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Mid-term Production Planning System. A Case Study of an Engine Assembler[*]

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1. Introduction

The Production planning problem involves determining the most effective means of satisfying forecast demand by adjusting output rates, hiring and laying off personal, inventory levels, overtime work, subcontracting, backlogging orders and other controllable variables (Wang y Liang, 2004).

The problem has received much attention in literature where it is addressed under diverse names such as APP, workforce planning, production and employment smoothing, capacity and production planning (Kogan y Khmelnitsky, 1995). In 1955, it was published what is said to be the seminal paper on aggregate production planning (APP) (Holt et al., 1955).

(Buxey, 2003) claims that perhaps APP models are unfocused, since they are not broadly used at the industry. It can be said that although many models have tackled the medium term production planning problem, the implementation of these models is rare (Nam y Logendran, 1992).

Furthermore, a number of reasons for this rare implementation have been cited in the literature and include: Developed models and techniques do not accurately reflect the APP process in the real world, the assumption that all products are homogeneous and can be easily aggregated and that all labor have the same skill level, Functional areas like human resources, marketing and finance are ignored, The sales forecasted and the cost information given by the industry is not accurate, thus mathematical models used to describe the production planning problems are complex in nature, since there are many links with other influential areas of the planning.

One of the major concerns that might arise is about the connection between production planning and JIT is that inventory has to be reduced. Since inventory is the very first waste why should we plan it?.(de Haan y Yamamoto, 1999)

The motivation of the project that is the framework where this paper arises, was to substitute the manual ways of creating production plans that a lean factory producing engines had.

In 1977, it was published what is claimed to be the first paper written in English on the principles of the Toyota Production System, (Sugimori et al., 1977). In such paper it is clearly stated that different levels of production planning are required even for absolute Lean

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Factories, but also that information systems were cost added centers, that were not adding enough value.

Perhaps due to that belief those factories, held by large companies with enourmous R&D departments, and with an operational framework that it is intended to be general, have not standard and automated tools to plan the production.

As the overall production system has become more complicated, and the Information Systems Technology has improved its performance and reduce the cost, the practices are converging into hybrid production systems. (Riezebos et al., 2009). Many Lean companies now use ERP/MRP methods to communicate demand through the supply chain and hybrid situations have become common at the automotive industry.

The work that is presented here shows a Production Planning model and its implementation, that has been developed and it is working in an engine factory that runs under strict JIT rules. The model, through the DSS that holds it, is today used to plan the 6 months production plan, including different calendars, for each of the 6 main manufacturing groups of the plant.

The Decision Support System presented here takes into account that the PP problem is a multifunctional one. Decisions are taken not only considering materials and operations, but also unions and other stakeholders.

The mathematical model that runs underneath the DSS takes into consideration constraints that limit the stock on different points of the calendar or the possibility to adapt the line rates to cope with reality.

Initially a proper aggregated production plan was to be used, but soon this limitation was not worthwhile, and the aggregation only stood for the time buckets used.

The system works with a horizon of 6 months, but (as reality has shown us during the whole process) accurate information cannot be expected. Therefore the system is prepared to to relax those constraints that can be relaxed, helping the managers to have a better view of the alternatives.

The model that has been used, considers three objectives that are reduced into one: minimize the holding inventory cost, minimize the overall production costs, and adopt a leveled program, while respecting the demand requirements. Of course the costs are simply features that help to define the preferences of the user.

The rest of the paper is structured as follows next section gives the detailed description of the problem. The third section describes the mathematical model that has been used, and the fourth section presents the DSS. Afterwards, closing remarks are pointed out.

2. Problem Description

2.1. The Product and the process

An internal combustion engine is a product, composed of a variety of components that are manufactured and assembled in a assembly line (Wang y Sarker, 2005). The most relevant components are cylinder blocks, cylinder heads, crankshafts connecting rod and camshafts (so called 5C) although there are many others that are also assembled in the final product.The variety of engines has grown during last decades, and so has the variety of components and the raw materials used.

The main clients of an engine assembly line are the car assembly lines. Usually each car factory is in different countries, having thus different working calendars. Then the factory has to adapt its inventory levels, and its production rates to cope with such instability.

Other clients of the engine plant are mainly Part Spare Operations and customized car builders (among those R+D departments). These clients represent less than the 10% of demand, but they also hold more than 75% of the final end products variety.

The system has to keep some safety stock levels at the end of each period, but it is not compulsory, only required.

