

# Expert System For Assembly Line –Group Technology- Batch Sequence-Dependent Set-Up Time

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## Abstract

This study carried out several tasks. First, it investigates the effect of set-up times and its frequency, and batch size on production by simulating a real manufacturing industry that produces automobile lead acid batteries. Secondly, develop and present heuristic algorithm for product sequencing based on minimum setup time. Thirdly, make the analysis of selecting general programming language such as Fortran vs. object oriented expert system. Finally, object oriented expert system model and its feature is presented in detail.

## 1. Introduction

In multi-type production-environment, some industrial plants are required to do machine setups. The setup time may be viewed as bottleneck, where it causes delay by stopping production to get the machine ready for production of different kinds of products. This leads to increase in the lead-time for the product to be delivered to customers and distributors. To alleviate this problem, the industry can invest on new machinery. However, this may not be possible for all due to high investment cost, or lack of production floor space or insufficient demand.

Most industries manufacture vast varieties of products through one assembly line. Usually with this type of industry, it resorts to adopting group technology (GT). GT technique involves identifying similar products, which requires similar parts or processes as a family. In some cases, the setup time within products' family is needed to make minor or major adjustments. Some products are included in a family because of the gained benefits such as ease of performing setups. Assembly line-group technology dependent sequence setup-time is the process of determining the sequence of products to be assembled on the assembly line based on group type and minimum setup-time.

## 2. Prior Research

The issue of setup and batch production has been widely discussed in the literature. It had large views from researchers depending on their point of view to the problem and the system under consideration. These views were incorporated in studies related to JIT, MRP and Quick Response Manufacturing (QRM), production sequencing and scheduling, queuing and so forth.

Aquilano & Chase [2], Harrison [6] and Monden [16] discussed how the Japanese were able to reduce setup time. First they divided the setup time into two parts, internal and external. Since internal setup requires stopping the machine, they have reduced this requirement and instead increased external machine set up which can be performed while the machine is operating. Secondly, they performed time and motion studies to establish the time requirements and evaluate possibilities of reducing the setup times. In addition, operators were able to reduce the setup time by practicing setups in their slack time. When it was not possible to reduce set-up time they resorted to use Signal Kanbans as reorder point. Philipoom et al [19] developed two integer mathematical programming models. The first model is an inventory minimization model while the other is cost minimization model. These two models determine the optimal lot size for a signal Kanban system. Other studies related to setup time in JIT system is presented by Lee [14], Lee & Seah [15], and Ramnarayanan & Gillenwater [20].

The finite production scheduling of MRP was studied by Shayan & Fallah [21]. The authors conclude that MRP is incapable of efficiently accommodating the needs of scheduling. They outlined some key concepts such as priority rule assigned to each customer order and precedence networks for effective scheduling. Ghosh & Gaimon [4] proposed a network model representing multi-product, multi-period, multistage flexible manufacturing system. The model produces plans and schedules of order releases. However, this model assumes that set-up time is negligible. The model provides the interface and linkage between MRP component planning system and the shop scheduling system. The model is solved using a price directive decomposition technique. In experimentation, a number of production factors were examined. These factors are impact of shop flexibility on total cost, inventory levels, existence of bottlenecks, shop utilization, and the number of setups and split lot production. The results show important cost benefit trade-off implication for system design and acquisition. The study concluded that increase of routing flexibility of a system without parallel decrease in setup cost is unlikely to reap significant benefits.

Suri et al [25], and Suri [23,24], in their studies of QRM stressed on the importance of reducing the lead-time. Suri [25] pointed out that time taken for setup is considered as a waste and thus tend to produce large lot sizes to increase the efficiency. As a result of this, it increases work-in-process and queuing time of parts increases. On the other hand, if batch production is too small it becomes infeasible. The author concluded that somewhere in between the two extremes lays the proper lot size. Further, each factory must determine the appropriate lot size for its products.

