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Young Moon
Syracuse University, ybmoon@syr.edu

Dinar Phatak
Syracuse University

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Enhancing ERP system's functionality with discrete event simulation

Young B. Moon and Dinar Phatak

Department of Mechanical and Aerospace Engineering, Institute for Manufacturing Enterprises, Syracuse University, Syracuse, New York, USA

Abstract

Purpose – To develop a methodology to augment enterprise resource planning (ERP) systems with the discrete event simulation's inherent ability to handle the uncertainties.

Design/methodology/approach – The ERP system still contains and uses the material requirements planning (MRP) logic as its central planning function. As a result, the ERP system inherits a number of shortcomings associated with the MRP system, including unrealistic lead-time determination. The developed methodology employs bi-directional feedback between the non-stochastic ERP system and the discrete event simulation model until a set of converged lead times is determined.

Findings – An example of determining realistic production lead-time data in the ERP system is presented to illustrate how such a marriage can be achieved.

Research limitations/implications – The research demonstrates that the limited planning functionality of the ERP system can be complemented by external system such as discrete event simulation models. The specific steps developed for this research can be adopted for other enhancements in different but comparable situations.

Practical implications – The organizations who have been using the discrete event simulation in their planning and decision-making processes can integrate their simulation models and the ERP system following the steps presented in this paper. The ideas in this paper can be used to look for automatic data collection process to update or build the simulation models.

Originality/value – The ERP implementation is a significant investment for any corporation. Once the ERP implementation is completed successfully, the corporations must look for ways to maximally return on their investment. The research results may be used to enhance the implemented ERP systems or to fully utilize the capabilities in a corporation.

Keywords Simulation, Lead times, Uncertainty management, Resource management, Production planning

Paper type Research paper

1. Introduction

The enterprise resource planning (ERP) system is an information system designed to integrate and optimize the business processes of an enterprise (Davenport, 1998). Functions integrated by the ERP system include manufacturing, distribution, personnel, project management, payroll, and financials. The ERP systems identify and plan the enterprise-wide resources needed to take, make, distribute, and account for customer orders.

The implementation and maintenance of the ERP systems is very high, typically ranging between 15 and 50 million dollars (Mabert *et al.*, 2000; Olhager and Selldin, 2003; Okrent and Vokurka, 2004). Therefore, the project of implementing an ERP system is normally the biggest single project that an enterprise has ever launched in its lifetime. These complex, expensive, powerful, proprietary systems are off the-shelf

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solutions requiring professionals to customize and implement them based on the company's requirements. In many cases, they require companies to reengineer their business processes to accommodate the logic of the software modules for streamlining data flow throughout the organization. Despite its high implementation and maintenance cost, the ERP system has become the *de facto* solution in industry to realize an enterprise-wide information system.

However, there are a number of limitations with the ERP systems. First of all, current ERP systems are mainly designed for transaction bookkeeping purposes. The ERP system in its original intent is good at monitoring events and bookkeeping trails of the events, but it is not meant to help the decision-making process. Second, even though there are provisions for taking real-time data from its environment, the ERP system needs additional external systems or devices such as Manufacturing Execution System (MES) and Supply Chain Management System to actually monitor and collect real-time data (Davenport and Brooks, 2004; Mandal and Gunasekaran, 2002; MESA, 2003). Third, the ERP system contains and uses the material requirements planning (MRP) logic as its central planning function. As a result, the ERP system inherits a number of shortcomings associated with the MRP system. Such shortcomings are due to two critical assumptions made in the original MRP logic:

(1) the assumption of unlimited capacity of resources; and

(2) its non-stochastic nature.

The capacity assumption is addressed in some degree in the ERP system through constraint management and feedback-loop mechanism. However, the problem of inability to handle stochastic situations continues in the ERP systems.

This paper investigates the possibility of addressing this ERP system's inability of handling uncertainties and unexpected events using the discrete event simulation model. The discrete event simulation models use probability and statistics to explicitly consider the effects of uncertainties. The benefits are bi-directional. Not only the functionality of the ERP system can be expanded with the aid of the simulation models, but also some of the simulation model's inherent challenges can be addressed by the ERP system. For example, the problem of collecting data for building simulation models can be addressed by integrating in real time with the ERP system's comprehensive depository of enterprise data.

The paper is structured as follows. Section 2 introduces the MRP, MRP II and ERP and extends the discussion on fundamental problems associated with these systems. Section 3 presents a brief description of the discrete event simulation technology and a few known issues. A problem for addressing the shortcomings of the ERP system is defined and a methodology to address the defined problem is described in Section 4. Section 5 presents an illustrative example and its results using leading industrial solutions such as SAP R/3 ERP system and ARENA simulation package. Future research works are discussed and a conclusion is made in Section 6.

2. MRP and MRP II/ERP systems

MRP was the acronym given to the methodologies developed for the material planning process that uses a production bill-of-material (BOM) and a production forecast to determine future material needs and replenishment timing. The MRP concepts were originally developed in the late-1960s and early-1970s by Orlicky (1975), Peterson (1975) and Wright (1970).

Despite its wide acceptance in industry, there are significant shortcomings inherent in the MRP approach. These shortcomings are well-documented (Hopp and Spearman, 2000; Maxwell *et al.*, 1983) and briefly discussed in this section.

2.1 Fixed lead-time

The MRP system assumes fixed lead-time to plan for material purchase and product manufacture. This ignores the reality of uncertainties in supply availability, setup and run times in the shop floor. As a result, when significant shortages and/or surpluses in material, subassembly and finished products occur, the decisions generated by the MRP may not be accurate (John, 1985; Melnyk and Piper, 1985).

2.2 Infinite resource

Net requirement plans generated by the MRP do not consider the availability of resources simultaneously, but consider a required resource as a separate, subsequent activity (Musselman and Uzsoy, 2001; Toye, 1990). This results in a repetitive loop of re-planning. But in reality, this re-planning process is often not carried out, causing inherent inaccurate results associated with expected due date. The MRP logic does not take into account any of the significant effects of efficiency and utilization losses as well.

2.3 Fixed routing

In MRP systems, a predefined route is used to sequence the flow of materials and subassemblies from machine to machine or from workstation to workstation. In an unplanned event, e.g. machine breakdown, the initial flow would possibly need re-routing. However, the MRP systems do not have a provision for suggesting an alternative route in such a circumstance. The effect is a shortage of component or subassembly at the next level up, which eventually may result in missed due dates (Figure 1).