The engine assembly line is a mixed model assembly line that might run at different rates using different "manning levels". As an example it could be said that with 70 workers about 1000 engines can be assembled per shift, but with half of them, the rate is less than 300 (and only for some special models)

The five component lines are multi model lines, with large setup costs. The manning level that each line requires to run is different among lines, but low compared with the assembly line. But each time that a setup is scheduled a large number of people is required.

The raw material for each one of the five main components is bought directly from different foundries with long lead times. The transformation process is a quite complex and highly automated process that usually is located close to an engine assembly line.

Some of the raw material suppliers are local, but in some other cases, the transit time goes to more than 10 weeks, due to the use of global suppliers for some components, (Mexico to serve to a Spanish factory for instance, with a lead time of 8-10 weeks).

2.2. Production Planning Process. The infrastructure

Each week plant managers try to settle which is the best combination of production rates and working calendars. And for that, with a 6 months horizon, an APP approach is proposed.

The multi product PP problem can be described as determining the most effective means of satisfying forecasted demand by adjusting output rates, inventory levels and other controlled variables. The objective function of this objective functions is to minimize production costs and inventory costs.

There are different strategies for tackling the capacity demand problem. (Piper y Vachon, 2001) states that there is an overwhelming trend to follow the chase strategy, that is claimed to be fuelled by the spread of JIT. Tthe considered plant is a JIT plant, and therefore the most appropriate strategy is again the chase strategy, but it has to be adapted. since the basic chase strategy is not going to work.

The plant staff has to decide with months in advance, the production rate of each line, and a working calendar for each line. Setting daily production rates will have an impact on the manning required: as the production rate increases, it does increase the people required to work with it. Therefore the flexibility to change production rates is limited by the ability to hire people. Moreover the production rate cannot be changed too frequently, since those changes affect stability (Bozarth et al., 2009)

Thus the working calendar of the factory is used to "chase" the demand, by adding extra shifts or new down days. But, since each line (both assembly and component lines) have different demand requirements and different production rates, a different working calendar has to be defined for each of the six lines.

As it has been said the plant is serving a number of clients in different countries that hold different working calendars. Since the plant capacity is limited a minimum stock piling is admitted. The way of controlling that the inventory is not rising too much is to establish objective inventory levels at the end of any long stop period, such as Christmas or Summer

Holidays. The plant, then will stockpile during weeks and even months ahead of the holiday period, but the stock levels will have to be reduced at the end of the period, with a given objective.

As (Wang y Liang, 2004) points out, product life cycles have also to be considered. An engine plant in a leading car manufacturer, deals with dozens of product changes (both minor and major) during the year. It is not sensible to start the process of stock piling of a product that is going to be changed or phased out. If it's going to be eliminated then the solution is easy, but if it is going to change, the decision problem is much more difficult, since the release date can be changed the production cannot be advanced by too much.

Some of the suppliers have long lead times, therefore it is necessary to do a production plan that also considers the requirements for some raw material. The same model that allows to propose the calendar is used to generate the production requirements.

Others constraints like safety stocks levels, storage capacity limits, setup minimization and interdependence of lines, dependence of the lines and other resource limitations are treated.

2.3. Production Planning Process. The requirements

One of the major concerns when designing the model is the high degree of uncertainty both in data and in objectives. Although some work has been done with fuzziness to approach the problem of uncertainty (Mula et al., 2006)and although the managers always claimed that they wanted the optimum, it was agreed that a tool that helps them to analyze scenarios will deliver better insight.

However, since extra work and down days have to be agreed with unions, and in some cases with the government, a scenario analysis is considered to be useful on the search for an agreement.

Thus, the system that was asked to be implemented to first define working calendars, making variations from a original calendar that has been agreed together with unions and fulfilling official working calendars. Then, with various scenarios on prospective daily rates of productions, new working calendars are calculated.

Once the staff decides which is the best calendar, the calendar variables are constrained, and the same model is used to create the production mix for each line and the materials requirements plans for overseas clients.

In this production planning model six calendars in different production lines are calculated.

Since most information for the six months plans cannot be considered in an automated way the results of the model have to be presented in such a way that can be adapted if required.

3. Model Formulation

3.1. Basic Assumptions

The horizon is divided into time buckets of one week. That was the way of working and it has been maintained. For each week demand forecast are known. Also, for each week, original working days are known and the capacity for adding new extra-shifts is also known.

Inventories, Backlogs and the BOM (Bill Of Materials) of every product are known, but only the main 5C components are considered.

Plant staff defines a production rate for each production line and week. The operating costs of the different lines are given for two types of days, the normal working days and the extra shifts.

Stock levels are considered in two different ways. One, is that each product has to have an inventory level over the predefined safety stock. Second, is that the overall stock level should be limited on given periods (for instance, at the end of a holiday period).

