JEDI: Just-in-Time Execution and Distribution Information Support System for Automotive Stamping Operations

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Abstract Stamping is one of the most complex operations in the automotive supply chain, providing over 400 end items to dozens of assembly plants and service facilities. This operation consists of a complex network of blankers, presses, and subassemblies. Stamping is affected by much variability, such as unexpected machine and tool down time, quality concerns, and customer requirement fluctuations. These facilities typically run a tight schedule, and supply chain visibility is a critical factor in efficient operations. The data pertaining to operations is distributed across several systems including material requirements planning (MRP), plant floor automation, and logistics management. As a result, decision makers are faced with too much data and not enough information. This leads to time loss and effort spent in consolidating and comprehending the data. This chapter describes the Just-in-time Execution and Distribution Information (JEDI) system that collects and integrates relevant data from a set of disparate systems and generates a set of spreadsheet models that represent the stamping production and supply chain status. JEDI not only presents the information in an intuitive way, but also provides what-if analysis capability and decision support for scheduling and distribution.

1 Introduction

This chapter addresses scheduling in a complex manufacturing environment within the automotive supply chain. Specifically, we concentrate on the scheduling of automotive stamping operations. The main goal of stamping operations is to satisfy customer requirements posted using the electronic data interchange (EDI). Demand for individual plant operations is propagated using material requirements

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planning (MRP). The plant strives to follow an optimized cycle plan using safety stock to compensate for demand and production fluctuations. In the last decade, the competitive pressure to become a just in time (JIT) manufacturer has resulted in a substantial decrease in inventory at the plants that used to compensate for problems common to the manufacturing environment, such as machine failure and quality problems. In the absence of inventory cushions, plants need to rectify effects of such events through changes in the schedule.

The data for scheduling and manufacturing execution control is scattered across multiple corporate business and plant floor systems. These data may have inconsistencies, errors, and may not reflect the latest changes in the inventory status. Plant personnel typically manage the schedule with pencil and paper and utilize local Excel files. This leads to time lost and effort spent in consolidating and comprehending the data. There were a number of attempts to implement automatic stamping scheduling systems that were not successful because they overlooked the challenges related to ensuring the quality of the input data and complexity and breadth of operational decisions available to plant schedulers. Besides the data accuracy itself, the given input data might not warrant a feasible solution and might require deviations from the normal business practices, such as overtime, premium freight, non-optimal shipment batches, delaying shipment of service parts, outsourcing jobs, etc. Capturing and formalizing all these decisions is either impossible or may lead to an intractable model. In most cases, traditional scheduling approaches focus on optimization or heuristic methods for finding a scheduling solution with a given set of input data; however, in practice, establishing quality input data usually requires substantial user involvement. As a result, there is often a gap between the advancements of optimization capabilities and existing plant floor scheduling practices.

A system for effective and efficient support of scheduling and manufacturing execution must accomplish the following to close this gap:

- consolidate relevant data and organize it into meaningful information;
- support data validation and verification by making each input data element easily traceable to the original source;
- provide an intuitive and clear representation of the actual decision-making environment with visibility into the demand, supply chain, scheduling, and production constraints;
- allow for what-if and sensitivity analysis;
- provide a highly interactive interface with immediate feedback on the effect of decisions.

Then such a system can be an efficient front-end to powerful optimization algorithms.

This chapter introduces the just-in-time execution and distribution information (JEDI) system, which is a decision support system that allows plant floor personnel to customize, visualize, and manipulate the scheduling data for supply chain visibility and what-if scenario analysis capability. JEDI provides visibility to the schedulers so that they can interactively change the input data (e.g. part demand, or inventory counts) when appropriate to enable feasible scheduling. JEDI leverages the scheduler's expertise and enhances the scheduler's capabilities, by allowing simultaneous analysis of the schedule and distribution options, such as using premium freight, and immediate visualization of the impacts of the decisions on both the upstream and downstream supply chain operations. JEDI also provides an interface to a number of optimization algorithms that can be called on demand. The focus of this chapter, however, is on the models to integrate and manipulate the data. For optimization methods related to JEDI, refer to [1–4].

The chapter is organized as follows. We first present an overview of both the automotive supply chain data flow and automotive stamping. Second, we present the automotive supply chain spreadsheet model and its Excel implementation. Then, we discuss the decision support interface illustrated with some usage scenarios. Finally, we review how JEDI integrates with other stamping and enterprise-wide systems. We conclude with a short summary and system benefits.

2 Automotive Supply Chain Data Flow

Successful relationships between Original Equipment Manufacturers (OEM)s and suppliers are dependent on effectively communicating data between all levels of the supply chain. Most suppliers are not dedicated to one OEM, and similarly OEMs interact with multiple suppliers. Therefore, having a means for standard communication between all parties is required. The relationship between the automakers and supply base is governed by a long-term contract, while individual transactions are handled through an EDI. The key of EDI is that it follows a standard and can be thought of as a language for communicating structured documents [15]. There are two main standards: American National Standards Institute (ANSI) X12 and Electronic Data Interchange For Administration, Commerce and Transport (EDIFACT). ANSI X12 is the EDI standard used in the United States, and EDIFACT is the international EDI standard developed under the United Nations and used by most of the rest of the world. For a comparison of the two see MEMA [14]. The North American automotive EDI has been developed by the Automotive Industry Action Group (AIAG), using the ANSI X12 format.

The following North American EDI transactions are related to scheduling, manufacturing execution, and logistics: 1. Material Release — 830 [6, 10]; 2. Shipping Schedule — 862 [8, 9]; and 3. Production Sequence — 866 [7] that supports In-line vehicle sequencing (ILVS) [11]. These EDI transactions are critical in that they describe how the demand information is posted into the supply chain.

The 830 provides the "weekly" or planning release that is calculated and issued to suppliers weekly. It authorizes labor, materials, or other resources within a specified timeframe and provides the requirement forecast beyond that. The 862 provides the "daily" or ship release schedule. It is calculated and issued to suppliers daily, covering around two weeks of consecutive calendar days of requirements. This shipping schedule transaction set enables customers to convey precise shipping schedule requirements to a supplier and supplements the planning schedule transaction set (i.e., 830).

For suppliers who provide in-sequence parts, the 866 is calculated and issued to suppliers daily, covering short-term requirements in the vehicle rotation sequence. The use of 866 EDI transactions facilitate the JIT manufacturing practice by providing OEMs with a mechanism to issue precise shipping sequence requirements.

For the first tier assembly plant suppliers, such as stamping, the customer releases are generated from the assembly line schedule. An assembly plant has its own schedule, which depends on customer orders, plant and supply chain constraints, etc. The customer releases are generated based on this schedule and other inputs, such as balance on hand (BOH), parts in transit, and logistics constraints. For scheduling of stamping operations, the 862 release is a primary source for the customer requirements data, and the 830 release is required for planning beyond the 862 release timeframe.