Several studies presented the batch scheduling involving set-up time as queuing models. More specifically as M/G/1 and MG/C models. Kekre [11] studied the impact of change in product mix size i. e. an increase or decrease in number of products in the group on average job queueing time. The study concluded that average job queueing time in the cell would increase at a decreasing rate as the product mix increases. The study was concerned on the “savings” in job setups when consecutive batches of job arriving at the cell are the same type of product. He et al. [7] examined the relationship between batch size and flow time in a single server queue in which individual customers are grouped before processing. The study shows that the variability of setup time and processing time increases the mean and the variance of flow time as well as the corresponding optimal batch size. Karmarkar et al [9], studied multi-item batching to minimize queueing delay. They presented heuristics batching rules as well as an optimization model.

Lee, et al. [13] studied optimal batch size in multistage manufacturing facilities with scrap and determining the optimal amount of investment. Their study was concerned with set-up cost, holding cost and profit loss. Anderson and Cheah [1] studied a multi-item Capacitated Lot Sizing Problem (CLSP). To solve this problem, the authors used two methods; a heuristic algorithm based on lagrangean relaxation and dynamic programming algorithm. The authors acknowledge that feasible solution may not be obtained.

The search of studies related to lead acid battery manufacturing revealed only one paper. That one was conducted by Elimam and Udayabhanu [3]. The study presented detailed production process of a lead-acid battery manufacturing plant. In addition, it presented two solution procedures for the production planning. The first deals with a heuristic uses an MRP framework combined with a version of economic production quantity model and the other is a mixed integer-programming model.

Several studies looked at sequence-dependent setup time and group technology. Hynn [5] determined that applications of both sequence-dependent setup procedures and group technology principles increase output capacity in cellular manufacturing shop. Krajewski et al. [12] found that setup time has substantial influence and impact on the production system. In addition, simultaneous reduction of setup times and lot sizes is the most effective way to reduce inventory levels and improve customer service. Wortman [26] stressed the importance of considering sequence-dependent setup times for the effective utilization of the manufacturing system resources. Panwalkar et al [18] discovered that about three quarters of the managers reported at least some operation they schedule require sequence-dependent setup times, while approximately 15% reported all operations requiring sequence dependent setup times. Huang and Li [8] considered two-stage semi-conductor industry. They assumed products are grouped into family and set up time is required when processing new family. A heuristic and 8 sequencing rules were developed. In that study they examined the trade-off the costs and the speeds of the machine at the second stage. In order to take full benefit of group technology Karvonen and Holmstrom [10] found that it is necessary to perform tooling analysis. They presented nine steps to perform this task and concluded that this procedure has reduced the set up time by 30% hence it increased the production capacity by more than 40%.

### 3. Objectives of the study

The purpose of this study base on three folds. First, show the effect of set-up time and frequency, and batch size on production by simulating a real manufacturing industry that produces automobile lead acid batteries. Secondly, develop and present heuristic algorithm for product sequencing based on minimum setup time. Thirdly, make the analysis of selecting general programing language such as Fortran vs. object oriented expert system. Before dealing with subject, introduce the industry under study.

### 4. Industry under Study

A manufacturing plant produces 24 types of lead acid automobile batteries. These types are classified in three groups namely; American, European and Japanese. Each group type has several automobile batteries, which differ in capacity [Ah (ampere-hours)] and cranking capability [A (ampere)]. The production process of the automobile batteries takes place in two shops, i.e. processing and assembly shop. In the formal shop, the manufacturing is characterized by batch and continuous. While it is on discrete single item processing in the assembly line. The manufacturing process of lead acid batteries is also characterized by the long lead-time before it reaches the assembly line. This lead time is some time due to necessary process such as requirement of grid cell hardening, formation, and washing and drying (For more detail on the manufacturing process before reaching the assembly line see Elimam & Udayabhanu [3]. This study choose to concentrate on the assembly line. Even though the assembly line is timely balanced and the lead-time is short (2 min per battery per battery/machine), but it requires a considerable long setup time. The setup time varies widely depending on the type of battery to be produced. It may take 30, 60, and 240 minutes. Table 1, shows From-To Setup time of 24 types of automobile battery products. Top row and first column represents products name. There are three groups which are separated by thick dark line. The first group of batteries is set in the first through the fifth row and column, located on the top left hand side. The last group type of battery lays on the last four row and columns at the right bottom side, while in between these two groups lays the second group type of batteries.