Aggregation holds only for the time (time buckets are weeks, with a constant production rate). The model creates as output the number of days that are to be used on each week.

Because of the location of its international suppliers, the plant uses the aggregated plan to purchase its raw materials.

3.2. Notation

The parameters notation is introduced in table 1.

C_i^Y : Cost of holding a unit of i	$C_{i,t}^Z$: Cost of non stable plan for product i in week t
$C_{\xi,t}^{ND}$: Cost of a normal day in week t at line ξ	$C_{\xi,t}^{ES}$: Cost of a normal day in week t at line ξ
$SM_{i,t}$: Maximum level of stock i on time t	$SS_{i,t}$: Safety stock of product i in week t.
L_ξ : Set of products produced on line ξ	T : Time Horizon t=1..T)
$D_{i,t}$: External Demand of product i in week t.	$Q_{i1,i2}$: Number of units of i2 required to produce one i1
$NS_{\xi,t}$ Number of shifts that a day has in week t at line ξ	$K_{\xi,t}$: Daily production capacity of line ξ in week t.
$J_{\xi,t}^{TD}$: Number normal days in week t that the line ξ is planned to work.	$J_{\xi,t}^{ND}$: Idem for normal days
$J_{\xi,t}^{ED}$: Idem for normal days	$J_{\xi,t}^{MAXND}$: Maximum number of normal days that the line can work in week t
$J_{\xi,t}^{MAXES}$: Maximum number of extra shifts that the line can work in week t	$AcX_{\xi,t}$: Minimum cumulated production level for line ξ in week t
X_ξ^0 : Cumulated production level for line ξ in week t	

Table 1. Parameters notation

The variable notation is presented in table 2. Except when otherwise noted, the variables are positive integer integers.

$y_{i,t}$: Stock level of product i at time t	$x_{i,t}$: Production of product i in week t
$z_{i,t} \in R$: production instability in week t	$w_{\xi,t}$: Working days in week t.
$n_{\xi,t}^{ND}$: Proposed new normal days in week t.	$d_{\xi,t}^{ND}$: Proposed new down days in week t.
$n_{\xi,t}^{ES}$: Proposed extra shifts in week t.	

Table 2. Variables notation

3.3. Objective Function

The objective of the proposed model is to minimize total costs (1)

The holding costs of inventory are only considered if the stock is over the safety stock (1.1). In fact it can be said that this peculiarity of the cost is due to the possibility of relaxing the model (if infeasible) through the relaxation of constraint (3). On the final model, when relaxing that constraint, an auxiliary variable that is the inventory over the safety stock is created.

Summatory (1.3) holds to minimize the use of days and extrashifts. The parameters are tunned to prefer a normal day rather than an extrashift, but if the staff wants to consider that extra-shift then it can be added as a parameter.

$$\min \left\{ \begin{array}{ll} \sum_{t=1}^{U}\sum_{\beta}\left(C_{i,t}^{Y}\times\left(y_{\beta,t}-SS_{\beta,t}\right)\right)+ & (1.1) \\ +\sum_{t}\sum_{\xi}(C_{\xi,t}^{WN}\left(n_{\xi,t}^{ND}-d_{\xi,t}^{ND}\right)+C_{\xi,t}^{ES}n_{\xi,t}^{ES}) & (1.2) \\ +\sum_{t}\sum_{i\in L_E}(C_{i,t}^{Z}z_{i,t}) & (1.1) \end{array} \right\} \quad (1)$$

3.4. Constraints

The constraints of the model are presented at this section. When not stated specifically the constraints apply to the whole set represented by the index.

The classical continuity constraints apply on the model. The element consumption has two origin, external demand and internal demand.

$$x_{i1,t} + y_{i1,t-1} - D_{i1,t} - \sum_{\forall i2} Q_{i2,i1}\cdot x_{i1,t} = y_{i1,t} \quad (2)$$

As can be seen, the demand might be the external demand, but also the internal demand due to the production of engines. That second part of demand applies only to those components that are to be used by the engines at the assembly line.

The initial inventory for each product is a given value for each product. For any engine and component, inventories should not be less than the safety cost, but also there are some other limits that should be considered, such as, that a user imposes a limit in terms of quantity at a given time, or in terms of run out; not wanting to hold more than a given amount of days.