3 Automotive Stamping

Stamping is one of the most complex operations in the automotive supply chain. Individual stamping plant daily requirements may include thousands of parts making over 400 different end items (i.e., part type that represents a finished product that is shipped to a customer) to dozens of assembly plants and service facilities. In general, automotive stamping plants are comprised of three main areas: blankers, presslines, and subassemblies. The *blanking press* uses a large sheet roll of metal (e.g. steel, aluminum) to cut *blanks*, which are pieces of sheet metal slightly larger than the desired part (see Fig. 1). These are then sent to the presslines (see Fig. 2), which consists of several *dies* that form the three-dimensional part. Example parts are inner and outer door panels and hoods. Once the parts are made, they are sent to welding subassemblies (see Fig. 3) or directly as end items to be shipped to the assembly plants or service facilities.

Figure 4 shows the complexity involving only one stamping part, the front floor panel assembly, that must be shipped to six customers. Note that this assembly consists of five subassemblies, three of which must also be shipped to three customers. One can extrapolate from this figure for only one part the complexity in a stamping environment with hundreds of parts.

The pressline area shown in Fig. 2 is the bottleneck operation since it has the most binding constraints [1]. Each pressline is capable of making roughly 5–15 different parts, with some parts having the ability to be made on multiple presslines. Small stamping facilities have around four presslines, where large stamping facilities have over 50 presslines. There are usually long changeovers involving the need of indirect labor for die changeover preparation. Typically, the pressline schedule is implemented first, and blanker and assembly are subsequently scheduled. Ideally, stamping would operate to a repeatable cycle plan that is optimized for the minimum cost of inventory, direct labor, and indirect labor services die changeovers [3].

Fig. 1 Blanker

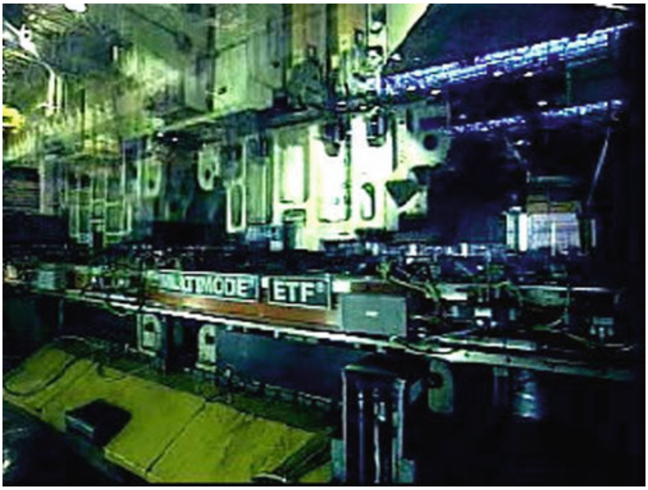


Fig. 2 Pressline

However, the execution of this plan is often affected by problems typical for any manufacturing operation, such as machine breakdowns, quality problems, etc. In the absence of large inventory cushions, these problems must be compensated for by the plant schedulers: they must modify the existing cycle plan, for example, by reducing the batch sizes and working overtime. This type of change creates a ripple effect through the complex supply chain network, such as the one in Fig. 4, and may lead to the inability to satisfy assembly plant shipping requirements.

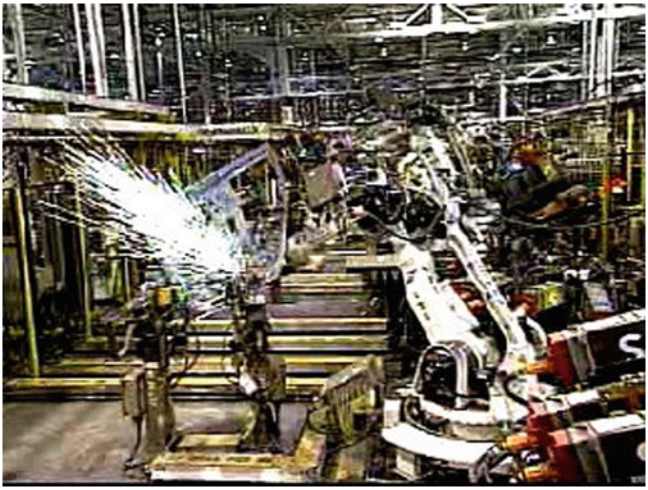


Fig. 3 Welding assembly

The job of the scheduler is very difficult due to the complexity of stamping operations and the multitude of data that needs to be analyzed. The scheduler must first get and consolidate data from many different systems, including the corporate MRP 3270 terminal emulator (e.g. Fig. 5), numerous plant floor systems, paper reports from the plant floor, and radio and phone communication. The MRP screen in Fig. 5 shows how the data is available, but not in an integrated or easy to use and manipulate interface. Hence, systems such as the MRP are not designed for decision support. As a result, decision makers are faced with too much data and not enough information. There is a need for a decision support system that will help to analyze and modify the data and support the scheduling for all operations and specifically the presslines. Additional complications arise because the bottleneck area, the press lines, is not the last area in the process. Consequently, the build requirements for the press line or blanker have to be exploded from customer releases through the bill of material (BOM). The net demand generated by the MRP for individual parts does not allow for distinguishing between actual assembly plant consumption demand from the demand raised by the need for safety stock or transportation optimization. Thus, the decision support system needs to combine scheduling support and MRP logic of BOM explosion.

The JEDI system, discussed in this chapter, integrates and consolidates supply chain and production data and generates decision support models as spreadsheet models, which provide a natural representation for the multi-period, multi-product scheduling problem at hand. JEDI implements MRP logic as a spreadsheet model of basic functions; thus, it allows on-the-fly analysis of how changes in the input data affect the scheduling demand in upstream operations. It is implemented using Microsoft Excel, which is the most commonly used system at the plant, and hence reduces the need for training and facilitates system acceptance.