The assembly line is composed of 6 machines i.e. Enveloping (Env), Cast On Strap (COS), Inter-Cell Welding (ICW), Heat Sealing, Post Burning, and Packing process. On the assembly line, the output of each machine is 100% tested and inspected by a dedicated machine for that purpose. Rejected items are routed automatically to special zone through the conveyor. These rejected items are again inspected and fixed manually by skilled labor or shipped to adjacent sister company for recycling.

The assembly starts with enveloping process. In the enveloping station, the positive (or negative) electrode are embedded in a highly porous polyethylene separator material and stacked automatically with its counter electrode to the right size of group. These are then transported to COS where all positive plates in the group are welded together on one side and the negatives on the other. This finished cell now having electrical terminals automatically put into plastic containers/boxes and transported along with assembly line to the Inter Cell welder. The ICW squeezes the terminals in neighboring cells together through a prepared hole in the container where a resistance welding takes place. The battery now being internally ready follows the conveyer to the heat sealing station where the cover is fixed to the container using a hot mirror melting the surfaces to be joined. Finally the terminals from the end cells are joined to the external terminal by "Post burning". Now the packing process starts with placing warranty stickers as well as company name "logo", and serial number of the battery.

#### **4.1 Simulation Model**

Simulation modeling is a powerfull tool and its usage is on the rise. It is the tool used to carry out in investagation and to obtain answer to "what if" questions. In this study, the impact of setup times and batch size on this particular industry is investigated. Few assumptions were made. The model assumed as the real assembly line six stations and the processing time is 2 minutes per battery. Transfer time between stations is considered negligible. Batch sizes were set to 100, 400, 600, 800 and 1000 units to be produced. The setup time periods were 60, 120 and 240 minutes. In every experiment conducted in this study, long and exhaustive questioning of results and debugging were made. The Welch procedure was followed to determine steady state. This procedure showed that in every case, the steady state was reached after 50 days of warm-up. At that time the arrays were cleared and statistics were collected for 50 days.

##### **4.1.1 Discussion of Results**

Figure 1 shows the experimental results of the simulation model. It shows that as the setup time period increases, the units production decreases. The drop in production capability is more noticable as the batch size decreaes and setup time increaes. It also means that if the machine setup frequency and time required to set up increases, the production capacity decreases.

**Table 1. Time taken for mold/layout change**

[illegible]

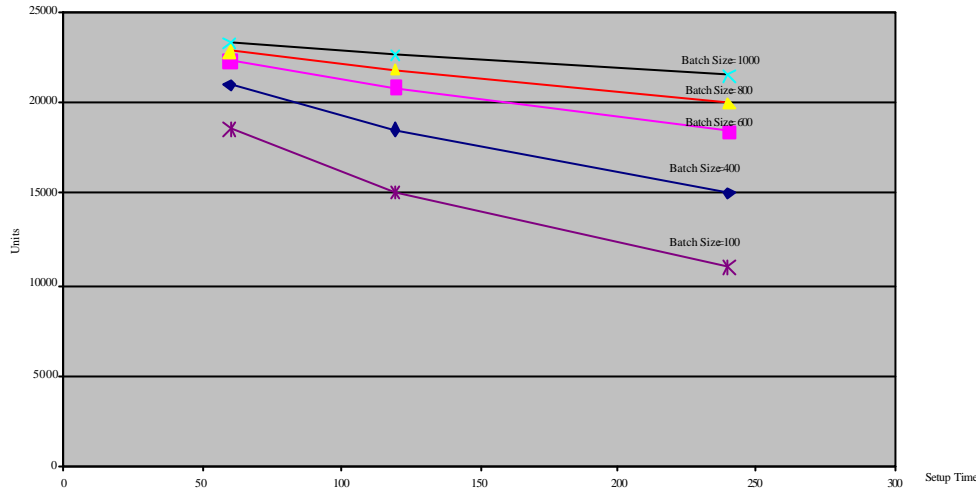


Figure1. Number of units produced at different setup times and batch sizes

#### 4.2 Group Technology Production Sequencing Heuristic

The following heuristic can be used to obtain the products sequence.

Step 0: Construct From-To setup timetable.

Step 1: Find  $IN_{t-1}$  and  $G_{t-1}$  which are the index and group type respectively of the last product produced in period  $t-1$ .

