, production planning, human resources, sales and distribution. This comprehensive system begins when the production orders are created at the ERP level and the MES
manages the production operations based on the order information. Using the accurate and real-time data, the MES provides details production scheduling and controls production on the shop floor through the equipment, devices and sensors. The MES also records the relevant manufacturing data and gives secure feedback to the ERP level.

In this case study, as shown in Fig. 7, the MES consists of the following module functions: production sequencing, production ordering, production tracking and control, production recording and interfacing with other systems. All module functions are intended to support lot-size-of-one production, to improve the manufacturing efficiency and logistic processes, to provide accurate and timely information and to track the vehicle status on real-time basis.

The MES receives the sequencing data from production planning in ERP and broadcast the data to the lines via Local Area Network (LAN). The production sequence module also allows the manufacturer to reschedule the plan for maximum operating efficiency. Then the order will release to the printer, computer, fax machine and production equipment such as robots, conveyor and machines. At the same time, the manufacturer will order parts from supplier using a supplier management portal which connecting to ERP. The order is based on daily basis schedule which content information such as part number, quantity and location to supply.

The production tracking and control module will allow users to track-and-trace WIP or production data schedule. The integration with e-kanban system provide a sub-daily schedule with the information concerning a specific time to deliver and estimated time of arrival through the MES web portal. The AIS and SSS will be printed at the shop floor for assembly line and supermarket area. This feature also manages and analyzes the WIP to ensure the types of parts variants are supplied synchronize with the assembly line. At the supermarket area, the shopping man will read the SSS and take the required parts on racks. The parts will put on the SPS trolley and the shopping man will push them to the assembly line. At the time the SPS trolley arrives at the first workstation, the car should just arrived at the first workstation for the assembly operator to carry out the assembly task.

5. Result after improvements

The result after parts supply improvements were compared from the previous data. By using this integration of synchronized
parts supply and e-kanban system with MES, the parts can be supplied with the JIT to the manufacturer receiving area. At the receiving area, the manpower received parts from supplier in containers and racks for synchronized parts. After the improvements, the task at the receiving area especially for rearrange part was decreased. Therefore, six manpower at the receiving area were eliminated as shown in Fig. 8. The number of shopping man and the assembly operator were mainly the same. The manpower allocation can be saved about RM3,600. The total cost of manpower, Cm is obtained from the Eqs. (1) and (2).

\[
C_m = N_t \times C_w
\]  
(1)

and

\[
N_t = Na + Ns + Nr
\]  
(2)

Where

- \(C_m\) = total cost of manpower
- \(C_w\) = cost of basic wage \(\sim\) RM600 per month
- \(N_t\) = total number of manpower
- \(Na\) = assembly operator
- \(Ns\) = shopping man at the supermarket area
- \(Nr\) = manpower at the temporary storage area

After the improvements, the floor space at the receiving area also reduced because some parts were not supplied using containers. The flow racks which allocate for empty containers were eliminated. The reduction of floor space was 1500 sq ft and the manufacturer could save RM3,000 in the utilization of receiving area. The Eq. (3) is the total cost of floor space.

\[
C_s = L \times W \times C_f
\]  
(3)

Where

- \(C_s\) = cost of floor space
- \(C_f\) = 1 square feet \(\sim\) RM2.00
- \(L\) = length
- \(W\) = width

Before improvements, \(C_{s1} = 50 \times 60 \times 2 = RM6,000\).
After improvements, \(C_{s2} = 50 \times 30 \times 2 = RM3,000\).
Total cost saving = \(C_{s2} - C_{s1} = RM3,000\).

From the receiving area, the parts are then transferred to the supermarket area in 30 min interval. Before the improvements, the parts were stored at the receiving area for 2 h Fig. 9. This situation contributed to the inventory cost saving about RM46,200 per month. The average of waiting time for parts at the supermarket area and assembly line also were reduced from 300 to 0 s and 60 to 0 s, respectively as shown in Fig. 8.