Based on the technological foundations of MRP and MRP II, ERP systems integrate business processes including manufacturing, distribution, accounting, financial, human resource management, project management, inventory management, service and maintenance, and transportation, providing accessibility, visibility and consistency across the enterprise. The architecture of the software facilitates transparent integration of modules, providing flow of information between all functions within the enterprise in a consistently visible manner. Corporate computing with ERPs allows companies to implement a single integrated system by replacing or re-engineering their mostly incompatible legacy information systems. American Production and Inventory Control Society (APICS) has defined ERP systems as:

> . . . a method for the effective planning and controlling of all the resources needed to take, make, ship, and account for customer orders in a manufacturing, distribution or service company.

3. Discrete event simulation

Simulation is the process of designing a dynamic model of an actual dynamic system for the purpose either of understanding the behavior of the system or of evaluating

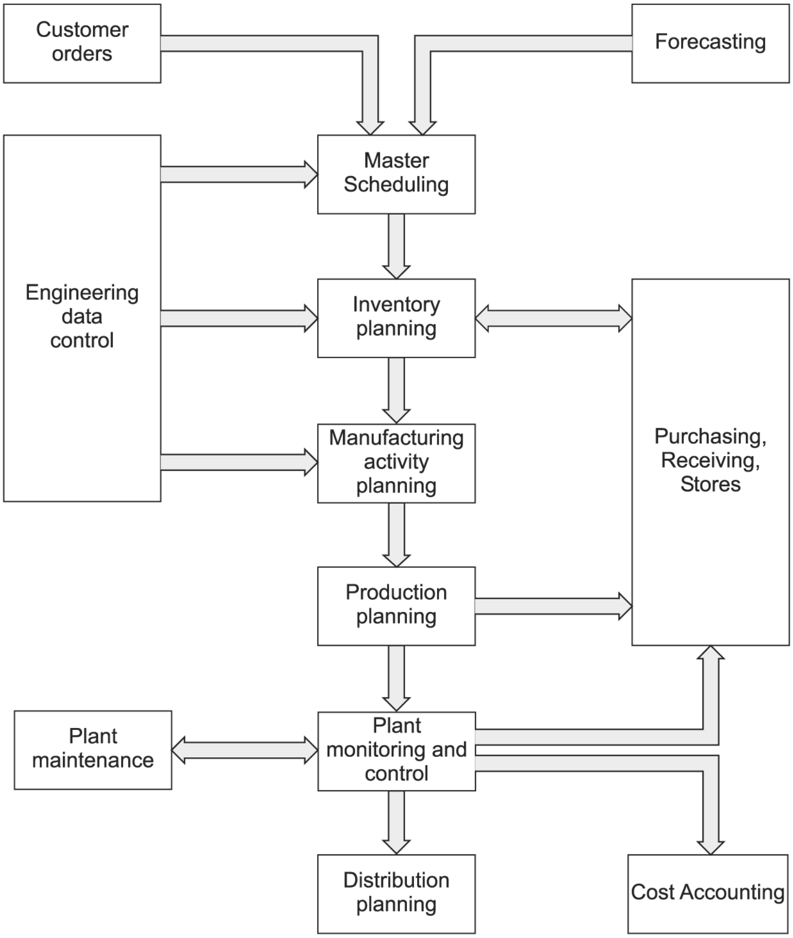


Figure 1.
ERP framework

various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system. Simulation, according to Pegden *et al.* (1995), is:

> . . . the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system.

The power of discrete event simulation is the ability to mimic the dynamics of a real system. The ability to mimic the dynamics of the real system that gives discrete event simulation a structure, a function, and a unique way to analyze results.

Simulation is commonly used to gain insight into manufacturing systems (Smith and Joshi, 1995). The reason for using simulation is that simulation can often capture and describe the complex interactions within a particular manufacturing system where analytical methods fail (Erickson *et al.*, 1987; Wu and Wysk, 1989). Normally, simulations are developed offline using custom software packages/languages with limited direct connections to the actual data generated by the production system (Drake and Smith, 1996).

Traditional simulation models are usually not built for repetitive and continuous usage partly because their data collection process is difficult and laborious. These simulation models generally analyze the long-term performance from a planning and design point of view, but are seldom used after the initial plans or designs of a project are finalized. Therefore, subsequent operational changes in the real system are not handled properly. Typically, the input data for a simulation model is gathered and analyzed outside the simulation environment. Collecting accurate and reliable data is time-consuming, and is often one of the most difficult issues in building a simulation model. Difficulty in automatic collection of data and continuous update of the data for the built simulation model discourages further usage of the initial model.

4. The problem and a methodology

4.1 The problem addressed

Usually in a production environment, uncertainties exist in the various process parameters such as process times, setup times, breakdowns and failures, etc. Since the ERP system requires "pre-set" lead-time data, the lead-time data often do not reflect the actual lead-time on the shop floor. The process data are often collected from informal interviews with operators who have a tendency to inflate the actual lead-time significantly. The operators who have experiences with MRP plans know that the discrepancy between the actual lead time's variability and the fixed lead-time required by the MRP system may affect their work demands. They know by experience that more pressure will be imposed on them if the lead-time data are not inflated than actual.

In addition, the actual lead times usually vary considerably from the fixed lead times used by ERP when resources are highly utilized. In order to determine whether or not a plan generated by ERP is actually realistic and feasible, a kind of prediction model is needed to estimate whether the start times generated by the plan will actually allow the manufacturing orders to be completed by their due dates.

4.2 A methodology for production lead-time determination

A methodology has been developed to determine realistic production lead-time data in the ERP system with the aid of a discrete event simulation model. The simulation model, in turn, draws necessary data from the ERP database. Even though the research results described in this paper use the example of the production lead-time determination, the same framework can be adopted for other problems of handling uncertainties in the ERP system with the aid of simulation models.

The lead-time for a product is specified as a fixed, deterministic number in the ERP systems. However, the actual lead-time in the shop floor varies significantly due to the variances in individual processing times and a queue built up in front of a highly utilized workstation. Such phenomena are captured in a simulation model and their results are fed back to the ERP system to determine the most appropriate lead times. The procedure employs bi-directional feedback between the non-stochastic ERP system and the discrete event simulation model until a set of converged lead times is determined.

4.3 The simulation model

The ERP systems contain much of the manufacturing relevant data, so their databases can serve as data depository for simulation models. There are three components that form the basis for the system determining the realistic lead times: the ERP system, the production data acquisition (PDA) system, and the discrete event simulation system (Figure 2).