Step 2: For  $i = 1, \dots, n$  products, obtain the following information  $IN_i$ ,  $ON_i$ ,  $G_i$ ,  $S_i$  representing Index, Name, Group type and Selection of products to be produced in period  $t$ .

$$S_i = \begin{cases} 1 & \text{if product is selected} \\ 0 & \text{otherwise} \end{cases}$$

Step 3: Set  $m = 0$

For  $i = 1, \dots, n$  and  $S_i = 1$ , compute

$$m = m + 1$$

$$IN1_m = IN_i$$

$$G1_m = G_i$$

$$NM_m = ON_i$$

Step 4: Find the first group type products

$$j1 = 0$$

$$j2 = 0$$

For  $i = 1, \dots, m$

IF  $G1_i = G_{t-1}$  Then go to 5, Else go to 6

Step 5:  $j1 = j1 + 1$

$$NW1_{j1} = NM_i$$

$$I1_{j1} = IN1_i$$

$$FG_{j1} = G1_i$$

Step 6: In similar fashion separates the second and third group products types.

Step 7: Produce products sequence list based on minimum setup time.

$$i = I_{t-1}$$

For  $j = 1, \dots, m-1$

$$k1 = j + 1$$

For  $k = k1, \dots, m$

IF  $S_{i,j} \succ S_{i,k}$  Goto 2

$$KSAVE = S_{i,k}$$

$$S_{i,k} = S_{i,j}$$

$$S_{i,j} = KSAVE$$

$$j = j + 1$$

Where  $S_{i,j}$  is the setup time it takes from  $i^{\text{th}}$  to  $j^{\text{th}}$  product.

Step 8: Repeat step 7 for the other two product groups.

#### 4.3 General programming languages Vs. Object Oriented Expert System

This heuristic can be easily formulated to general programming languages such as Basic, Fortran or Pascal. Partical flow chart is shown in the appendix. Because some of the manufacturing planning personnel are computer illiterate and do not want to deal with input as well as knowledge of programming. In addition it was stipulated the software that to be used must meet the following conditions:

Friendly interfacing.

Must not require typing only click on.

It must produce the product sequence that minimizes the set up.

It must produce a sequence of products by group type.

It must be flexible and dynamic to re-sequence the products.

For the above reasons object-oriented expert system called “level 5” was used. The following figures illustrate the design and features provided by this software. Figure 2 shows the expert system application introduction screen. The user simply clicks on continue button to proceed with the application or click the exist button to exit.

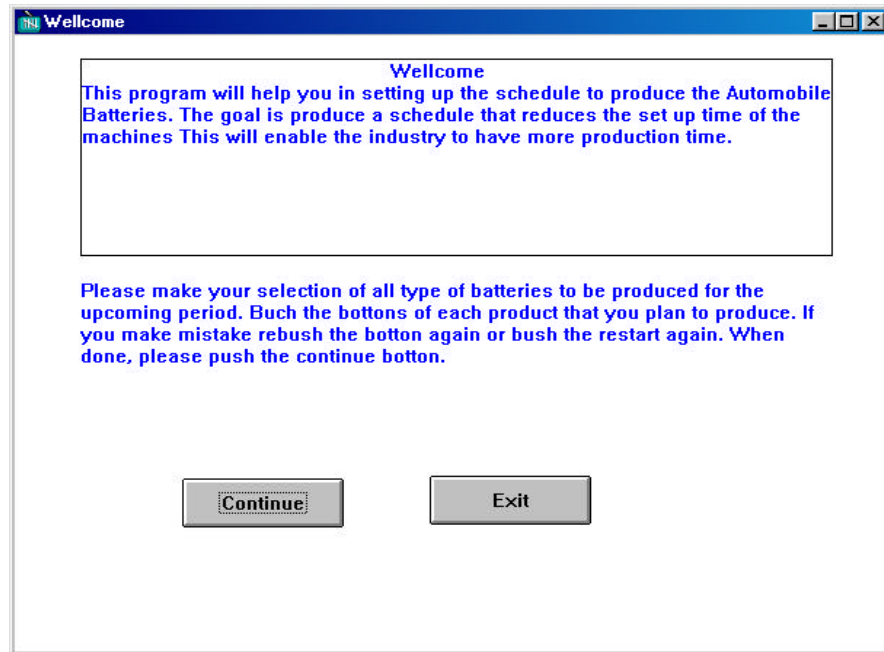


Figure (2). Application introduction screen

Figure 3 shows the “click on” screen from where the user can select only one product as input. The rules are referenced in level 5 object-oriented programming by attributes of class name. To prevent any error, the attribute is defined as COMPOUND, which means that the user can only select one product and in figure 3 it is N40R.

