A Decision Support System for Detailed Production Scheduling in a Greek Metal Forming Industry

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Abstract
The purpose of this paper is to thoroughly present the findings of a research project undertaken by the authors regarding the development of a detailed production scheduling system and its implementation in a Greek metal forming industry. The proposed system, entitled "eGantt", was developed through the scope of a decision support tool and was aimed at aiding the production planner in scheduling weekly production orders to work centers along various manufacturing cells. The core design principles were: ease of use, simplicity, flexible Gantt chart based GUI (Graphical User Interface), generation of manageable reports and low development budget. The practical application occurred in a dynamic, Make-To-Stock (MTS) manufacturing environment. A key aspect in the full scale implementation was the successful integration of the "eGantt" system with the legacy applications and ERP system. The selected approach was one that neither overburdened the current information system architecture with software pipeline spaghetti, nor overshoot implementation costs.

Keywords: detailed production scheduling, decision support tool, system integration, dynamic job shops

Introduction

This paper presents the findings of a research project undertaken by the Sector of Industrial Management and Operations Research of the School of Mechanical Engineering, National Technical University of Athens and a Greek SME that specializes in door locks, keys and aluminum mechanisms for window panes. The project's end goal was the design of a detailed production scheduling system that is fully integrated with the PPC (Production Planning and Control) application and the ERP (Enterprise Resource Planning) system the SME utilized up to that point.

Most production planning frameworks are hierarchical three tier architectures that span over three basic time horizons (Barbarosglu and Ozgur, 1999, Zijm, 1999, Riezbezos, 2001, Miller, 2002): long term, midterm and short term. The first two levels are considered planning problems, whereas the bottom level is a scheduling problem (Kreipl and Pinedo, 2004). With each level the degree of product needs disaggregation increases. At the long term level end items needs are aggregated based on product families. Later on these needs are further broken down to individual item, component and raw material needs and production orders are issued. Finally, at the bottom planning level these orders are dispatched via various scheduling algorithms to machines and work centres in order to facilitate work load control (Suresh, 1979, Olhager and Rudberg, 2002)

Detailed production scheduling is an extremely complex problem (Pinedo and Chao, 1999, Bruker, 2007) whose most cases are considered NP-hard (Gunther and van Beek, 2003). Additionally it is worth noting that it is significantly diversified from regular planning problems. Whereas in production planning aggregate information is used and the resultant plans are depicted on either long term or midterm horizons, scheduling uses detailed shop floor data to produce schedules that are narrowed down to a day or sometimes a single shift. Furthermore, planning optimization algorithms utilize a total cost objective, while scheduling mathematical techniques are concerned with minimizing time based objective functions that involve makespan, tardiness, flow time etc. (Bhaskaran and Pinedo, 1992) and are subject to numerous resource availability constraints. As the time horizon is reduced, uncertainty grows and optimal solutions become intractable.

Various approximation and optimization algorithms have been developed for scheduling problems (French, 1982, Morton and Pentico, 1993, Jain and Meeran, 1999, Wang and Zeng, 2001, Chiang and Fu, 2006), for a thorough review of scheduling algorithms the reader is referred to Brucker (2007). Optimization algorithms, such as branch and bound (Martin and Schmoys, 1996) and mixed integer linear programming (Manne, 1960), are seldom applicable in actual shop floors since they can only solve small scale problems in a reasonable amount of time. Approximation algorithms mainly constitute of heuristics such as priority dispatch rules (Panwalkar and Iskander, 1977) and the shifting bottleneck procedure (Balas and Vazacopoulos, 1998), artificial intelligence approaches such as constraint satisfaction (Sadeh et al., 1995), neural networks (Feng et al., 2003) and fuzzy logic (Kacem et al., 2002) as well as modern metaheuristics such as tabu search (Glover and Laguna, 1997), simulated annealing (Van Laarhoven et al. 1992) and genetic algorithms (Mattfeld 1995).

The application of approximation algorithms is deemed more suitable to actual shop floors mainly due to their smaller computational overhead. However, their implementation should not be standalone but coupled with an array of decision support tools to aid the production planner in construing the preferable detailed schedule without relinquishing full control to the scheduling system (Brown and Davies, 1984, Jacobs and Lauer, 1994). In this manner, dynamic events can be incorporated in the schedule faster, fluctuating demand addressed promptly and due dates satisfied (Baker, 1974). Therefore, the preferred approach in achieving efficient detailed production scheduling is the implementation of a DSS (Decision Support System) which embeds simple yet auspicious algorithms and provides tools that enable the planner to adapt the algorithm generated production order sequence according to the latest shop floor conditions (Sanderson, 1989, Crawford and Wiers, 2001).