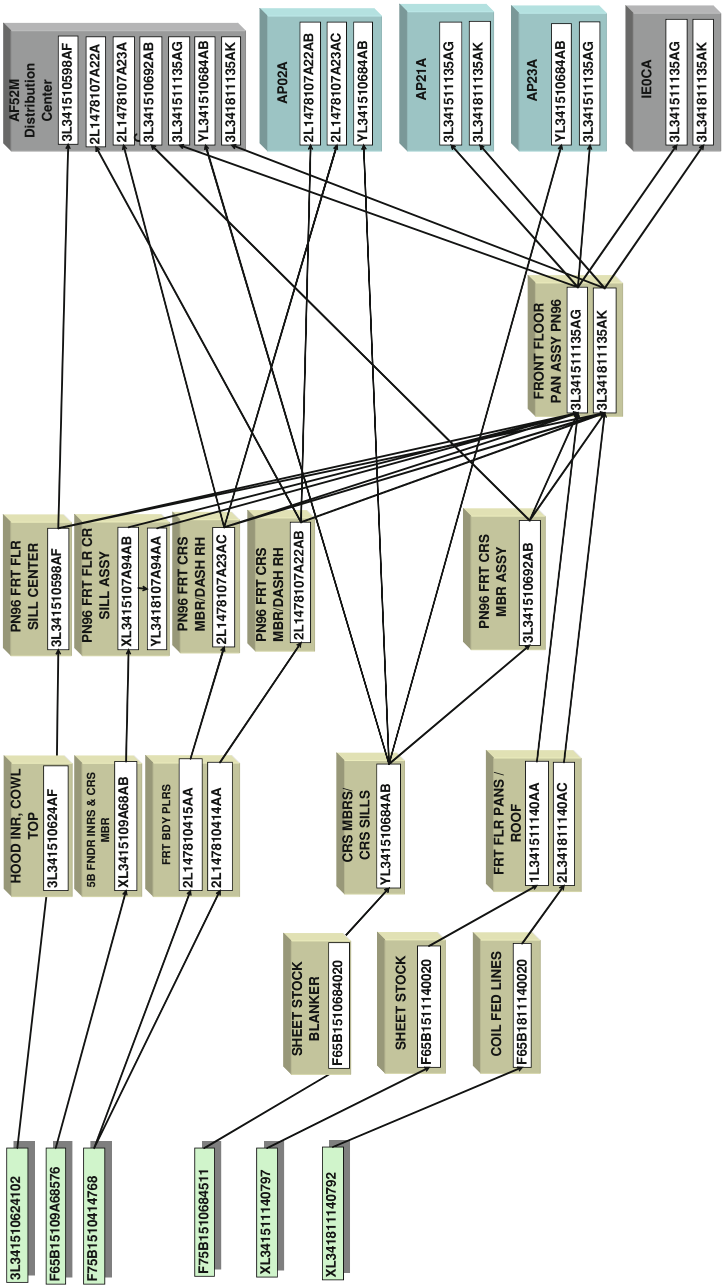


Fig. 4 Stamping complexity

Fig. 5 Corporate MRP screen with 862 data

4 Spreadsheet Model of Automotive Stamping

As we stated previously, stamping is driven by the schedule of bottleneck operations (e.g. presses), while the requirements for the press operations are driven by the customer releases on the end items. To obtain press line parts requirements, the customer releases on end items are propagated through the BOM explosion into the net requirements for the make parts (i.e. components produced at a facility that are used in a higher level items), running at the presses. Thus, our decision support model needs to integrate BOM explosion calculus with the machine finite capacity scheduling. In this section, we first describe the mathematical model that is based on recursive calculations of the net requirements of the component parts at any level in the BOM from the gross requirements of the parts in which they are used. Second, we illustrate the implementation of this model in Excel and describe the algorithm to automatically generate such a model.

4.1 BOM Explosion Calculus and Scheduling

To simplify the overview of the model, we make following assumptions:

- we assume zero lead time for all of the orders between shipping and presses, since in most cases assembly can expedite the parts through the lines;
- part demand needs to be met by the end of each time bucket;
- the parts are assigned to a specific machine (i.e. the same part does not run on different machines);

- a part must run in a single batch in a given time bucket (i.e. there can not be more than one changeover for a part in a given time bucket).

Note that the JEDI implementation addresses the cases where these assumptions are not valid.

In the model we will use the following notation for the part, customer, machine, and time bucket sets.

ρ	= number of parts.
τ	= number of time buckets.
ξ	= number of customers.
μ	= number of machines.
P	$= \{1, \ldots, \rho\}$ set of parts.
T	$= \{1, \ldots, \tau\}$ set of time buckets.
C	$= \{1, \ldots, \xi\}$ set of customers.
M	$= \{1, \ldots, \mu\}$ set of machines.
$A_p \subset P \bigcup C$	= set of items for which the make part p is an immediate successor in the BOM. For an end-item p it is the set of customers for part p.
$P_m \in P$	= the set of parts assigned to machine m.

Then, we define the input values and introduce the calculated parameters that keep track of the inventory position, the balance on hand, the machine capacity, and the net demand.

r_p	= the hourly production rate to make part p.
h_{pt}	= the hours scheduled to make part $p \in P$ in time bucket $t \in T$
l_{pt}	= the hours of changeover for part $p \in P$ scheduled in time bucket $t \in T$
Q_{mt}	= the number of hours available for machine $m \in M$ in time bucket $t \in T$
D_t^p	= the net demand for part $p \in P$ in time bucket $t \in T$
G_t^p	= the gross demand for part $p \in P$ in time bucket $t \in T$
B_t^p	= the balance for part $p \in P$ in time bucket $t \in T$, which represents either the projected inventory or demand in time bucket t.
S_t^p	= the scheduled quantity of part $p \in P$ in time bucket $t \in T$
I_t^p	= the projected inventory on hand for part $p \in P$ in time bucket $t \in T$
$\bar{I}_t^p$	= the inventory position for part $p \in P$ in time bucket $t \in T$, which represents either the projected inventory or cumulative demand in time bucket t.
$\bar{I}_0^p = I_0^p = B_0^p$	= initial balance on hand for part $p \in P$.

The gross demand for part $p \in P$ in time bucket $t \in T$ equals the sum of the net demands coming from all successors to part p: $G_t^p = \sum_{\tilde{p} \in A_p} D_t^{\tilde{p}}$, where $D_t^{\tilde{p}} \leq 0$. If part p is an end-item, then the demand D_t^p is the customer release. However, if p is a make part, then the gross demand will be the sum of net demands from the successor part in the BOM. In this case, the net demand for the part is be calculated using BOM explosion calculus from the customer releases as follows.

We introduce B_t^p to be the balance for part $p \in P$ in bucket $t \in T$. We define D_t^p to be the net demand of part $p \in P$ in bucket $t \in T$. Note that if there is any net demand for a part in a given bucket, then the value is always less than or equal to zero. That is,

$$D_t^p = \begin{cases} B_t^p & \text{if } B_t^p < 0 \\ 0 & \text{otherwise} \end{cases}$$

This logic can be represented, for example, by the following formula:

$$D_t^p = \min(B_t^p, 0). \tag{1}$$

We define I_t^p to be the projected inventory on hand for part $p \in P$ in time bucket $i \in T$: if there is any projected inventory on hand for a part in a given bucket, then the value is always greater than or equal to zero. Hence,

$$I_t^p = \begin{cases} B_t^p & \text{if } B_t^p > 0 \\ 0 & \text{otherwise} \end{cases}$$

Similar to (1), this logic can be represented, for example, by the following formula:

$$I_t^p = \max(B_t^p, 0). \tag{2}$$

B_t^p can be thought of as the non-zero part balance, which will either be the net demand or the projected inventory on hand and is calculated as

$$B_t^p = I_{t-1}^p + \sum_{\tilde{p} \in A_p} D_t^{\tilde{p}}, \tag{3}$$

where $I_{t-1}^p \geq 0$ and $\sum_{\tilde{p} \in A_p} D_t^{\tilde{p}} \leq 0$.