**Find the last Product Produced in this period (select one)**

**Product Title**

- ☐ NS40Z
- ☐ NS40ZL
- ☒ N40R
- ☐ NS60R
- ☐ NS60L
- ☐ N50R
- ☐ D50L
- ☐ D55\_23R
- ☐ D55\_23L
- ☐ N70R
- ☐ N70L
- ☐ N70ZL

**When done selecting the product press the Continue button**

**Determine End Product**

**Continue**

Figure (3). “Click on” for selecting last product produced in period  $t - 1$  .

Figure 4 shows the list of products that the user can “click on” to make the selection of products to be produced on period  $t$  . The attribute in this case is defined as MULTICOMPOUND meaning that the user can select more than one product.

**Name of Product**

- ☐ NS40Z
- ☒ NS40ZL
- ☒ N40R
- ☒ NS60R
- ☒ NS60L
- ☒ N50R
- ☒ N50L
- ☒ D50\_L
- ☒ D55\_23R
- ☒ D55\_23L
- ☒ N70R
- ☒ N70L
- ☒ N70ZL
- ☒ N100R
- ☐ N100L
- ☐ N120R
- ☐ .....

**Determine Products**

**Continue**

Figure (4). “Click on” for ease of entry to select products to be produced in period  $t$

Figure 5 shows an example of batch production sequence.

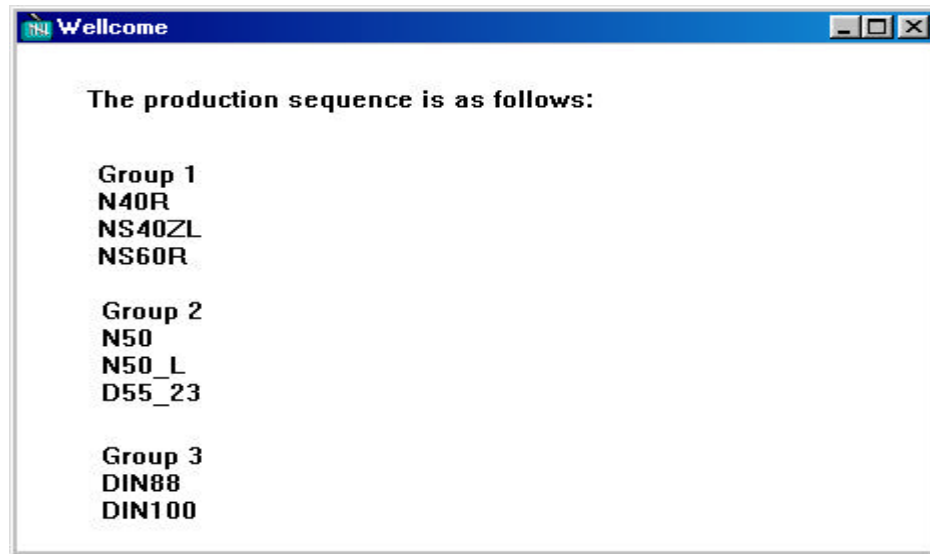


Figure5. Example illustrates batch poduciton sequence

## 5. Conclusion

This study has mostly focused on setup time affects on manufacturing. Setup time remains a problem to many industries. It must be dealt with carefully to minimize lost valuable production time. A real manufacturing case was brought forward. The use of expert sytem was favored over general programing languages because of better user interfacing. Possible extensions to this study is to include more rules suitable for specific manufacturing environment.