DSSs for detailed production scheduling are an emerging pattern of the past 15 years (McKay and Wiers, 2003). Often found in literature as FCSs (Finite Capacity Software) (Melnyk, 1997), Leitstand (Adelsberger and Kanet, 1991) and APS (Advanced Planning and Scheduling) (Stadtler and Kilger, 2001), these systems are regarded as complementary applications to ERP/ MRP (Material Requirements Planning) software

(Markus and Tanis, 2000). Their aim is to generate schedules and plans for the shop floor or the entire supply chain through a mixture of algorithms such as constraint based scheduling, genetic algorithms, mixed integer programming models and simulated annealing (Bansal, 2003) as well as manual input from the planner (Zoryk-Schalla, 2001). Although initially such systems were widely considered the practical IT-supported application of operation research principles and as such a competent shop floor control tool (Gracking, 1998), the resulting implementations were seldom successful (Fontanella, 2001).

The generic nature of the embedded algorithms can seldom accurately depict the actual specialized shop floor conditions (genetic algorithms, simulated annealing) and when it can (mixed integer programming, theory of constraints) then computational running times are way too large to promote valid rescheduling (Gunther et al., 2006). Except for the above drawback, APS systems are plagued by a variety of other singularities rending them applicable solely on large enterprises and a prohibitory choice for SMEs (Bermudez, 1998). These are (Bermudez et al., 2003, Grackin and Gilmore, 2004): high acquisition, parameterization, implementation and maintenance costs, overly complex system operation, disbelief by administration in regards to efficiency, small installed user base, interoperability and integration issues with legacy applications and ERP systems, even if the ERP and APS vendor are one and the same.

In light of the above, numerous research efforts in the past have focused on the development of customized DSSs for scheduling so as to overcome the APS deficiencies and drawbacks: Murthy et al. (1999) contrived an agent based DSS following a multi-criteria based approach for the paper industry, Cowling (2003) presented a flexible DSS for steel hot rolling mill scheduling which incorporated tabu search and various other local heuristics to create semi-automatic schedules, Ozbayrak and Bell (2003) proposed a knowledge based DSS for the intelligent management of tools and parts in a FMS (Flexible Manufacturing System) with a built in priority dispatching rule based scheduling module and finally, McKay and Wiers (2003) put forth a DSS targeted at the integrated planner (a planner that handles planning, scheduling and dispatching) and applied it to a focused factory.

A similar approach to the above was taken by the authors who opted for the development of a customized DSS system fully integrated with the current IT infrastructure of the case study which will be presented. The rest of the paper is structured as follows: in Section 2 the production process of the case study will be presented, Section 3 outlines the proposed DSS as a subsequent of the specifications arising from Section 2, Section 4 demonstrates the implementation results and finally in Section 5 conclusions are drawn and further research efforts are mapped out.

Case Study Description

The case study of the detailed production scheduling research project is a Greek medium-sized make-to-stock manufacturer of light metal sheet products. The company is an SME and the sole industrial producer of safety door locks, keys and aluminum mechanisms for window panes in Greece. Except for the Greek market some of the products are exported to various other countries in Europe and more specifically the Balkans. The production process followed has a high degree of complexity with some end items requiring as many as 10 level BOM trees. Furthermore, numerous subcontractors are utilized to carry out some of the production phases coupling the complex BOMs with equally complex routings that transgress the shop floor boundaries.

The shop floor follows a typical functional layout: equipment and processes capable of performing identical or similar operations are grouped and located in close physical proximity (Johnson and Wemmerlov, 1996). The organizational units within the layout specialize in a single process and parts or products are routed through the layout from one process area to another. There are in total eight work center pools which consist of casting, nickel plating, cylinder components, intermediate phases, seizure and nailing, mill cutting, proton assembly and lock and aluminium mechanism assembly. The work centers that comprise these pools are frequently unrelated parallel machines, meaning that their processing speed and ergo their capacity is differentiated (Brucker, 2007). In some rare cases, there are unrelated parallel machines between machine pools, for example: a work center in mill cutting may be parallel with one in the intermediate phases.

One interesting aspect of the entire production process is the extensive outsourcing of various production phases to numerous subcontractors. When assimilated into the shop floor the subcontractors are regarded as unrelated parallel work centers with specific capacities and augmented lead times (their processing time plus the transportation time). Subcontractors may undertake most of the part producing phases, but end item assembly is strictly handled in the manufacturer’s shop floor.

The production planning and control process is carried out by a custom built application, whereas other processes such as accounting, inventory management, sales etc. are relegated to a commercial ERP software package. Both these systems will be discussed in detail in the following two subsections.