Using the formulas in (1) and (2), the material balance equation in (3) can be reformulated as follows:

$$B_t^p = \max(B_{t-1}^p, 0) + \sum_{\tilde{p} \in A_p} \min(B_t^{\tilde{p}}, 0) \tag{4}$$

Note that B_0^p is the existing balance on hand for every $p \in P$ and is always non-negative. Also, in the case that $p \in P$ is an end-item, the net demand is the customer release (i.e. 862) and is represented as a negative number.

We can recursively apply formula (4) to go from the customer demand to the net requirements of the parts assigned to the machine that we will schedule. Then, for each bucket $t \in T$, machine $m \in M$, and part $p \in P_m$ (i.e. parts running on machine m), we calculate the inventory position as

$$\bar{I}_t^p = \bar{I}_{t-1}^p + G_t^p + S_t^p, \tag{5}$$

where $\bar{I}_0^p$ is the initial balance on hand for part p, and $G_t^p = \sum_{\tilde{p} \in A_p} \min(B_t^{\tilde{p}}, 0) \leq 0$ is the gross demand for part p in time bucket t. S_t^p is the quantity of parts $p \in P_m$ scheduled on machine $m \in M$ in time bucket $t \in T$. The inventory position $\bar{I}_t^p$ gives the cumulative demand up to the current time bucket and takes into account parts scheduled for the given time bucket, while B_t^p gives the demand only for the given time bucket.

The desired schedule should ensure that for any time buckets within the period for which a schedule exists, $\bar{I}_t^p$ is at least non-negative or ideally close to a preset safety stock number. In other words, for any period in which we have a schedule, we should not have any unsatisfied demand. If for a certain time bucket $\bar{I}_t^p$ is negative and $\bar{I}_{t+1}^p$ is non-negative, then this indicates that certain orders are potentially late against the shipping demand and requires the scheduler's attention.

The quantity S_t^p of parts $p \in P_m$ that can be scheduled in any time bucket $t \in T$ is bound by the finite capacity of machine $m \in M$. We let r_p be the rate at which part $p \in P_m$ can be made per hour on machine $m \in M$ and h_{pt} be the hours scheduled to make part $p \in P_m$ on machine $m \in M$ in time bucket t. Then, the quantity of parts $p \in P_m$ scheduled in time bucket $t \in T$ on machine $m \in M$ is

$$S_t^p = h_{pt} r_p. \tag{6}$$

We consider that each part is assigned to a dedicated machine, but we must guarantee that in each time bucket every machine is not over its maximum capacity, Q_{mt}, defined by the number of hours available. If we let l_{pt} be the hours of change-over required for part $p \in P_m$ in time bucket $t \in T$ on machine $m \in M$, then we can satisfy the condition that the machine's maximum capacity is not exceeded by the following constraint:

$$\sum_{p \in P_m} (h_{pt} + l_{pt}) \leq Q_{mt} \quad \forall \ m \in M, \quad t \in T. \tag{7}$$

In addition to the above constraint, a valid schedule would need to satisfy other constraints such as no overlapping jobs on the same machine in the same time bucket and that the run hours are always preceded by changeover hours. These constraints can be enforced through customized data input or highlighted through Excel conditional formatting. Note that the goal of this model is not to serve as a basis for scheduling optimization but to provide a visual representation of the relations between the data and constraint violations in the decision support system, which we demonstrate in the next sections.

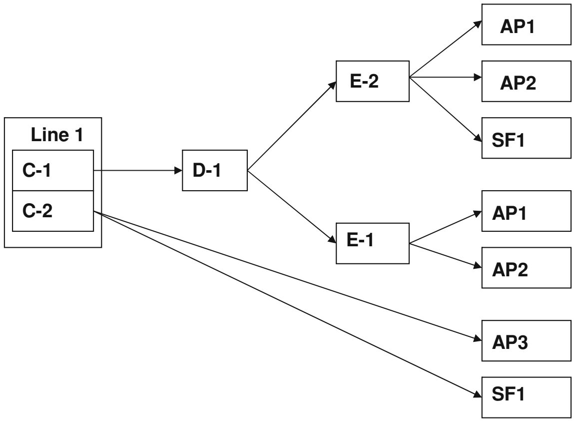


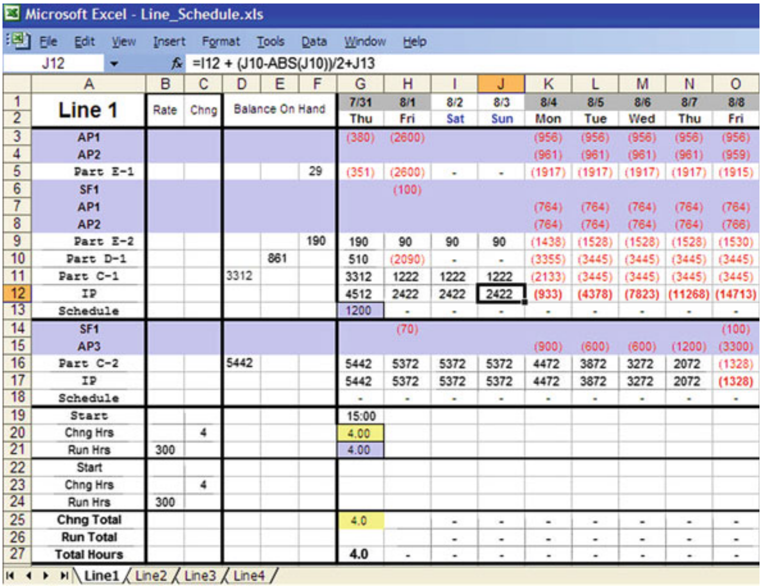
Fig. 6 Pegging tree for work center Line 1

4.2 Excel Implementation

For illustration purposes, consider the example presented in Fig. 6. Assume we have two parts, C-1 and C-2, which run on work center Line 1. The first part, C-1, is a component, which is required by another component, D-1. This part, in turn, is used in two different end items, E-1 and E-2, which are shipped to several customers, AP1, AP2, and SF1. The second part, C-2, is an end-item that is directly shipped to two different customers, AP3 and SF1. The customers whose names begin with "AP" are assembly plants, and those beginning with "SF" are service facilities.

Figure 7 shows the excel implementation of the model presented in Fig. 6. Note that the parentheses are used to represent negative numbers. The rows associated with the BOM structure for each of the parts assigned to the work center (e.g. C-1 and C-2) are grouped together. Rows 3–11 represent the demand chain rooted in the part C-1, and rows 14–16 represent the demand chain rooted in the part C-2. The customer demand is organized into daily buckets. The customer requirements, the 862 shipping release, are populated in the cells corresponding to different time buckets (see rows 3, 4, 6, 7, 8, 14, and 15 with a gray background).