![Fig. 8. Number of manpower before and after parts supply improvements.](image1)

The result, it shows that the integration between MES and e-kanban system offered a better result. The number of delivery and total inventory to supply was controlled by the system. The data of WIP can be tracked start from trigger point until it reach at the assemble trigger point. From that moment, the data will deduct from the system. The total quantities of parts for order are the quantity balance from the production. When the order form has been approved, the supplier will deliver parts to the manufacturer.

The required quantities of parts can be obtained from the Eqs. (4)–(10).

\[
N = \text{Number of required quantities of parts,}
\]

\[
= \left(\frac{D}{q}\right) \times (\beta + \alpha)
\]  
(4)

\[
B = \text{Number of quantities of parts for order,}
\]

\[
= Opcs - R
\]  
(5)

\[
D = \text{quantity parts needed,}
\]

\[
= r \times u
\]  
(6)

\[
\beta = \text{kanban coefficient (time for parts replenishment after the order is given)}
\]

\[
= \frac{X(Z+1)}{Y}
\]  
(7)

\[
Opcs = \text{order part per pieces}
\]

\[
= Op \times q
\]  
(8)

\[
Op = \text{order part per container/racks}
\]

\[
= \text{roundup}(R/q)
\]  
(9)

\[
R = \text{Total of requirement}
\]

\[
= N + A - P
\]  
(10)

Where,

- \(X\) = day
- \(Y\) = frequency of delivery
- \(Z\) = interval time (at time to make the next order)
- \(r\) = production rate per day
- \(u\) = usage per car
- \(q\) = quantity parts in container/racks
- \(\alpha\) = safety stock
- \(A\) = Additional order
- \(P\) = quantity previous balance

![Fig. 9. The average of waiting time before and after improvements.](image2)
6. Conclusions

With the demand for using a huge data exchange, the complexity of parts supply has forced the manufacturer to go for online communication systems to enrich the communication between the manufacturer, supplier, customer and manufacturing process itself. While technology and information system are clearly very important in production, manufacturers still face a restriction in respect of the resources and capabilities. Therefore, it is important to select effective strategies for supplying parts to achieve a smooth production with the adoption of the JIT concept.

The findings from this study indicate that the e-kanban system, synchronized parts supply and correct information from MES have been very beneficial to the process of supplying parts in SPS implementation. The integration between SPS and MES facilitated the operator to get the accurate data in real-time and creates more than JIT inventory control. As a result, there is no waiting time for assembly operator at the assembly line since the shopping man at the supermarket area supplied the correct parts to them. The task of shopping man became easy because of the SSS and the synchronized parts supply on the flow racks at the supermarket area.

Although the research findings confirm the benefits of SPS integration system, there were many area of research in this case study that not been investigate yet. This research focuses only on the three strategies within parts supply issues in SPS implementation with lack of optimization. This paper also studied on certain performance measure which there is still gap to fill in the future research. In order to get more understandable and information regarding SPS system, further studies is needed especially on performance evaluation which also can be as an externship study from several researchers in kitting system such as Hanson and Brolin (2012) and Hanson and Medbo (2011), which investigated the relative effects of kitting and continuous supply on in-plant materials supply. A more wide-ranging assessment from case studies could subsequently be used in simulation and modeling to provide a better result on performance evaluation of SPS integration system.

Besides comparing the kitting system and continuous supply with certain criteria which has been proposed by Hua and Johnson (2008), the SPS integration system also can be compared with several criteria in terms of design and performance of route strategies on SPS trolley either manually or using automated guide vehicles. The optimization model of parts supply for kitting has been constructed by Limère et al. (2011) and the optimization model of SPS integration system also could be one of the new researches in the future. Further knowledge on the critical success factors of SPS implementation that impacts on the change management and business processes is an excited topic to do the comprehensive study.

References