Production Planning and Control System

Prior to the detailed scheduling project, the SME used a hierarchical two level planning framework. At the highest level lies the APP (Aggregate Production Planning) module that handles demand management with a yearly time horizon. This function can be performed by employing the concept of component families and not simply of end products. The only purchasing or ordering that can be initiated at this level is of common parts that have the longest lead times such as metal castings. The highest level is supplemented by the MPS module that construes a plan with a three month time horizon in mind. This module also handles demand management not in the context of component families but of end product families. Synoptically, the inputs are demand forecasting and undertaken orders and the output is the master production schedule. Applicability of the schedule is ensured by a first level rough cut capacity check, performed manually by the planner who compares resource capacity required by the schedule with a rough estimation of available machine pool capacity. The schedule is revisioned on a monthly basis to incorporate the unexpected events that took place in that period.

The second planning level is midterm planning and incorporates a hybrid MRP- PBC (Periodic Batch Control) approach. Although the PBC approach is targeted at cellular manufacturing and not functional layouts (Burbidge, 1990) the SME employs the basic concepts such as planning periods and backwards planning to better to maintain higher visibility than the one offered by myopic standalone MRP implementations. MPS information is used to calculate component and material requirements and issue the necessary production orders. Through a BOM explosion the final product needs will be broken down to component needs and allotted in specific periods and machine pools. The period length is a week and allocation begins from the lock assembly in the final period and moves backwards until the first day of the first period that usually contains the casting phase. The ordering policy is not lot for lot in traditional PBC fashion, but EPQ (Economic Production Quantity) which specifies that a certain amount of additional components must be produced in order to gain full benefit from long setup times and create safety stocks. The end plan is revisioned on a weekly basis using the feedback from the detailed scheduling module that will be discussed later. The process uses predefined, fixed lead times that in essence are as long at worst as the planning period.

Except for the production plan, the output of the MRP-PBC module is the order backlog which contains the new and delayed production orders. The backlog is usually accompanied by a report regarding the capacity status of all the work centers in the machine pools so the planner can perform a second level rough cut capacity check. Since this is not an automated process, the planner must proceed with releasing orders from the backlog to the shop floor by taking into account overloaded machines, period length and late orders.

The issuing of production orders is based on the unification of BOMs and routings as presented in Tatsiopoulos (1996). The reason for such a choice was to lower the computational effort of the MRP- PBC execution. At the same time this approach created SKUs and single phase routings for every BOM component the proliferation of which was in part countered by the incorporation of phantom SKUs, meaning SKUs for which the inventory was not monitored. Due to discrepancies between the PPC system and the ERP package, phantom SKUs were later abandoned leading to the issuance of production orders for all parts and the encumbrance in inventory monitoring. From a planning perspective the main drawback of this approach is the vast amount of orders traversing the shop floor at any given period which significantly undermines the planner’s planning and tracking capability.

Once production orders are released the production groups are considered black boxes and dispatching is left up to the foremen’s experience. Due to the large amount of production orders capacity planning is inadequate and as practice has showed the mid-term plan’s nervousness arises significantly over time due to late orders, violated due dates by the subcontractors, machine breakdown, alternate routings and wandering bottlenecks.

ERP Software Package

The implementation of the ERP software package succeeded development of the PPC system. In order to facilitate EAI (Enterprise Application Integration) the phantom SKUs used up to that point were abolished leading to the aforementioned exhaustive issuing of production orders. The integration methodology chosen was ODBC (Open Database

Connections) which directly links specific fields of the PPC database with relevant fields of the ERP database. It is evident that the out of the box MRP module of the ERP system is redundant, thus exciding the entire system from the shop floor level. Therefore, the ERP is constrained to handling inventory, supplies, sales, and financial management. The modus operandi is as follows: initially, MPS, MRP and production and procurement ordering are executed by the PPC system. The output data is then transferred via ODBC to the ERP. Production report is handled by the monitoring module of the PPC and the resulting data is anew transferred to the ERP in order to update the inventory levels and cost estimate production. During each MRP run the updated stock levels are automatically extracted.

Detailed Production Scheduling Requirements

As a result of its complex production process and lacking IT infrastructure the presented case study during the last few years faces numerous problems concerning violated due dates, accumulated late orders, supernumerary production orders, excessive component inventory, lackluster management of outsourcing, poor releasing policies, non systematic dispatching methods, inadequate work load control and low shop floor visibility. To counter these mishaps the SME considered implementing a detailed production scheduling system that would render the production groups visible within a planning period, shift dispatching control from the foremen to the planner and provide the latter with all the necessary decision support tools in releasing, dispatching, work load control and dynamic event management. Although such an approach is by no means a panacea, it will aid the planner in better organizing and managing the entire production process by adding another level to the hierarchical planning framework, one that extends from a day or shift to a single period (week).