The first step involves feeding the data stored in an ERP system to the pre-built simulation model. The simulation model reflects a rather long-term status of the shop floor. The dynamic nature of the shop floor is captured through updating the input data to the simulation model. An interface to directly read the data stored in the ERP database has been designed which would result in an automated update of the simulation model. The production data could be read into the simulation model at specific predefined intervals (e.g. hourly, end of the shift, daily, etc.). This enables the simulation model to effectively simulate a near "real-time" production environment and to automatically update the necessary data.

The second step requires the incorporation of the current shop floor status into the simulation model. A PDA system can be utilized for this purpose, such as MES to trace the current state of a shop floor. The necessary input or the company specific strategies are stored in additional databases or ERP database extensions. From an ERP system and/or additional databases connected to the PDA system, we extract all the necessary data to update the simulation models.

The third step is to use a simulation engine for production planning on a daily basis. Scenarios can be computed very fast by the simulation engine (typically a 2-5 week prediction in 1-5 seconds) and results are returned to the ERP system. A template model is developed by a simulation expert, which only needs to be populated with up-to-date data from the ERP system and other extra databases. The template model can be adapted in special cases to implement additional strategies. A simulation run generates an event list that is finally returned to the ERP system with other

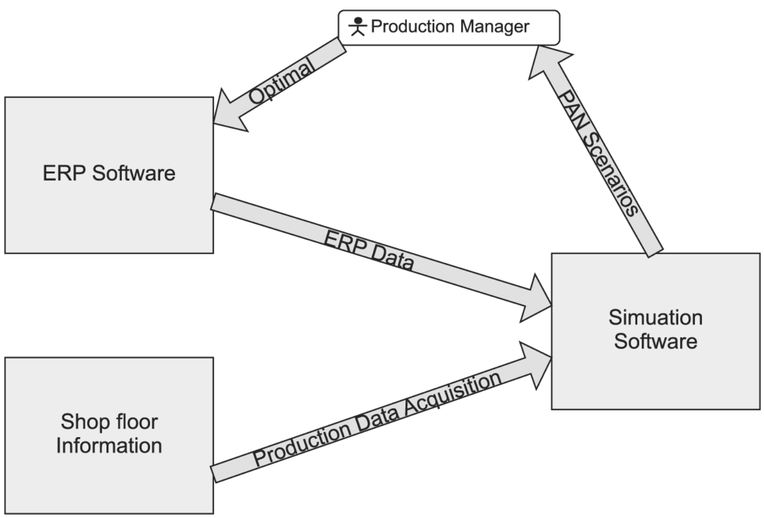


Figure 2.
The ERP/simulation system

information and is allocated manufacturing resources. The considered data in the simulation model includes resources (work centers, labor, and operating resources), product orders and parameters (amount, release dates, due dates, priority), current production state for each order and each resource, shift system and working calendar, and maintenance intervals.

The MRP portion of an ERP system is driven by the master production schedule (MPS). The MPS begins as a trial schedule. If these schedules are feasible, the schedule becomes input for the ERP system. ERP sees this schedule as given: the system cannot check if a schedule is correct or incorrect, for example, if a schedule goes beyond production capacity or not. The MPS can be updated or modified any time a production manager wants. As a result of these changes, the ERP input changes, as does the production output (Figure 3).

4.4 The feedback routine to determine the lead-time

The feedback routine follows two steps. The initial lead times originally defined in the ERP system for the products are used as a starting point. Based on those initial data, the ERP software would make a MRP run. This schedule is then fed into the simulation software to check the validity of the MRP run in the current shop floor conditions. Ideally the flow times obtained by the simulation software should be close to the initial lead times. If not, changes are required in the parameters of the production schedule.

The first step is at a macro level and involves increasing the lead-time by a predetermined amount of time. This is done by taking into account an "allowance factor" for delays. The updated lead times are fed into the ERP and another MRP run is then made. The schedule, which is now obtained, should be close to the flow times of the simulation run. If the two items are comparable then we conclude that we have

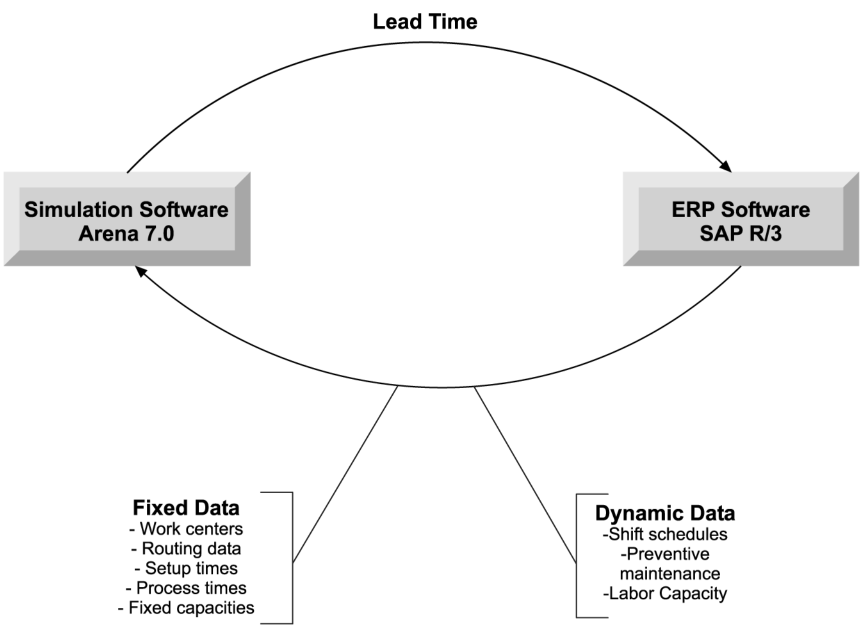


Figure 3.
Iterative framework for determining production lead-time

reached an optimal schedule. Otherwise, we need to move onto the second step, which is at a micro level. It may not be always possible to increase the lead-time by more than a certain amount of time because the job may get late. In such cases, we would need to change other parameters to ensure that the job gets completed on time. The factors that can be changed include "overtime – (machine hours)", "overtime – (labor hours)", and "priority for a particular product (rush job)".

The simulation model has several scenarios pre-built and configured according to some different permutations and combinations. Different scenarios can be simulated "manually" by changing parameters. A better way to fit the required objectives is an automated optimization process. For example, Arena provides a facility of using the process analyzer (PAN) to select which scenario would be the optimal one. The objective of the PAN would be to see which scenario has the least flow time. As the simulation runs are fast, automatic changes of input parameters (overtimes, priorities, strategies) can be easily investigated. The user can visually see the effects of different scenarios and select the best one to use. The results of this are automatically fed back into the ERP system. The schedule now generated is the most optimal solution (Figure 4).