The two end items E-1 and E-2 are associated with part C-1. Rows 5 and 9 contain the demand net on-hand inventory for these end items, which is calculated from the customer release and the existing on-hand inventory derived from equation (3) in Sect. 4.1 . The existing on-hand inventory for these end items are in cells F5 and F9, respectively. For example, the daily net demand on 7/31 in cell G5 is calculated using equation (4) as "= MAX(F5,0) + MIN(G4,0) + MIN(G3,0)," where F5 corresponds to the inventory in the previous period, G3 is the 862 shipping release associated with the assembly plant AP1, and G4 is the shipping release to assembly plant AP2. As a result, each cell associated with the demand of part E-1 will contain either the projected inventory for the given day in the case of a positive number or the net demand for this day in the case of a negative number.



Microsoft Excel - Line_Schedule.xls

File Edit View Insert Format Tools Data Window Help

J12 =I12 + (J10-ABS(J10))/2+J13

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Line 1	Rate	Chng	Balance On Hand			7/31	8/1	8/2	8/3	8/4	8/5	8/6	8/7	8/8
2							Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri
3	AP1						(380)	(2600)			(956)	(956)	(956)	(956)	(956)
4	AP2										(961)	(961)	(961)	(961)	(959)
5	Part E-1					29	(351)	(2600)	-	-	(1917)	(1917)	(1917)	(1917)	(1915)
6	SF1							(100)							
7	AP1										(764)	(764)	(764)	(764)	(764)
8	AP2										(764)	(764)	(764)	(764)	(766)
9	Part E-2					190	190	90	90	90	(1438)	(1528)	(1528)	(1528)	(1530)
10	Part D-1				861		510	(2090)	-	-	(3355)	(3445)	(3445)	(3445)	(3445)
11	Part C-1			3312			3312	1222	1222	1222	(2133)	(3445)	(3445)	(3445)	(3445)
12	IP						4512	2422	2422	2422	(933)	(4378)	(7823)	(11268)	(14713)
13	Schedule						1200	-	-	-	-	-	-	-	-
14	SF1							(70)							(100)
15	AP3										(900)	(600)	(600)	(1200)	(3300)
16	Part C-2			5442			5442	5372	5372	5372	4472	3872	3272	2072	(1328)
17	IP						5442	5372	5372	5372	4472	3872	3272	2072	(1328)
18	Schedule						-	-	-	-	-	-	-	-	-
19	Start						15:00								
20	Chng Hrs		4				4.00								
21	Run Hrs	300					4.00								
22	Start														
23	Chng Hrs		4												
24	Run Hrs	300													
25	Chng Total						4.0		-	-	-	-	-	-	-
26	Run Total								-	-	-	-	-	-	-
27	Total Hours						4.0	-	-	-	-	-	-	-	-

Line1 / Line2 / Line3 / Line4

Fig. 7 Excel implementation of work-center Line 01

The combined demand from parts E-1 and E-2 constitute the gross demand for part D-1. The net demand for D-1 is calculated in row 10 and is then used to calculate the net demand for part C-1 in row 11. The net demand for part C-2 is calculated directly from the shipping releases to service facility SF1 and assembly plant AP3 in rows 14 and 15, respectively.

Rows 12 and 17 contain the inventory positions for parts C-1 and C-2, respectively, which are calculated using Eq. (5): this is the cumulative demand minus the inventory on hand plus the cumulative parts scheduled up to this period that are assigned to the given work center. The schedule for parts C-1 and C-2 are entered as the quantity of run hours in rows 21 and 24 starting from column G. Run hours are converted into the quantity of parts using the hourly rate in cells B21 and B24: for example, the formula to calculate the number of parts of type Part C-1 scheduled in cell G13 is "=B21* G21" that results in the value of 1,200.

We include in the schedule for any part the number of changeover and run hours. For example, for parts C-1 and C-2, the number of changeover hours are in cells C20 and C23, respectively, and the number of run hours are in cells B21 and B24, respectively. The item associated with "Start" in column A is an informational field containing the start time of the changeover if different from beginning of the day. For example, cell G19 contains the start time of the changeover of part C-1 to be at 15:00. Rows 25 and 26 provide a summary for the total changeover and total run hours for the day, while row 27 summarizes the total work center hours scheduled for the day to make sure that the hour limits are not exceeded, such as 24 hours for a three shift operation. To visualize the constraint violation for hours available, we can implement conditional formatting that will change the cell background in row 27 to red when the value in the cells exceeds the number of hours available.

4.3 Automatic Model Generation

Generation by hand of such models described in the previous section would be prohibitively time consuming and error prone. The way to address these issues from manual generation is to automate the generation of such models from the MRP data. In doing so, the models can be formatted and protected so that the users can only modify the cells for which they have permission based on their job function. Furthermore, this ensures the models would match predefined templates that would allow storing all modified data back into the database.

As we can see in Fig. 6 , the data behind the model has a tree structure with a root at the given make part and leaves associated with customers. The model is generated using data from the MRP system, including the BOM, parts and their associated work center, and end items and their associated customers shown in the tables in Fig. 8. Based on these tables, we create a new table that defines a pegging tree for each part by listing pairs of consecutive nodes in the tree structure with a root in the given part. Figure 9 provides an example of such a table for parts C-1 and C-2. The column Root has a reference to the part ID that defines the root of the tree. Other columns are "Node" (i.e. a part or customer ID that is downstream from the root), "Node Prev" (i.e. node that immediately precedes the specified Node), "lineage" (i.e. concatenation of the unique node ids from the root to the given node, and "depth" (i.e. how many levels are between the root and the given node). Then for the given work center, we can create a query that includes all the rows from this table associated with the parts at the given work center sorted in descending order by lineage. Sorting this way guarantees that the order of the rows in the resulting set satisfies that the calculations for the given row are derived from the values in the rows preceding the given row in the result set.

At first we determine the maximum number of levels for the given set of parts and determine the starting column in Excel to start generating the requirements. Figure 10 provides a schematic of the algorithm used to generate the model. The algorithm reads one row at a time starting with the first customer, c4. The algorithm generates an appropriate set of rows in Excel. For a row that is associated with customer requirements, the cells are merely inputs that will be subsequently populated with customer release data. For assembly plant customers, the algorithm will generate additional rows for the assembly plant status.