## References

- [1] Anderson & Cheah, "Capacitated lot-sizing with minimum batch sizes and setup-times". *International Journal of Production Economics*, 30-31, 137-152, 1993.
- [2] Aquilano N. J. & Chase R. B., *Fundamentals of operations management*, IRWIN, 1991.
- [3] Elimam, A. & Udayabhanu, V., "Production Planning for Lead-Acid Batteries". *Proceedings, the IIE Solution conference*, 1993.
- [4] Ghosh, S. & Gaimon, C., "Routing flexibility and production scheduling in a flexible manufacturing system". *European Journal of Operation Research*, 60, 344-346, 1992.
- [5] Flynn B., "The effects of setup time on output capacity in cellular manufacturing". *International Journal of Production Research*, 25, 1761-1772, 1987.
- [6] Harrison, A. *Just-in-time Manufacturing in Perspective*. Prentice-Hall international, 1992 .
- [7] He, QI-Ming and Jewkes, "Flow time distribution in queues with customers batching and set-up times". *INFORMS*, 35(1),76-91, 1997.
- [8] Huang, W. & Li, S., "A Two-Stage Hybrid with Uniform Machines Setup Times". *Proceedings, The IEEE/CPMT International Electronics Manufacturing Technology Symposium*, 1997.
- [9] Karmakar.Uday, S., Kekre, S., and Kekre, S., 1992, Multi-item batching heuristics for minimization of queuing delays. *European Journal of operation Research*, 58,99-111, 1992.
- [10] Karvonen, S. and Holmstrom, J., "How To Use Tooling Analysis To Reduce Setup Time and Improve Throughput". *Production and inventory Management Journal*. 37(3), 75-80, 1996.
- [11] Kekre, S., "Performance of a manufacturing cell with increased product mix". *IIE Transactions*, 19,329-339, 1987.
- [12] Krajewski LJ, King BE, Ritzman LP, & Wong DS., "Kanban, MRP, and shaping the manufacturing environment". *Management Sciences*. 33, 39-57, 1987.
- [13] Lee, Hsu, Chandra, M. J. & Deleveaux, V. J., "Optimal batch size and investment in multistage production systems with scrap". *Production Planning and Control*. 8(6), 586-596, 1997.
- [14] Lee, L. C., "Parametric appraisal of JIT system". *International Journal of Production Research*, 25 (10), 1415-1429, 1987.
- [15] Lee, L. C. and Seah, K. H. W., "JIT and the effects of varying process and set-up times". *International Journal of operations and Production Management*, 8(1), 19-35, 1988.
- [16] Monden, Y., "Toyota production system". *Industrial Engineering and Management Press*. Norcross, Georgia, 1983.



- [17] Ostwald PF., "Cost estimating". Salvendy G, editor. Handbook of Industrial Engineering, 2<sup>nd</sup> ed. 1263-1288, 1992.
- [18] Panwalkar SS, Dudek RA, & Smith ML., "Sequencing research and the industrial scheduling problem. Proceedings, The theory of scheduling and its applications Symposium. 29-38, 1973.
- [19] Philipoom, P. R., Rees, L. P., Taylor III, B. W. & Huang, P. W, A., "Mathematical programming approach for determining work center lot sizes in a just-in-time system with signal Kanbans". *International Journal of Production Research*, 28 (1), 1-15, 1990.
- [20] Ramnarayanan, R. & Gillenwater., "Evaluation of multi-line-multi-stage stochastic just-in-time production system using Kanbans", *Annual Proceedings, The Decision Sciences Conference*, 1591-1593, 191.
- [21] Shayan, E. & Fallah, H., "A new approach to finite scheduling. International journal of production Research, 37(8), 1903-1915, 1999.
- [22] Suzaki, K. The New Manufacturing Challenge: Techniques for Continuous Improvement. New York: Free Press, 1987.
- [23] Suri, R., "Common misconceptions in implementing Quick Response Manufacturing. Journal of Applied Manufacturing Systems. 9-21, 1995.
- [24] Suri, R., "Quick Response Manufacturing A Company Approach to reducing Lead Time". Productivity Press, 1988.
- [25] Suri, R., Veeramani, R. & Church, J., "Industry teams Up with University Drive Quick Response Manufacturing". IIE Solutions. 27-30, 1995.
- [26] Wortman DB., 1992, "Managing capacity: getting the most from your firm's assets". *Industrial Eng*, 24,47-56.

Appendix: Partial Flow Chart