4.5 The integration architecture

The current solution is based on a layered architecture that separates applications, services, and databases. The SAP R/3 architecture stores all its data in a database such as MS SQL Server database. There are several interfaces to directly export the data from within SAP R/3 to external applications. An automated tool has been implemented which transfers the required data into an MS Excel file format. On the simulation end a custom built VBA routine allows the simulation software to directly read this MS Excel file and load the data into the model. This configuration allows for an automated link between SAP R/3 and Arena 7.0. The feedback loops provide the output data back from Arena 7.0 into the ERP software depending upon the user's choice (Figure 5).

5. Illustrated example and results

The IDES (International demonstration and education system) in SAP R/3 4.6B was used an example for this approach. The IDES is a fictitious corporation, which was developed for demonstration and educational purposes for SAP R/3. It has regional companies and plants in three continents and contains a vast amount of data on products, customers, accounts, etc. In this study, an entire subset of a factory in Germany in the IDES was simulated. The main product line was a pump and there were about 12 different product variations being made. The focus was kept on the six work centers through which the bulk of the production was being routed. A detailed simulation model was developed in Arena 7.0 for the shop floor level.

5.1 Base case example

In the simulation model, entities represent the parts which are flowing through the system. The create module is used to create each entity based on an arrival schedule. This arrival schedule is generated based on the MPS. In this case, the orders are released to the shop floor at the start of the week. Each order has certain attributes assigned to it such as arrival time, due date, batch size, etc. The order needs to be

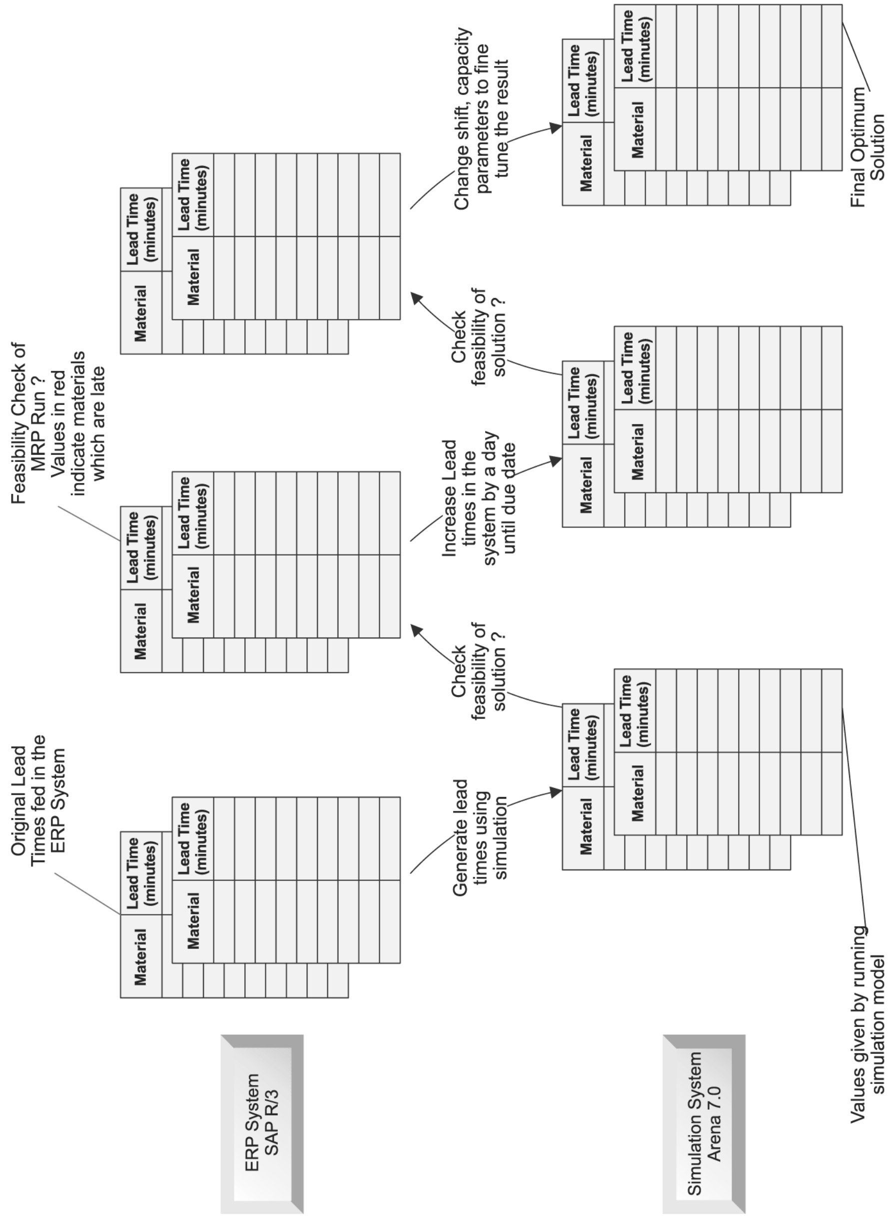


Figure 4.
The iterative framework details

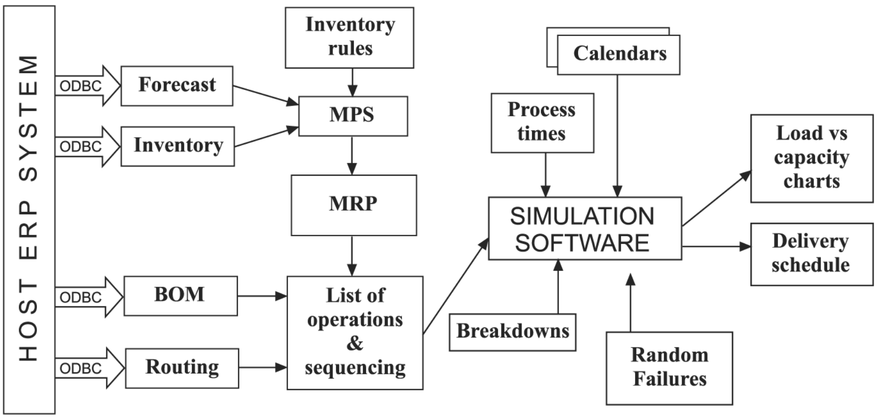


Figure 5.
Functions in the iterative framework

completed before its due date. An assign module is used to assign the appropriate production plan sequence to each job (or entity). Since this is a process oriented shop floor layout, station and route modules were used to direct the flow of entities through the system. At the entry station, depending upon the first step in the process plan, each entity is routed to the appropriate work center. On reaching the work center station, the entities wait in front of the batch module until the required number of entities arrives in order to form a batch. When a batch is formed, a combined batch entity is created which then seizes the operator resource and the work center resource to setup the machine. After the setup is complete, the batch entity is again split into its original entities for the processing on that work center and operator resource is released although the work center is kept occupied. Each entity then again seizes the operator resource for the process run-time. After this the batching process is again repeated to release the work center resource. The entities then move to the route module and are routed to the next station according to the process plan. At the last step in the model, detailed statistics are collected for each entity, which is then used for further analysis of the flow time. A screen shot of the simulation model is shown in Figures 6 and 7.