The Proposed DSS

The complex production process of the SME in conjunction with the shortcomings of the underlying IT infrastructure would pose a significant drawback to the implementation of a commercial APS package to fulfill the detailed production scheduling requirements outlined in the previous section. In this light, the preferred approach was the development of custom built DSS, tailor made to the aforementioned production process and fully interoperable both with the PPC system and the ERP software package.

The planner’s needs for manual control over releasing/ dispatching and rapid rescheduling as well as the frequent occurrence of dynamic events due extensive outsourcing deemed redundant the development of myopic standalone optimization suite. Furthermore, due to the vast amount of production orders, subcontractors and parallel work centers, that subsume the scheduling problem in question in the NP-hard category, the formulation of an efficient approximation algorithm, both in terms of computational time and schedule quality was considered utopian. Instead, the research team opted for simple, yet effective priority dispatching rules and an assortment of complementary decision support tools that promote fast generation of production schedules, what-if analysis and rapid rescheduling to accommodate dynamic events. In the following two subsections the functionality, the accompanying methods and the interfaces with the other systems of the proposed will be presented.

Functionality of "eGantt"

The functionality of the proposed DSS, henceforth "eGantt" will be analyzed through the scope of the planner who wishes to construct a feasible schedule to turn over to the foremen in order for production to commence. The first step is to initiate data extraction from the PPC system database of production order data (due dates, order quantity, code, processing work center and time, measurement units, priority level etc.) and work center data (code, production group, capacity, efficiency, setup time, shifts per day, parallel machines, number of operators etc.). The next step for the planner is to choose the production group he wishes to schedule.

From then on "eGantt" acts as a releaser by enabling the planner to manually select which production order he wishes to include in the schedule based on the current load of the work centers. For example, he can opt to exclude all the orders with low priority levels to alleviate bottlenecks. Dispatching is automatically handled by the application using a heuristic which will be discussed, along with all other methods, in the next subsection. The end result is a Gantt chart (Gantt, 1919) that depicts all the orders allocated to work centers (**Figure 1**) and at the same time serves as the GUI (Graphical User Interface) that opens up the rest of the "eGantt" functionality to the planner.

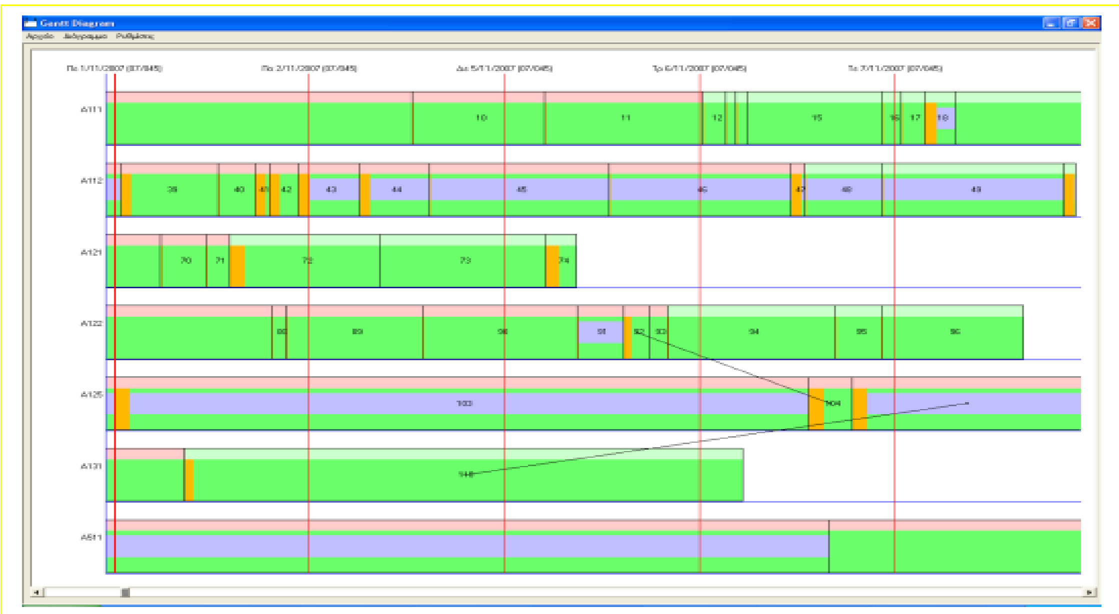

Figure 1: "eGantt" Graphical User Interface

In **Figure 1**, the bars represent the production orders and their length the processing time. If a work center is scheduled to work with two or three shifts per day the bars are colored yellow and dark blue respectively. The orange interval at the beginning of each bar represents the processing time, while the pale green and red overheads the order status: on time and delayed respectively. All pre-subcontractor orders, meaning orders whose next phase is outsourcing, are flagged by an internal purple rectangle. Finally, BOM relationships (child-father) are depicted via conjunctive arcs pointing from the child to the father component.