After processing the initial row, the algorithm puts the references to the Excel row in the last-in first-out stack and proceeds to the next row. The next two rows are other customers, c3 and c2, for the same end item, p5. In this case, the algorithm generates appropriate rows in Excel and puts the appropriate references to rows associated with c3 and c2 in the stack. The next entry is part p5: the algorithm creates Excel

Part

ID	Part
p1	C-2
p2	C-1
p3	D-1
p4	E-1
p5	E-2

BOM

PartID	NextPartID
p2	p3
p3	p4
p3	p5

WorkCenter - Part

WorkCntr	PartID
Line 1	p1
Line 1	p2

Customer

ID	Customer	Type
c1	AP3	AP
c2	AP2	AP
c3	AP1	AP
c4	SF1	SF

Part - Customer

PartID	CustomerID
p1	c1
p1	c4
p4	c2
p4	c3
p5	c2
p5	c3
p5	c4

Fig. 8 MRP tables

Root	Node_Prev	Node	Lineage	Depth
p2	p5	c4	p2->p3->p5->c4	3
P2	p5	c3	p2->p3->p5->c3	3
p2	p5	c2	p2->p3->p5->c2	3
p2	p5	p5	p2->p3->p5	2
p2	p5	c3	p2->p3->p4->c3	3
p2	p5	c2	p2->p3->p4->c2	3
p2	p3	p4	p2->p3->p4	2
p2	p2	p3	p2->p3	1
p2	*null*	p2	p2	0
p1	p1	c4	p1->c4	1
p1	p1	c1	p1->c1	1
p1	*null*	p1	p1	0

Fig. 9 Pegging table containing the data set for Line 01

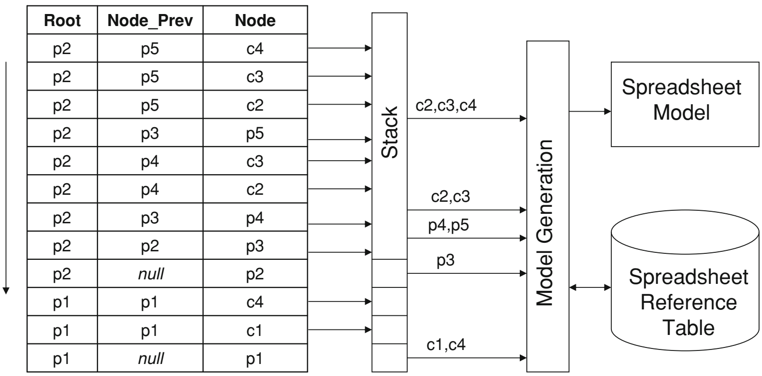


Fig. 10 Model generation algorithm schematic

rows associated with make part p5 and creates appropriate formulas by extracting the reference to children nodes of p5 from the stack and generating a formula that includes the sum of the net requirements from c4, c3, and c2. The algorithm puts a reference to the p5 row in the stack. The two next entries in the data set are the reference to the customers c3 and c2 for the end item p4. The algorithm follows the above logic until it reaches the entry with part p3. Here, the algorithm extracts the references to the children of p3, p4, and p5 and generates appropriate formulas with gross demand of p3 as the sum of the net demands from p4 and p5. The algorithm also builds a cross reference table that references the part numbers and customers with the position in Excel. This table will be used to create a scheduling portion of the spreadsheet model and to populate actual data from the systems. When the algorithm finishes performing this logic for all the parts assigned to the workcenter, it then generates the rows for schedule input using a cross-reference table. After generating the rows and formulas, the algorithm performs post-processing that formats and structures different elements of the spreadsheet to improve clarity and visibility of the information as described in the next section.

5 Spreadsheet-Based Decision Support System

The type of model described in Sect. 4.2 could be too cumbersome for the scheduler, especially when the number of parts assigned to a workcenter is relatively large (e.g. 10 or more parts). To address this, we exploit the Excel rich formatting capabilities to modify the representation described in Sect. 4.2 to provide a clearer view of the model together with supplemental information for decision support. First, we can hide all rows for intermediate parts for which the user will not provide input (e.g. rows 5, 9 and 10 in Fig. 7). Also, we use the Excel group function to group all rows associated with the supply chain representation of the individual parts.

As a result, we can get a clear view of the work center load and schedule with the capability to drill down on individual parts. For example, the Capacity view in Fig. 11 shows Line 01 with 10 parts representing inventory positions for every part and the schedule for parts. Different work centers are represented by individual excel worksheets: for example, you can see in Fig. 11 worksheet tabs associated with fifteen workcenters. The Capacity view shows all parts assigned to the given work center with associated projected inventory positions (the first row for each part) and scheduled quantity (second row for each part) grouped in daily buckets. The positive numbers in the inventory position row represent the projected balance on hand for the given part, while negative numbers denoted with parentheses represent the cumulative demand exploded from customer requirements through the BOM structure and associated inventory levels. The capacity view provides clear visualization of the capacity load and potential problems that could impact satisfying customer demand for every part in the work center.

The user can explore the individual parts in detail by clicking the '+' next to the part. The part information will expand to provide a supply chain and pegging view for

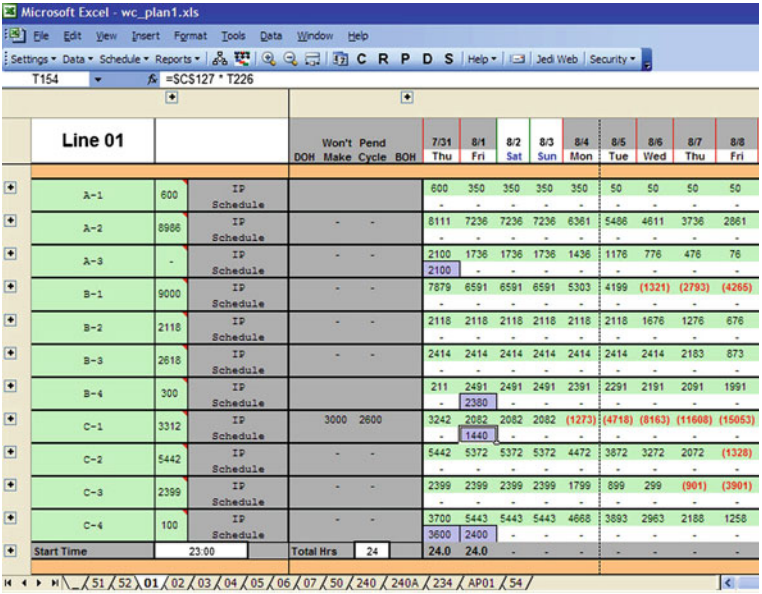


Fig. 11 Capacity view

individual parts. Figure 12 presents a supply chain view together with the BOH for every intermediate part: for example, we can see the expanded view for the part C-1 from Fig. 6. This view allows the scheduler to check and modify the BOH for every part in the chain. For critical parts, the user can inquire after the latest information on available parts from the floor (through radio) and modify the BOH in the model, accordingly. In this representation, all hidden part names from the BOM structure are defined in the comment field associated with appropriate cells and can be viewed by mousing over: see the comment highlighted for part E-1 in Fig. 12 .

For assembly plant customers, the system provides more detailed information pertaining to the given assembly plant status and consumption schedule. Specifically, this information includes the preferred transportation mode (e.g. rail or truck) together with the transit time. It also provides the assembly plant status information, such as

- days on hand: the number of days that can be covered by the existing assembly plant BOH
- will not make: parts in transit that are deemed to be late
- pending cycle: the variance between a part's physical count and the plant's record
- BOH: parts at the assembly plant warehouse and parts in transit less parts that will not make it on time.