Figure 8 shows the layout of the shop floor. There are six distinct work centers with each work center having two or more machines.

Figures 9 and 10 show the data interface from the ERP software SAP R/3. The Table I shows in detail the routing data for the 12 different pump types, which are there in the system along with short descriptive name of each pump type. Figure 11 shows the process plan for pump. A typical sequence usually involves six steps through the shop floor.

Table II shows the lead times and the due dates fed into the ERP software. The plant operates for 16 hours a day with two shifts of 8 hours each. The second shift typically has fewer people and less production output than the first. In the third shift the plant is usually closed.

The demand for the products is stable. A Lot for Lot order technique is employed by the company for the production of the pumps. Based on company forecast a production order is released to the shop floor every week for each of the product variety. Some times it is not possible for the company to meet the weekly demand while other times the capacity is under utilized. This occurs despite the fact that the demand data is

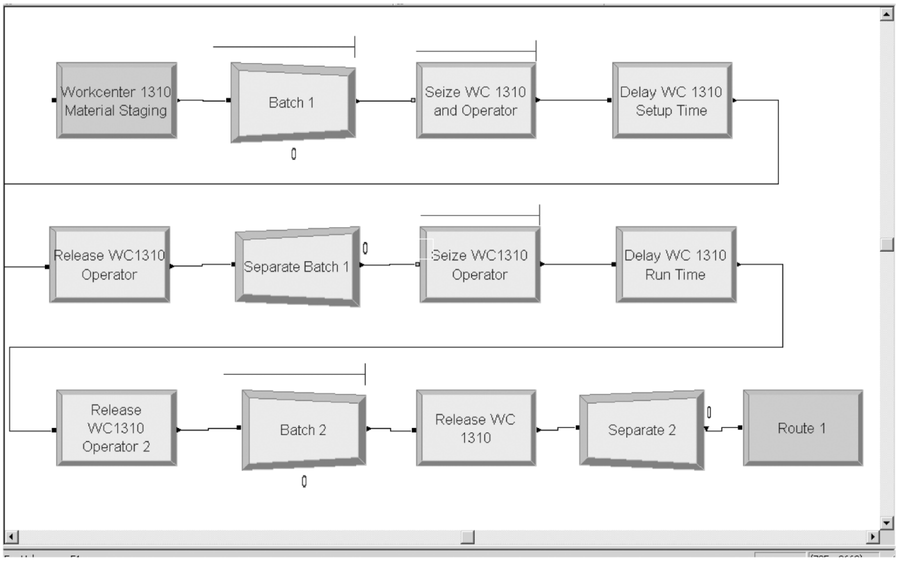
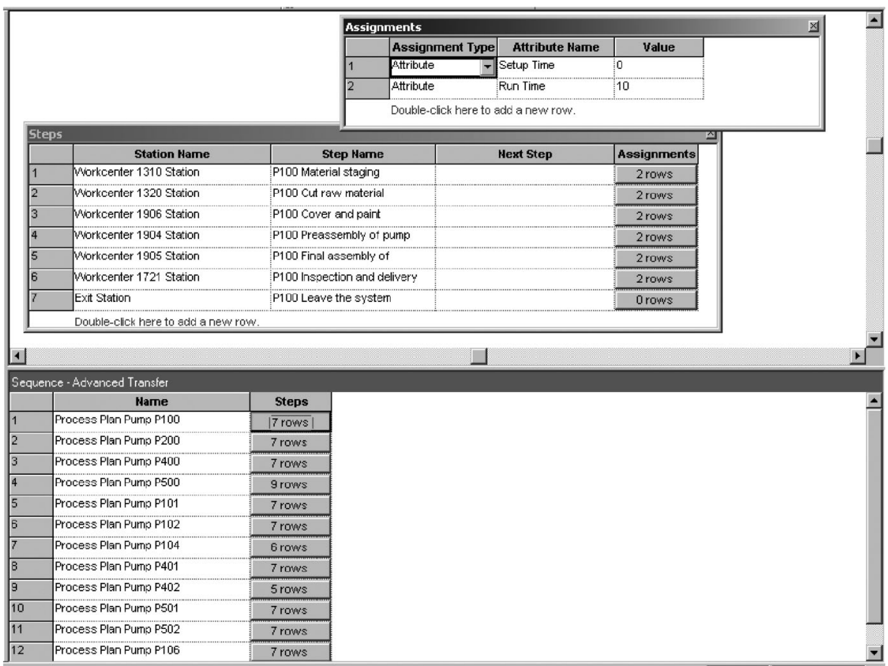


Figure 6.
Partial screenshot of the ARENA simulation model



Assignments

	Assignment Type	Attribute Name	Value
1	Attribute	Setup Time	0
2	Attribute	Run Time	10

Double-click here to add a new row.

Steps

	Station Name	Step Name	Next Step	Assignments
1	Workcenter 1310 Station	P100 Material staging		2 rows
2	Workcenter 1320 Station	P100 Cut raw material		2 rows
3	Workcenter 1906 Station	P100 Cover and paint		2 rows
4	Workcenter 1904 Station	P100 Preassembly of pump		2 rows
5	Workcenter 1905 Station	P100 Final assembly of		2 rows
6	Workcenter 1721 Station	P100 Inspection and delivery		2 rows
7	Exit Station	P100 Leave the system		0 rows

Double-click here to add a new row.