The planner can now view the status of production orders, the capacity of work centers and the current bottlenecks through various list boxes. Furthermore, he can orders drag and drop orders from one planning period to another and along various alternative work centers in order to control the work load, reduce late orders, minimize set up times and satisfy BOM precedence constraints. Once a move or numerous moves are made, the planner can view the impact on load and order information through the aforementioned list boxes. Although this aspect of the "eGantt" DSS requires full manual input, at the same time a no-idle time heuristic is employed to justify that no work center remains idle if there are orders requiring processing. This can be bypassed by enabling the "freeze" mode. During this mode idle time can be inserted in the chart to simulate maintenance, machine breakdown or an interval required to accommodate a rush order. The GUI provides the additional functionality to perform preemptions: a production order can be fractionated in two parts so production of this component can be resumed at a later time. This function can be either performed automatically through an algorithm, or manually by the planner in order to set the exact quantities the resulting two new orders will carry.

Another notable function is the ability of "eGantt" to perform component availability checks based on BOM relationships. Since the SME has a make-to-stock policy both for components and end items it was considered a computational overkill to satisfy all BOM constraints. A father component may start simultaneously or even earlier than its child as long as there is available stock to manufacture it. Availability of child components is checked through the ATM (Available-To-Manufacture) algorithm and the results are depicted by a red (if there is no availability) or green (if production may commence) subjacent bar. If there are numerous BOM violations and component stock is unable to satisfy all manufacturing needs, the planner can then select to manually transfer father or child orders at a later or earlier time respectively. Furthermore, he can automatically reschedule to minimize BOM relationship violations by choosing from two expletory algorithms, or form a composition of priority dispatching rules by assigning weights to each one.

Rescheduling is further enhanced by the usage of alternative scheduling scenarios. The planner can store the schedule he is currently working on and then try constructing others either on the same or other production groups by using different standalone or combined rules, order transferring and BOM algorithms. Once the desired schedule has been finalized it can be transferred to the PPC and the ERP system to update their databases. Concurrently, two reports will be generated: one will comprise of the entire schedule of the current production group (for example: nickel plating) and contain detailed information regarding the starting and finishing times of orders, the processing work centers and consumption quantities of child components so the foremen can begin production. The second report is a thorough estimation of the impact order manipulation has had on BOM tree precedence. For example if a child order was transferred at a later planning period, then the report will depict which father orders and in what production groups are affected and propose their rescheduling.

"eGantt" Methods and Algorithms

The "eGantt" functionality has a plethora of underlying methods and algorithms as was already mentioned in the previous subsection. The methods are utilized to enhance the decision support aspects of the proposed DSS, such as order transferring whereas the various algorithms execute the automated procedures, such as dispatching.

The preferred method for order releasing is that of manual selection by the planner though a list box depicting the entire production order backlog generated by the PPC system. Furthermore, the planner can select if the late orders will be presented in the chart or not. This addition was deemed essential since in some production groups late orders may not be of interest if there is sufficient stock of the relative SKUs and including them in the chart may drain resources and machine capacity from other orders with higher priorities and tighter due dates.

Once all the desired production orders are released on the chosen production group a first level dispatching heuristic algorithm is initiated to allocate them to the group's work centers. This heuristic classifies orders according to work center code, production planning period, late status and priority level. Specifically, the original $n \times m$ problem, where n is the number of production orders and m the number of centers, is broken down to $n \times 1$ sub problems whose objective function is the minimization of machine idle time. Although raw in nature the heuristic provides a good initial schedule which the planner can modify to his volition. All the resultant schedules are represented as Gantt charts since this method of representation is visually appealing and user friendly.

Except for the aforementioned heuristic, the planner has at his disposal various other priority dispatching rules such as: SPT (Shortest Processing Time), LPT (Longest Processing Time), Setup, Slack and PSF (PreSubcontractor First). The basis for such a choice was the direct alignment of dispatching rules with the shop floor mentality (Giegandt and Nicholson, 1998) and their speed in producing schedules. The latter is of great importance both in many industrial situations as well as the presented case study since rescheduling requirements arising from dynamic events can be more readily addressed.

SPT and LPT classify orders according to their processing time and dispatch them in ascending or descending order respectively. Setup aims at grouping together common components to minimize their setup time and can be further enhanced by choosing to schedule orders either by ascending or descending setup duration. Slack arranges order according to the processing time and due dates to minimize late orders. PSF gives priority to pre-subcontractor orders and schedules them towards the start of the production planning period so as to outsource the post processed components as early as possible. If these standalone rules are inefficient, the planner can formulate a combination of them by assigning weighted priority indexes to each one. Finally, for all the aforementioned heuristics there is the option of giving special priority to late orders.