Such limits are evaluated before the model is to be launched, and then the inventory level limits have the form of a bound constraint.

$$SS_{i,t} \le y_{i,t} \le SM_{i,t} \quad (3)$$

The sum of engine production at any time has to be equal to the daily rate of production multiplied by the number of working days.

$$\sum_{i\in L_\xi} x_{i,t} = K_{\xi,t}\times w_{\xi,t} \quad (6)$$

The number of working days for each line on each week is calculated adding (or subtracting) the new days to the proposed calendar.

$$w_{\xi,t} = J_{\xi,t}^{ND} + n_{\xi,t}^{ND} - d_{\xi,t}^{ND} + \frac{J_{\xi,t}^{ES} + n_{\xi,t}^{ES}}{NS_{\xi,t}} \quad (7)$$

Normal days are those proposed by the calendar that are going to be tested and to those some new can be added (neglecting previous down days) or new down days can also be added. The same applies to extra shifts, except that adopted extra-shifts are not to be removed by the model. Both extra-days and normal days have natural limits.

$$n_{\xi,t}^{ES} \le J_{\xi,t}^{MAXES} - J_{\xi,t}^{ES} \quad (8)$$

$$n_{\xi,t}^{ND} - d_{\xi,t}^{ND} \le J_{\xi,t}^{MAXND} - J_{\xi,t}^{ND} \quad (9)$$

It is well known that JIT systems require stability. Such stability is reached with this model by using constraints (10), that neglecting changes of less than 10%, compare production rates between a week and its consecutives

$$0.1 \cdot z_{i,t} - \frac{x_{i,t}}{J_{E,t}^{TD} K_{M,t}} + \frac{\sum_{\tau=t}^{t+T^{EST}} x_{i,\tau}}{\sum_{\tau=t}^{t+T^{EST}} J_{E,\tau}^{TD} K_{M,\tau}} \ge 0; \quad 0.1 \cdot z_{i,t} - \frac{x_{i,t}}{J_{E,t}^{TD} K_{M,t}} + \frac{\sum_{\tau=t}^{t+T^{EST}} x_{i,\tau}}{\sum_{\tau=t}^{t+T^{EST}} J_{E,\tau}^{TD} K_{M,\tau}} \ge 0 \quad (10)$$

Constraints (10) only hold for $\forall t \le T - T^{EST}$

A specific constraint has to be considered on the case that is being studied. To control capacity usage, the users of the model wanted to hold a constraint that defines a minimum quantity of production for each production line (even if it there was no demand for them). It is possible that this constraint interferes with other constraints related with stock, and therefore this is the first constraint that can be relaxed.

$$X_{\xi}^{0} + \sum_{\tau=1}^{t} \sum_{i \in L_{\xi}} x_{\beta,\tau} \ge AcX_{\xi,t} \quad (11)$$

Another characteristic of the model that we are deploying is that the number of derivatives to be planned each week could be bound. This constraint was required to limit the setup costs in some of the lines. The MM constant could be any large number, but it has been considered worthwhile to point out, that in order to get reasonable resolution times, “big M” should be carefully calculated, looking for the best bound of the x variable.

$$x_{i,t} - MM_{i,t} \times \chi_{i,t} \le 0 \quad (12)$$

$$DER_{\xi,t}^{\min} \le \sum_{i \in \xi} \chi_{i,t} \le DER_{\xi,t}^{\max} \quad (13)$$

4. The Decision Support System

4.1. The modeling and the implementation Process

The modeling process started on May 2008. And the first step was to understand how they were doing things initially. The original process was a quite iterative one, based on the intensive use of spreadsheets. Those spreadsheets, with a lot of conditional formatting, had both to transmit and to check the information. Of course the company had its own ERP system, but to work with them was somehow difficult.

Moreover the company’s ERP had a database, but it did not include all the data required, in some cases it could not, in some others it was simply too difficult to upload all the information that was much easier handled through the spreadsheet.

The approach to the model was based on interviews with the different users of the different and stakeholders solutions to be created.

From their definition of the problem a initial model was created. That model served as the basis to develop a three-parties contract (consultancy, the research group and the client). Once we started having real data the model was changed on a iterative process that lasted for more than 6 months. It is worth to say that the 2008 crisis came at the same time that the model. The crisis, (and the instability that came along) had some advantages and disadvantages. In one hand it allowed us to do real sensitivity analysis, since the model was thoroughly tested during those 6 months (since October 2008 till March 2009). Also as a positive thing, users realized that they needed a tool to help them to overcome the new and unstable environment.

On the negative part, the system took more than 3 months more than expected and several extensions of the original model had to be developed. Because they were not needed on the original problem but they were on the new one.