Sequence - Advanced Transfer

	Name	Steps
1	Process Plan Pump P100	7 rows
2	Process Plan Pump P200	7 rows
3	Process Plan Pump P400	7 rows
4	Process Plan Pump P500	9 rows
5	Process Plan Pump P101	7 rows
6	Process Plan Pump P102	7 rows
7	Process Plan Pump P104	6 rows
8	Process Plan Pump P401	7 rows
9	Process Plan Pump P402	5 rows
10	Process Plan Pump P501	7 rows
11	Process Plan Pump P502	7 rows
12	Process Plan Pump P106	7 rows

Figure 7.
Screenshot of process plan in the simulation model

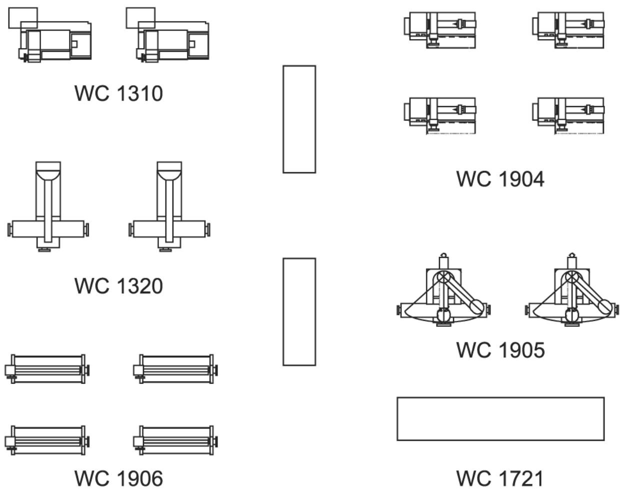


Figure 8. Floor plan for the simulated factory

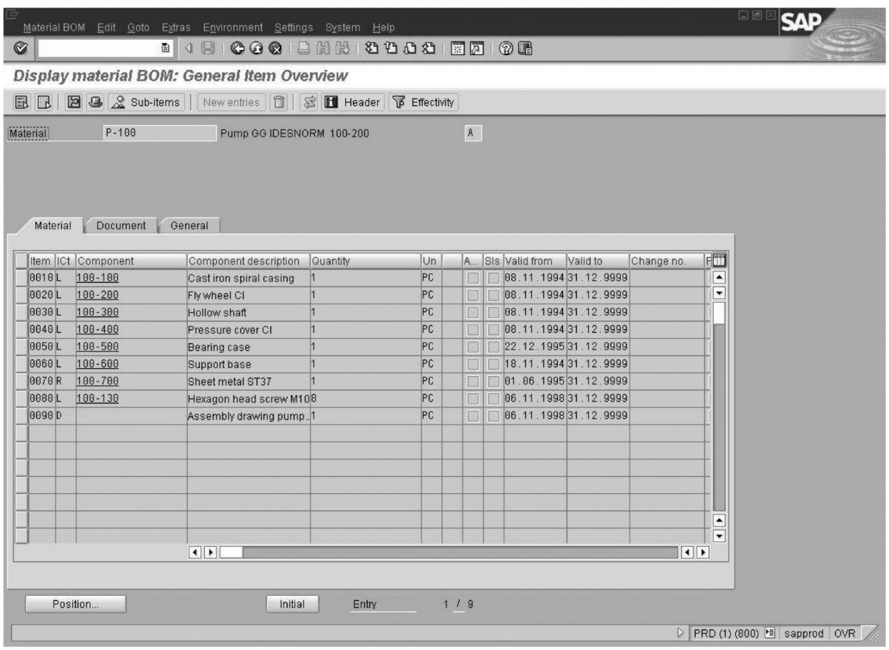


Figure 9. Screenshot of SAP R/3 – BOMs for pump P100

fairly stable. At the start of the week the production manager (or scheduler) looks over the weekly production and would feed it into the ERP system and make a MRP run. The projected lead times and estimated date of order completion based on the MRP run are then verified and checked to see whether it is feasible or not.

Table III shows that the initial lead times taken by the ERP system are all under due dates. In other words, if these initial lead times are actual, the expected due dates will

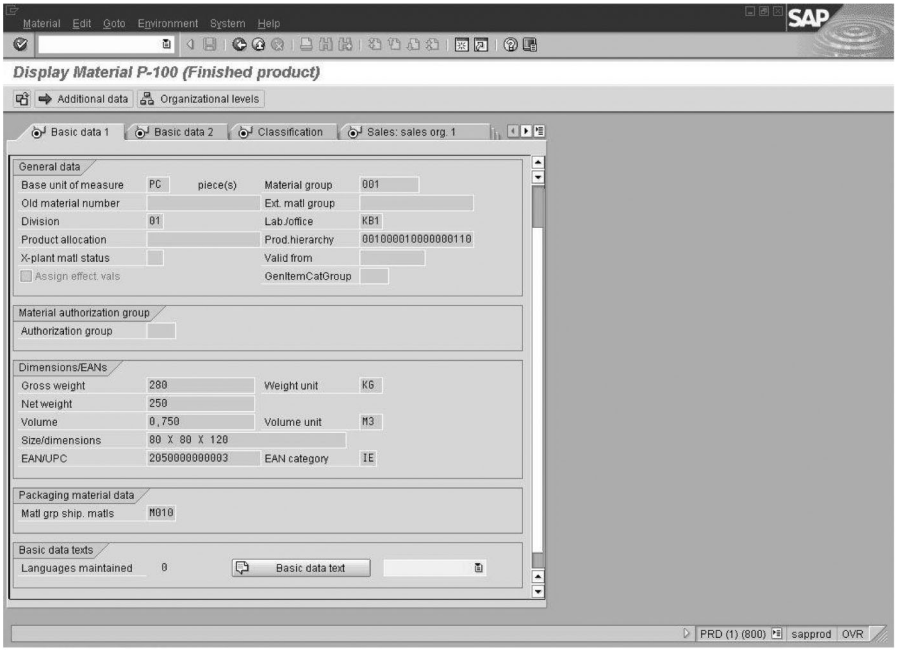


Figure 10.
Screenshot of SAP R/3 – materials master

Table I.
Detail routing data

Name	Description	Routing
P100	Pump GG IDESNORM 100-200	WC 1310-1320-1906-1904-1905-1721
P101	Pump cast steel IDESNORM 150-200	WC 1310-1320-1906-1904-1721-1721
P102	Pump sphere-cast IDESNORM 150-200	WC 1310-1320-1906-1904-1721-1721
P104	Pump CR IDESNORM 150-200 ATO	WC 1310-1320-1905-1906-1904-1721
P106	Pump GG IDESNORM 100-106	WC 1310-1320-1905-1904-1721
P200	Pump standard IDESNORM 100-200	WC 1310-1320-1904-1721
P400	Pump standard IDESNORM 100-400	WC 1310-1320-1906-1904-1721-1721
P401	Pump standard IDESNORM 100-401	WC 1310-1320-1906-1904-1721-1721
P402	Pump standard IDESNORM 100-402	WC 1310-1320-1906-1904-1721-1721
P500	Pump (single-level configuration)	WC 1310-1320-1906-1904-1721-1721
P501	Pump (SD BOM configuration)	WC 1310-1320-1905-1904-1721
P502	Pump (multi-level configuration)	WC 1310-1320-1906-1906-1906-1904-1721

all be met. However, many times the situation changes during a week. Rush orders, machine breakdowns and tool failures necessitate a change in the production schedule. This also creates a ripple down effect which further affects all the other processes down the chain.