The functions regarding work load control, bottleneck identification and order transferring are supported by capacity estimation algorithms. These techniques calculate a machine's work load using data regarding capacity, order quantities, shifts per day, hours per shift and efficiency. If the accumulated processing time of a work center exceeds the planning period then it is flagged as overloaded and the planner is prompted to reschedule it using either other planning periods or alternative centers. Since the production groups have machines that are parallel in an unrelated fashion, if a production order is transferred from one alternative work center to another with different capacity, shifts etc. the processing time, i.e. the length of the order bar, is reduced or increased accordingly.

As was mentioned in the previous subsection another method for alleviating bottlenecks is order preemption. Implementation of the method is two-fold: it can be either performed manually by the planner by explicitly stating the quantities of the new orders, or automatically by a simple preemption heuristic algorithm that checks the initial and currently produced quantity and issues a new production order for the remaining quantity which the planner can transfer to alternate planning periods. Except for work load control, this approach also serves as a valuable tool for post production accounting.

The remaining methods and algorithms concern the BOM tree precedence and availability constraints. Satisfaction of as many precedence constraints as possible is the objective function of two algorithms: a strict BOM adherence algorithm and a hybrid tabu search-priority rule implementation. Since extensive analysis of these techniques refrains from the scope of the paper it will suffice to present the general modus operandi: first the set of child-father relationships on a single BOM tree level within a planning period are identified and then automated scheduling is initiated with the sole purpose of positioning a child before a father order. The unification of BOMs and routings by the case study makes it obstreperous to track the route of SKUs along the entire BOM tree, which is why single levels are preferred.

Due to the high complexity of the production process, which in some cases, for example: the assembly production group with late orders included, is highlighted by as many as 200 child-father pairings, proper orientation of all pairs is intractable. Furthermore, the SME maintains inventory for most components by employing make-to-stock policies rending unnecessary precise orientation. Instead, availability of a child component in order to manufacture the father is ensured via the ATM algorithm that mimics the Available-To-Promise (ATP) function of various APS: the succeeding production phase, i.e. the next in sequence work center in the same or a different production group, is regarded as the customer who wishes to procure components from the preceding phase. From that point onward three distinct instances are identified: if there is child quantity in stock, the father and the child may be produced concurrently, if the child faces a stockout or inadequate quantity for concurrent production then the precedence constraint must be satisfied and finally if the child order along with its available stock can satisfy the father's requirements, manufacturing of the latter can begin a short time interval later.

All the above methods and algorithms can aid the planner in producing a variety of contrasting schedules in order to select the one that best fulfills the production requirements at the given planning period. To better facilitate this concept of what-if analysis "eGantt" embeds a method for alternative scenario management. The planner may store the current schedule for later retrieval and then proceed to either schedule an entirely different production group or modify the current production order sequence. The PPC and ERP system databases are not updated unless the planner explicitly defines the finalized schedule. Once finalization is concluded and the databases are updated, the impact analysis heuristic is executed for all the production groups and the final two reports are generated. The impact analysis heuristic identifies a father's children, the production group and work center they belong too, their starting and finishing times and their delayed status. If transferring or scheduling has positioned the father's children in the same planning period, then the planner is prompted to schedule the father at a later time. The same applies if the children have moved to earlier planning periods: the report indicates that the father should move at an earlier time.

Table 1 summarizes all the functionalities and methods analyzed thus far. The additional column labeled "Functionality Type" refers to the decision-making status of each function, for example: order releasing and dispatching are core decision support functions that support the planner in performing detailed production scheduling, while schedule representation and reports are supplementary since they are aimed in presenting and validating the outcome of the decision making process.

Table 1: "eGantt" Functionality and Methods

Functionality Description	**Functionality Type**	**Methods/ Algorithms**
PPC production order and work center data extraction	Supplementary	Common database schema, ODBC
Order releasing	Core	Manual selection by planner, automatic inclusion or exclusion of late orders
Order dispatching	Core	Weighted priority dispatching rules (SPT, LPT, Slack, PSF, Setup, Combo)
Schedule representation	Supplementary	Gantt chart
Supervision of order information, work load and bottleneck work centers	Supplementary	Capacity calculation algorithm
Order transferring either to alternative production planning periods or alternative work centers	Core	Manual input, unrelated parallel machine processing time estimation algorithm
Order transferring in "freeze" mode	Core	Manual input
Order preemption	Core	Manual input, preemption algorithm
Supervision and control of BOM precedence constraint violation	Core	BOM relationship representations, manual input, strict BOM adherence algorithm, weighted priority rule tabu search algorithm
BOM based component availability check	Core	Available-to-manufacture (ATM)

Functionality Description	**Functionality Type**	**Methods/ Algorithms**
		algorithm
What-if analysis	Core	Alternative scenarios management
Impact estimation of order transferring according to BOM tree	Supplementary	Impact analysis heuristic, report generation
Construction of final production schedule	Supplementary	Report generation
PPC and ERP database update	Supplementary	Common database schema, ODBC

Figure 2, depicts the scheduling process of the decision support tool (e-Gantt). For every step of the scheduling process, input and outputs are defined along with the methods or algorithms that support the transformation of information. Every step covers one or more functions described in Table 1. This flow is indicative and planner may choose to omit some of them, for example "second level dispatching" or "order preemption".