If we look at the expanded view for part C-1, we first see the balance on hand for part C-1 = 3312. Next we see the balance on hand for part D-1 = 861 and subsequently

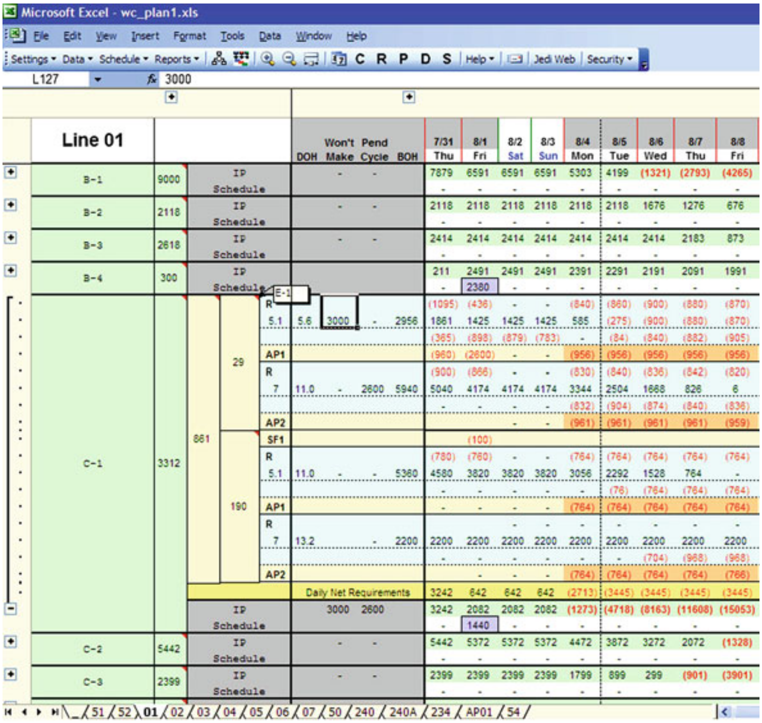


Fig. 12 Pegging supply chain view

the balance on hand for parts E-1 = 29 and E-2 = 190. Associated with the parts E-1 and E-2 is the information related to assembly plant demand and the 862 release schedule. In this example, we are shipping part E-1 to assembly plants AP1 and AP2. The rows with AP1 and AP2 in them contain the 862 release schedule. The information related to the assembly plant consumption schedule is organized in three rows above the 862 release schedule row. The first row shows the assembly plant consumption schedule. The second row shows the consumption schedule net the assembly plant BOH. Finally, the third row shifts the demand net inventory based on the transportation time associated with the given part-customer combination. This gives a base demand number (i.e., the minimum number of parts that a supplier must provide to satisfy the assembly plant's consumption) that can be compared to the customer release on the next row. The transportation time shift is implemented as a custom formula in Excel. We also implemented conditional formatting for the assembly plant demand to highlight the cases when the cumulative base demand of the assembly plant exceeds the cumulative customer release. This allows schedulers to compare the shipping release against the actual consumption requirement to validate the accuracy of the data and in case of shortages in capacity, modify the shipping release to non-optimal shipping alternatives that satisfy the assembly consumption schedule.

Furthermore, looking at the first customer in Fig. 12 AP1 uses rail transportation denoted by a “R” with a transportation time of 5.1 days. The inventory available to the assembly plant covers 5.6 calendar days. Also, part Part C-1 has 3,000 parts in transit to AP1 (in the “won’t make” column) that according to the transportation records will not make it to the customer on time, which causes an inflated customer release on the first two days. The user can analyze the details of this situation, which could reveal that the delay will be only for few minutes and that all of the parts can be considered “on time.” Based on this insight, the user can manually modify the customer requirements and gain a completely different perspective for the demand even before looking at the work center scheduling. The user can also analyze other what-if scenarios, such as how would requirements change if we can use a truck with 1.2 days instead of rail with 5.1 days. This way, the scheduler can see the tradeoff in shipping using a truck with less transportation time versus the existing preferred rail mode of transportation requiring more transportation time and can modify the original 862 release if the decision is for a transportation deviation.

In addition, Fig. 12 shows that customer AP2 for E-1 has 2,600 parts in pending cycle. When booked, it will affect the assembly plant’s BOH with an immediate jump in the customer’s shipping releases. This pending cycle column gives early warning of potential part shortage and allows the scheduler to take preventive actions to avoid overtime and premium freight for shipping, when possible. Our internal studies showed that 70% of premium freight transportation is due to pending cycle booking process.

This additional assembly plant information allows comparison between the actual requirements by the assembly plant and the current MRP generated customer releases: the scheduler can then correct potential errors in the BOH at the assembly plant or for intermediate parts and conduct different what-if analysis. These scenario analysis can address what happens if we use alternative faster modes of transportation, such as truck instead of rail or the effect from booking of pending cycle parts. As a result of this detailed analysis, the scheduler can modify the original customer release.

Finally, to improve editing and visibility into the daily schedule, we developed an Excel add-in that can provide a block diagram for the schedule representation (see Fig. 13). This add-in reads and interprets the data pertaining to the setup start time, changeover duration, and run time. This chart shows the detailed time required for changeover and to make each batch of parts. Each batch concatenates the changeover hours followed by the production run hours. The changeover time is the first time shown associated with a part number, and the second time associated with the same part number is the time required to make that part. We refer to this detailed portion of the scheduling chart as a “snake diagram” because as the length or position (i.e., start time) of the bars in the chart are modified, the bars instantly wrap around to the next day. For example, part C-1 cannot be finished being made on Friday, and so the needed time to make C-1 is reflected by the bar for that part on Monday, skipping the weekend. The snake diagram automatically skips days when the plant is shut

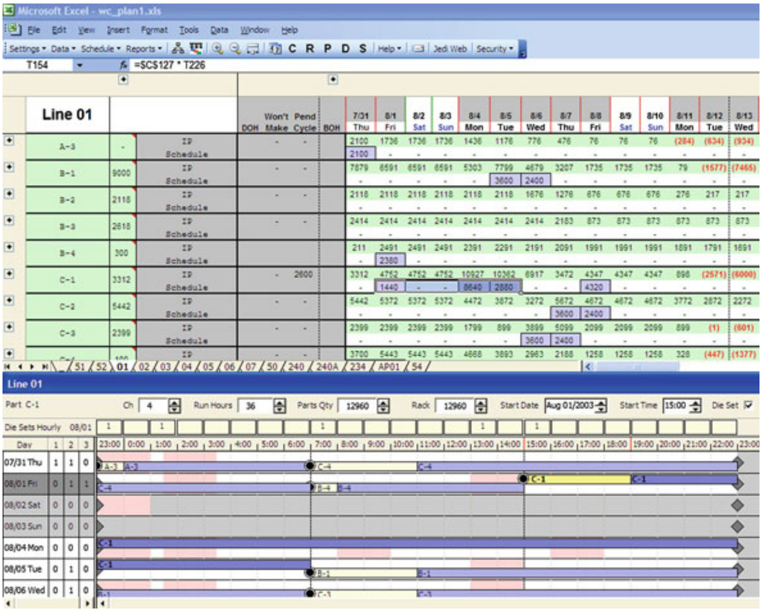


Fig. 13 Scheduling view

down as defined in the work center calendar, such as Sunday. If the plant wanted to conduct a what-if scenario to see if they should run the plant on the weekend with overtime, they could change Saturday or Sunday to be a working day, and the new batch parts for Line 1 would be reflected in the snake diagram. Any changes in the snake diagram are immediately connected to the appropriate Excel cells that show on the fly how changes to the schedule affect the part demand and inventory.