4.2. DSS Description

The system that has been deployed together with a Spanish consultancy company named everis SLU. The system not only includes the PP model here presented, but also and CMRP and other features. They have carried out the development process of the information system. The process of defining the models, implementing them into Java sw has been carried out by the team that signs this paper. The definition of the basic requirements was done by the principal of the paper, and from those basic requirements the university team and the consultancy team worked as a unique team.

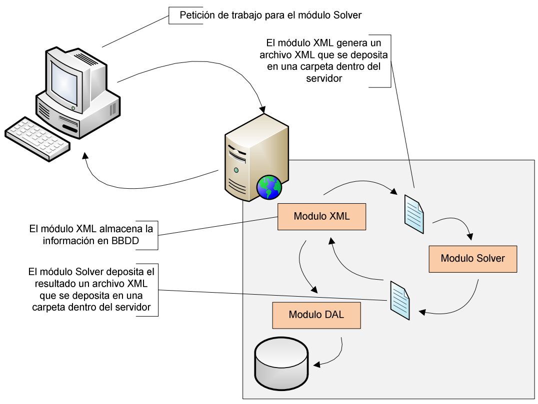

Figure 1. A view of the System designed.

The so-called APS system consists of three basic modules; DAL module, XML module and the solver module. The XML module is the one that retrieves information from the database and transforms them into XML files that are going to be read by the application with the resolution procedures and the models (so called Solver Module). When the Solver finishes generating new XML files, these are again processed through the XML module. Both data and the results are stored at the DAL module.

The Excel Module is a fourth module used to generate XML files that are going to be opened using standard Microsoft Excel ©. Those XML include not only the results, but also the formula that will be required to analyze the results. So, the user can work with a spreadsheet that in fact is an improved version of his old versions.

The whole system is activated using standard browsers as the interface. Each day the data is get from the company's standard ERP, and transformed to cope with the required data. A set of controls have been developed to ensure that data goes to the model as certain as possible. So configurations and data that might result into infeasible problems, are preevaluated and discarded, sending a message to the users.

The core of the system is the two linear mathematical models that are described at the problem, although the users never see that performance because they access as if they were using their standard tools.

4.3. Two models, an implementation key success factor.

During the implementation, due to client's expectation about the use of free software system (although in fact their decision was not to buy a better solver) and the natural concerns on computational time, two models were created.

The first is a general one considering variable the calendars over the 6 month plan and fixing production rates. The model is not solved until the optimum and a 20% of gap is allowed. Then results are exported in an Excel file.

As the major challenge is to be able to take decisions about the six different calendars, it has been observed that using high cost for working days in comparison with the inventory cost, the optimum calendars are obtained quickly. And they fit with the firms expectative.

Then the staff of the company might play online with different scenarios, and the DSS stores each scenario. When an agreement with the calendar is reached, then the model is executed until the optimum, but constraining the variables that allow to change the calendar to zero.

Thanks to this two stage planning tool, the planner is able to create various scenarios of acceptable calendars and to compare each of them in terms of inventory levels, total costs and requirements in raw materials.

The tool has been implemented during the worst periods that can be dreamed, the automotive crisis, with plans and production mixes, changing every day, since the systems were unable of create reliable forecast, together with Christmas and Easter holidays, and a severe ERE, had made stability disappear. But it can be said that the software has had the toughest test that can be imagined.

The tool now is able to be used every day if necessary, generating reliable calendars requirements plans, for each production stage.

5. Conclusions and remarks

A DSS including a Production Planning tool has been presented at this paper. The DSS has been implemented in a factory that assembles engines and produces its main components.

The main feature of the Production Planning Model is that it generates a multilevel production plan for all the products assembled at the factory.

The model is aggregated only on the time dimension. The intention was to produce a day-by-day calendar, but aggregating it into weeks. It does allow to generate many scenarios for the production capacity analysis that has not been incorporated in the model.

Since the same model is used to generate a feasible 6 months plan, once the calendar has been defined, some parameters of the model are changed and then a detailed production plan is released. At this second stage the model considers not only production and inventory limits but also produces stable plans while keeping into reasonable limits the number of derivatives.

The tool has been implemented in the company and it is utilized by the planners. Handiness and simplicity have been reached. Because the use of interfaces is very attractive, the automation of the calculations and the flexibility given by showing results through interactive Excel files, it can be said that the project has become a success.

Moreover, the development of the model resulted very useful theoretically because new constraints have appeared. This industrial case study has allowed shown that a production planning system should be developed for each company, since specific wys of tackling the problem always appear. and it has revealed that the literature limits its study on case where the human factor is important.

But, in practice, more and more, the automation of the production lines and the necessity to respond to an uncertain and variable demand make the models results, inapplicable for the most part of industrial cases.

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