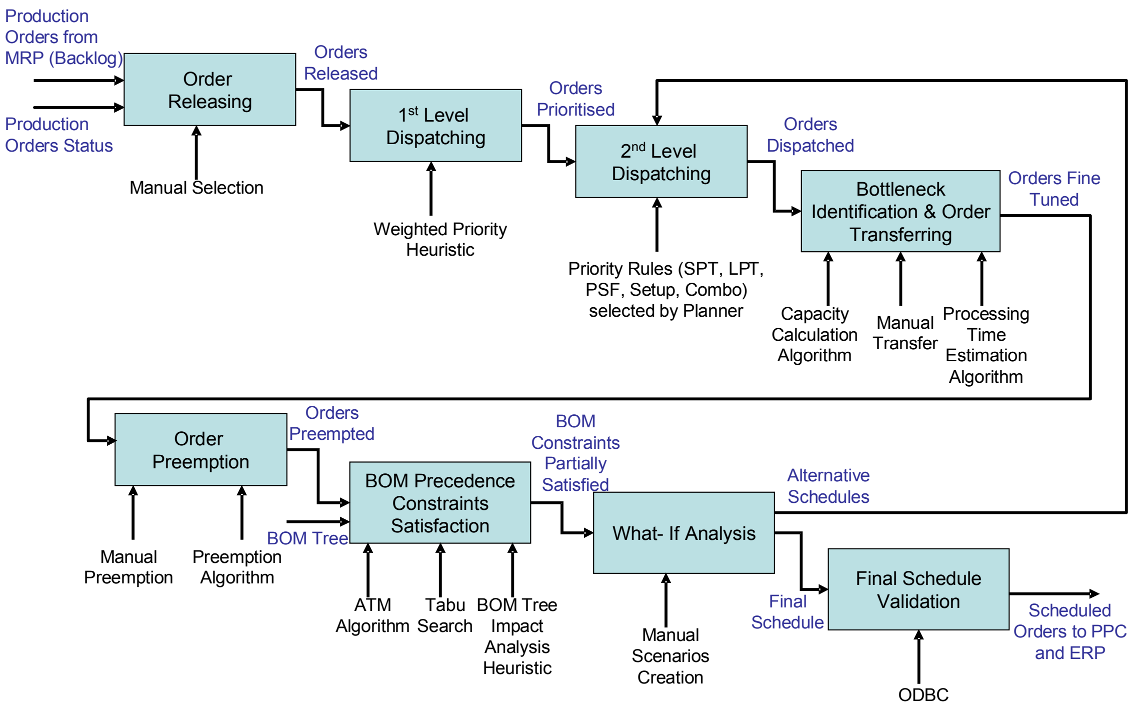

Figure 2: e-Gantt Scheduling Process and Algorithms/ Methods Used

Table 2 presents the various algorithms used in the scheduling process, their main objective, as well as the inputs and the outputs.

Table 2: "eGantt" Algorithms

Algorithm	**Inputs**	**Outputs**	**Objective**
Weighted Priority Heuristic	Quantities, Processing Times, Due date, Priority level	Sequence of orders on a single machine with no idle time	Prioritization of Orders

Algorithm	**Inputs**	**Outputs**	**Objective**
Priority Rule "SPT"	Quantities, Processing Times, Due date	Sequence of orders	Minimization of mean flow time
Priority Rule "LPT"	Quantities, Processing Times, Due date	Sequence of orders	Minimization of total tardiness
Priority Rule "PSF"	Quantities, Processing Times, Due date	Sequence of orders	Minimization of tardiness of pre-subcontractor order
Priority Rule "Setup"	Quantities, Processing Times, Due date, Setup time	Sequence of orders	Minimization of of total setup time
Priority Rule "Combo"	Quantities, Processing Times, Due date, Setup time, Priority level	Sequence of orders	Minimization of the four above objectives using weighted priority indexes
Capacity Calculation Algorithm	Work center capacity, Quantities of sequenced orders	Work centers load, Bottleneck identification	Calculation of overload of work centers
Processing Time Estimation Algorithm	Alternative work centers, Capacities, Quantities of sequenced orders	Processing time for alternate work centers	Calculation of processing times
Preemption Algorithm	Planned quantities, remaining quantities, due date	New production orders for the remaining quantities	Minimize late remaining quantities
Available to Manufacture(ATM)	BOM Tree, Quantity of "father items", Inventory of "children items", starting time of "children items"	Production orders of "father items" capable to manufacture	Calculation available "children items" quantities to produce "father items"
Tabu Search	Weighted priority indexes of priority rules, Quantities, Processing Times, Due date, Priority level	Improved Sequence of orders	Minimization of the "father – child items" pairing precedence constraint
BOM Tree Impact Analysis Heuristic	BOM Tree, Due dates, Production groups of "father items" and "children items"	List of proposed orders transfers	Minimization of common production planning period for "father items" and "children items" belonging to different production groups