6 System Integration

JEDI is an integral part of a suite of plant floor and enterprise business systems that collectively assist in managing the stamping production. Figure 14 provides an overview of the interactions of JEDI with other key systems. These seamless interactions to and from JEDI provide the foundation for its success: all of the necessary data is available to the scheduler in one location in an easy to use interface, and the schedule information is automatically shared back to other systems reliant upon this data.

As previously mentioned, JEDI relies on data from the corporate MRP, and in turn, sends the schedule back to the MRP to drive the upstream supply chain. JEDI uploads all of the data that is used to define the structure of the problem (e.g. the BOM, customer, part: see Fig. 8) to build the model. This structural data is updated

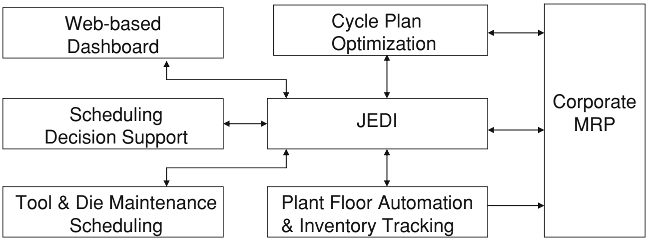


Fig. 14 System architecture

daily, comparing the the new data to the existing workcenter structure. If there are no changes in the problem structure, JEDI keeps the model and will update only the dynamic data (e.g. the BOH, demand, and schedule). If there are any changes, regeneration of a new model is triggered for the workcenter. Changes to a workcenter could include new part or customer introduction, part engineering level changes, changes in the BOM structure, and the removal of obsolete parts. When the model is completed, JEDI collects all relevant dynamic data from the MRP and plant floor systems and updates the model. This data includes customer releases, assembly plant consumption schedule and status, and parts in transit status.

Plant floor automation and inventory tracking systems provide up-to-date information on the BOH and status of critical manufacturing resources. Keeping track of the available inventory in a dynamically changing environment is a very challenging task. The methodological approach to proper integration is outlined in [13]. Data inaccuracies, incompleteness, and inconsistencies have to be rectified through intelligent integration of the information [12]. In recent years, the maturity of the RFID technology has tremendously helped improve plant floor data collection capabilities. Fodor et al. [5] describes the approach to track stamping rack location utilizing a forklift mobile RFID reader combined with forklift deadreckoning techniques. Directly tracking the location of the racks tremendously improves the accuracy and timeliness of the balance on hand data versus indirectly estimating it from production counts at the given workcenters.

Furthermore, JEDI supports collaborative scheduling and decision support. It allows schedulers for different areas of the plant (e.g. blankers, press, and assembly) to verify the feasibility of the interdependent schedules and collectively address any potential issues. For instance, we can substitute net demand exploded from customer releases with the actual assembly schedule, and this will allow the scheduler to see how the given press schedule supports the assembly schedule. Similarly, the blanker schedule can load the schedule from presses.

JEDI also facilitates collaborative scheduling between material planning and logistics and tool and die maintenance. When scheduling is done for preventive maintenance of tools and dies, there must be enough inventory to satisfy customer requirements while the die/tool is undergoing maintenance work. JEDI helps to coordinate die/tool scheduling to ensure inventory requirements are met.

The stamping complexity requires tight coordination between different shared resources, such as direct labor that can be reallocated between different workcenters based on the specific jobs and indirect labor services for die changeover, cranes, etc. Thus, it is important that based on the expected customer demand for different job types, we properly determine the needs for direct and indirect labor for upcoming time buckets, identify the needs for overtime, allocate resources among different shifts, and determine a feasible plan for each job and corresponding changeovers required. In addition, we would like to find the most cost-efficient plan that optimizes the tradeoff between labor cost and inventory: this is the goal of the cycle plan optimization module [4]. JEDI takes this optimized plan as a roadmap for the upcoming time period and develops corrective actions to compensate for events happening on the floor, such as parts shortages, machine breakdowns, customer requirement fluctuations, etc.

JEDI also provides a web-based plant and business unit management dashboard. The dashboards increase visibility of the stamping supply chain status, help quickly identify and collectively address critical issues, and facilitate information sharing between Material Planning and logistics, Manufacturing and Maintenance.

7 Summary

This chapter describes the JEDI support system designed and implemented for complex automotive suppliers, such as automotive stamping. JEDI serves as an interactive decision support system that allows schedulers to be an active part of the decision-making process, providing them the information that they need, consolidated in one location, available at the right time, and that can be manipulated within an intuitive system. It has filled a critical need as a front-end decision support system for seamless integration with scheduling optimization and other corporate systems.

The core element of JEDI is a spreadsheet model of the typical automotive supply chain with inputs mapped to MRP and automotive EDI standards. As such, the system and underlying model can be adapted to wide a range of automotive suppliers beyond stamping, such as powertrain, plastics or climate control. The system implementation leverages Microsoft Excel features of rich formatting and automation capabilities and takes advantage of familiarity of Excel to the plant user community.

JEDI has enabled early identification of problems by around two to three hours, allowing schedulers to address production problems in advance. JEDI is integrated with other enterprise and plant floor systems and supports collaborative scheduling between different interdependent manufacturing, distribution and maintenance departments: this has facilitated an improvement in data accuracy in various corporate systems and has enhanced collaboration between multiple stakeholders. Another important benefit is that it provides an efficient and effective interface to the mathematical scheduling models, leveraging optimization technologies while keeping the user in control of the solution.

The implementation of the system in a production environment has demonstrated significant benefits resulting in substantial financial savings associated with reduction in premium freight, overtime, inventory, and excessive material handling. The savings that are typically observed after the introduction of JEDI over the previous year are an average 30% reduction in overtime and a premium transportation reduction of 40% (which for some plants is over a million dollars a year). Some additional benefits that result from the reduction of excess inventory include a reduction in obsolete parts and excessive material handling and improved plant floor utilization.

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