To take into account the dynamics of the system the data is fed into the simulation engine. Table IV showed us that the MRP run made by the ERP software was not feasible based on the current production environment on the shop floor. Except pumps

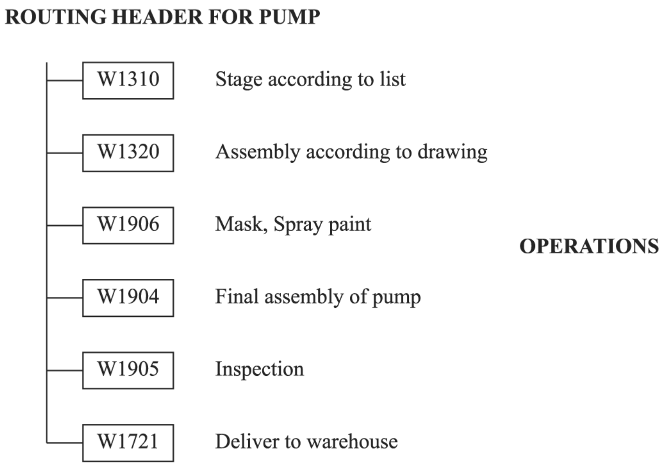


Figure 11.
A process plan for pump P100

	Base case			
	ERP lead time		Due date	
	Minutes	Days	Minutes	Days
Pump P100	2,880	2	4,320	3
Pump P101	2,880	2	2,880	2
Pump P102	4,320	3	4,320	3
Pump P104	2,880	2	2,880	2
Pump P106	4,320	3	4,320	3
Pump P200	2,880	2	4,320	3
Pump P400	1,440	1	5,760	4
Pump P401	2,880	2	2,880	2
Pump P402	2,880	2	2,880	2
Pump P500	2,880	2	2,880	2
Pump P501	4,320	3	4,320	3
Pump P502	4,320	3	4,320	3

Table II.
Lead time and due dates from ERP

Material	Initial results	Due dates
Pump P100	2,880	4,320
Pump P101	2,880	2,880
Pump P102	4,320	4,320
Pump P104	2,880	2,880
Pump P106	4,320	4,320
Pump P200	2,880	4,320
Pump P400	1,440	5,760
Pump P401	2,880	2,880
Pump P402	2,880	2,880
Pump P500	2,880	2,880
Pump P501	4,320	4,320
Pump P502	4,320	4,320

Table III.
Initial results and due dates

Table IV.
1st run results and due dates

Material	1st run results	Due dates
Pump P100	2,235	4,320
Pump P101	*2,886*	2,880
Pump P102	3,563	4,320
Pump P104	*3,070*	2,880
Pump P106	3,627	4,320
Pump P200	4,070	4,320
Pump P400	4,152	5,760
Pump P401	*4,539*	2,880
Pump P402	*8,966*	2,880
Pump P500	*4,564*	2,880
Pump P501	*5,001*	4,320
Pump P502	*5,561*	4,320

P100, P102, P106, P200, and P400, all other pumps are to be completed after their due dates. Particularly, pump P402 will be late more than 6,000 minutes.

A few adjustments are now made in the MRP data. The first step we take is to increase the lead-time for three products P104, P106, P200 by eight hours each (One shift length). This change in lead-time is fed back to the ERP and another run for MRP is made. The second run indicates that most of the simulation results now match with all the lead times. But pump P402 is still to be completed late (Table V).

The production manager then can adjust the production schedule based on certain pre-determined rules. This may include overtime on certain machines, increasing shift capacity, changing the order release dates for the products which are not due, expediting the late orders, etc. He examined the different pre-built scenarios in PAN and viewed their results in the simulation software. Some of the pre-configured scenarios include increasing the overtime in each work center, increasing labor hours, etc. In this case, the solution was to increase amount of overtime on work center 1,320 and increasing the shift capacity. Another MRP run was then made in the ERP software based on this adjusted schedule. This simple iterative approach was used in which we were able to match the lead-time generated from the MRP run by the actual feasible lead times, which are generated using the simulation. This enables us to

Table V.
2nd run results and due dates

Material	2nd run results	Due dates
Pump P100	2050.8	4,320
Pump P101	2711.4	2,880
Pump P102	3357.7	4,320
Pump P104	2680.9	2,880
Pump P106	3401.6	4,320
Pump P200	2467.4	4,320
Pump P400	1882.5	5,760
Pump P401	2167.5	2,880
Pump P402	*2802.1*	2,880
Pump P500	2252.6	2,880
Pump P501	2772.6	4,320
Pump P502	3,476	4,320

accurately predict the exact lead-time for the product. The final results are shown in Table VI.

A comparison of the results indicates that initially the ERP module generated inefficient schedules and did not take into account the dynamic shop floor conditions. However, the simulation model produced much better results and enabled us to predict the lead-time for the products much more accurately (Figure 12).

6. Conclusion and discussion

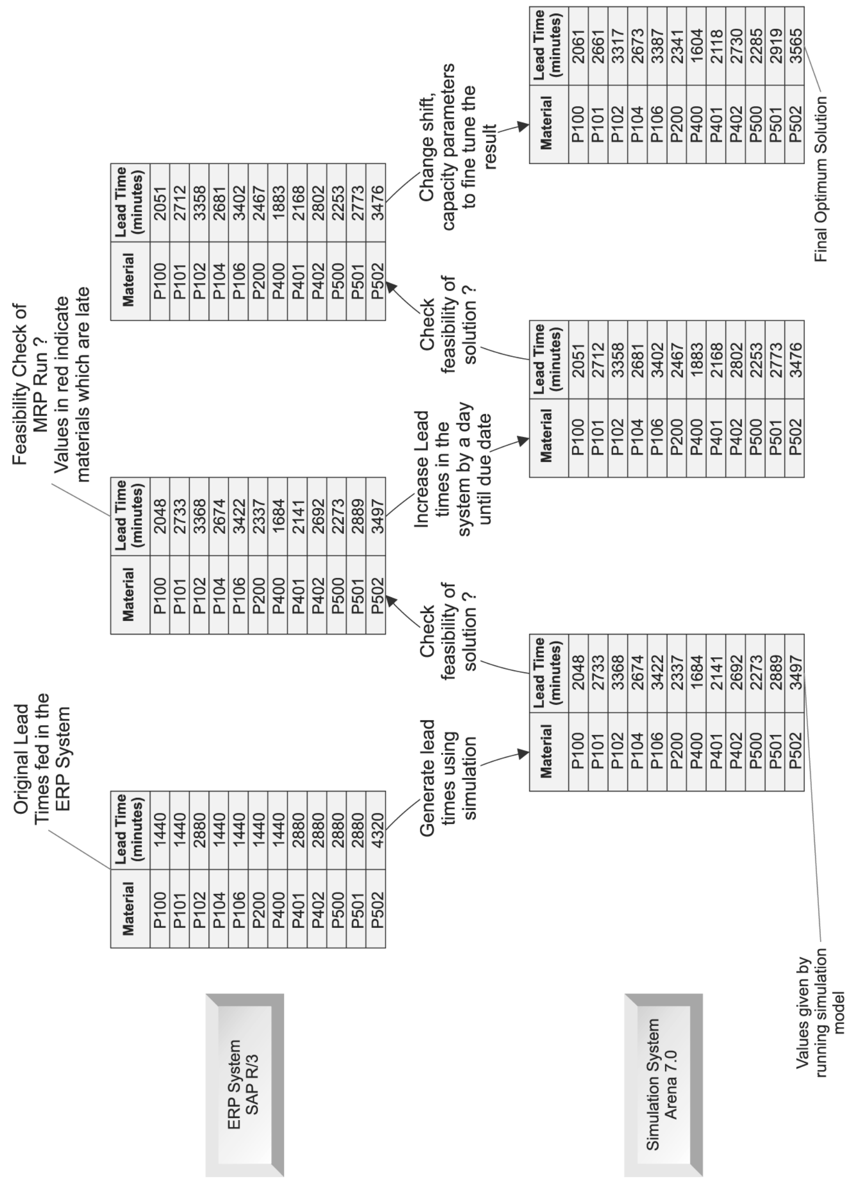
The limitations of the MRP have been well-known for many years. Despite of significant progresses made to correct those, a few problems remain and continue in ERP due to its fundamental assumptions. In this paper, the non-stochastic assumption has been visited and a methodology to address the problem by combining discrete event simulation technology and advances in ERP systems. An example of determining realistic production lead-time demonstrates not only the feasibility of the developed methodology, but also the potentials of applying the same principle in other specific problems caused by the MRP's non-stochastic assumption.

A few enhancements to the current system are possible. The feedback-loop, which we have made, can be made fully automated with the use of an expert system, which decides which strategy or rule to implement based on the change in the schedule. Right now human intervention is required to make that decision. An implementation of a continuous feed back-loop would enable the optimal solution to be generated fairly quickly. We were able to go through 30-40 loops in one hour for a fairly complex mix of products. Model generation could also be made fully automatic using a given template and the data fed from the ERP database. Right now it is manually updated for each variation.

Even though the title of ERP may indicate its planning function, the current ERP systems' planning function is quite limited. Today's ERP systems are adopted mainly for their transaction capability rather than for their planning ability. However, as many corporations adopt the ERP systems as their major information backbone, managers are looking for effective decision support and planning systems tightly connected with the ERP systems. The research presented in this paper contributes in a number of ways to address such managers' needs.

Material	Final results	Due dates
Pump P100	2,016	4,320
Pump P101	2660.8	2,880
Pump P102	3317.1	4,320
Pump P104	2672.8	2,880
Pump P106	3387.2	4,320
Pump P200	2340.9	4,320
Pump P400	1603.6	5,760
Pump P401	2118.1	2,880
Pump P402	2730.1	2,880
Pump P500	2284.9	2,880
Pump P501	2918.7	4,320
Pump P502	3564.7	4,320

Table VI. Final results and due dates



Original Lead Times fed in the ERP System

Material	Lead Time (minutes)
P100	1440
P101	1440
P102	2880
P104	1440
P106	1440
P200	1440
P400	1440
P401	2880
P402	2880
P500	2880
P501	2880
P502	4320

Values given by running simulation model

Material	Lead Time (minutes)
P100	2048
P101	2733
P102	3368
P104	2674
P106	3422
P200	2337
P400	1684
P401	2141
P402	2692
P500	2273
P501	2889
P502	3497

Feasibility Check of MRP Run ?

Material	Lead Time (minutes)
P100	2048
P101	2733
P102	3368
P104	2674
P106	3422
P200	2337
P400	1684
P401	2141
P402	2692
P500	2273
P501	2889
P502	3497

Increase Lead times in the system by a day until due date

Material	Lead Time (minutes)
P100	2051
P101	2712
P102	3358
P104	2681
P106	3402
P200	2467
P400	1883
P401	2168
P402	2802
P500	2253
P501	2773
P502	3476

Check feasibility of solution ?

Material	Lead Time (minutes)
P100	2051
P101	2712
P102	3358
P104	2681
P106	3402
P200	2467
P400	1883
P401	2168
P402	2802
P500	2253
P501	2773
P502	3476

Final Optimum Solution

Material	Lead Time (minutes)
P100	2061
P101	2661
P102	3317
P104	2673
P106	3387
P200	2341
P400	1604
P401	2118
P402	2730
P500	2285
P501	2919
P502	3565

Figure 12.
The iterative framework with results

First of all, the paper informs the managers that the central planning function in today's ERP systems is still based on the MRP concept. Therefore, the same set of limitations found in MRP should be expected in the ERP systems. For example, the informed managers now look for realistic lead-time data when they implement or run the ERP system. At the same time, those who are familiar with the traditional MRP systems should be able to tell the enhancements made in the ERP system such as feedback loop and the expanded scope of integration.

The organizations who have been using the discrete event simulation in their planning and decision-making processes can integrate their simulation models and the ERP system following the steps presented in this paper. The ideas in this paper can be used to look for automatic data collection process to update or build the simulation models. At the same time, the research demonstrates that the limited planning functionality of the ERP system can be complemented by external system such as discrete event simulation models. The specific steps developed for this research can be adopted for other enhancements in different but comparable situations.

The ERP implementation is a significant investment for any corporation (McAdam and Galloway, 2005). Once the ERP implementation is completed successfully, the corporations must look for ways to maximally return on their investment. Along with several recent research findings (Yu, 2005; Ho *et al.*, 2004; Gulledge *et al.*, 2004), the results presented in this paper may be used to enhance the implemented ERP systems or to fully utilize the capabilities in a corporation.

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