Interfaces

EAI between "eGantt" and the rest of the IT infrastructure is facilitated by using a common database schema with the PPC application and ODBC with the ERP system. The interfaces are depicted in **Figure 3.** In short, the chosen approach creates a fully integrated, flexible and scalable IT infrastructure without custom coded, expensive point to point integration solutions. In fact, direct connections are only utilized with frequently used database fields from the stock management, sales, and procurement modules of the ERP. The common schema between "eGantt" and the PPC establishes an extensible IT backbone that can easily transfuse changes or added functionality from one system to the other.

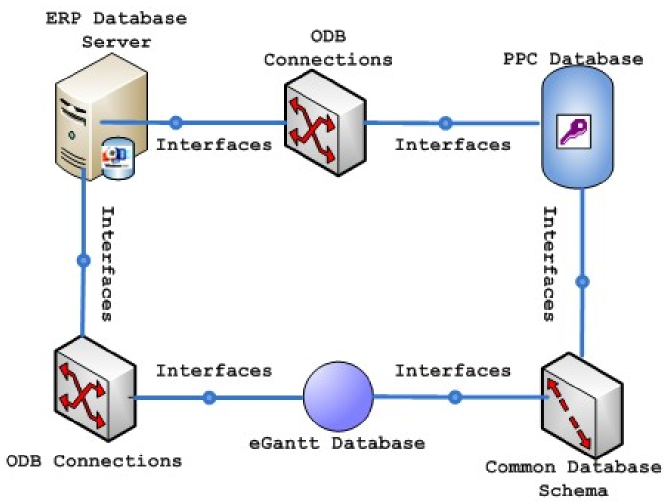

Figure 3: "eGantt" Interfaces

Furthermore, expensive SOA (Service Oriented Architecture) solutions were disregarded since, except for overshooting implementation costs, their B2B integration applicability in this case study is limited due to the select number of subcontractors that can be classified as borderline SMEs with some vestigial IT infrastructure. The rest are small scale job shops with no IT support, few work centers and even fewer foremen rending the purchase of integration brokers overkill.

Implementation

As of 2006 the SME presented explored the reengineering of its core production process. It was decided that the detailed production scheduling layer would be added to the two-tier planning framework. In this respect it was deemed essential that both the new planning process and the detailed scheduling layer be supported by a low cost custom built application fully interoperable with the remaining IT infrastructure, namely the PPC and the ERP system. Reengineering was estimated as an 18 month project and during the last 3 months a research subproject was launched for development of the application. The initial application underwent a test bed of trials and alternative usage scenarios to be finalized. The end result was the "eGantt" DSS embedding all the aforementioned functionality and methods.

The developmental platform of "eGantt" was visual basic .NET as the programming language and MS Access 2003 as the database manager. The choice for the latter was dictated by the current PPC database structure which also uses MS Access. The core design principles were: ease of use, scalability, interoperability, simplicity, flexible GUI, generation of manageable reports and low development budget. The implementation focus was solely on the shop floor and not the entire supply chain, as is the case with most commercial APS. This approach was preferred because it kept developmental costs low and retained the simplicity of the final DSS since supply chain optimization is geared towards mainly make-to-order environments. Despite not extending to the upstream (suppliers) or downstream chain (customers) special emphasis is given to pre subcontractor orders and outsourcing during dispatching.

The new hierarchical planning framework is depicted in **Figure 4.** The procedural sequence is as follows: the MPS calculates long term end item needs and feeds the PPC system which creates the production order backlog. The "eGantt" releases orders from the backlog, dispatches them to work centers and creates detailed schedules. The planner will typically run the "eGannt" DSS at the beginning of each planning period (commonly a week) extracting the latest production order data. Schedules will be generated for each production group and handed down to the foremen for production to commence. If dynamic events take place, for example: a rush order arrives, a machine breaks down or a subcontractor violates due dates, the planner reschedules to accommodate them. The whole process repeats on a weekly basis.

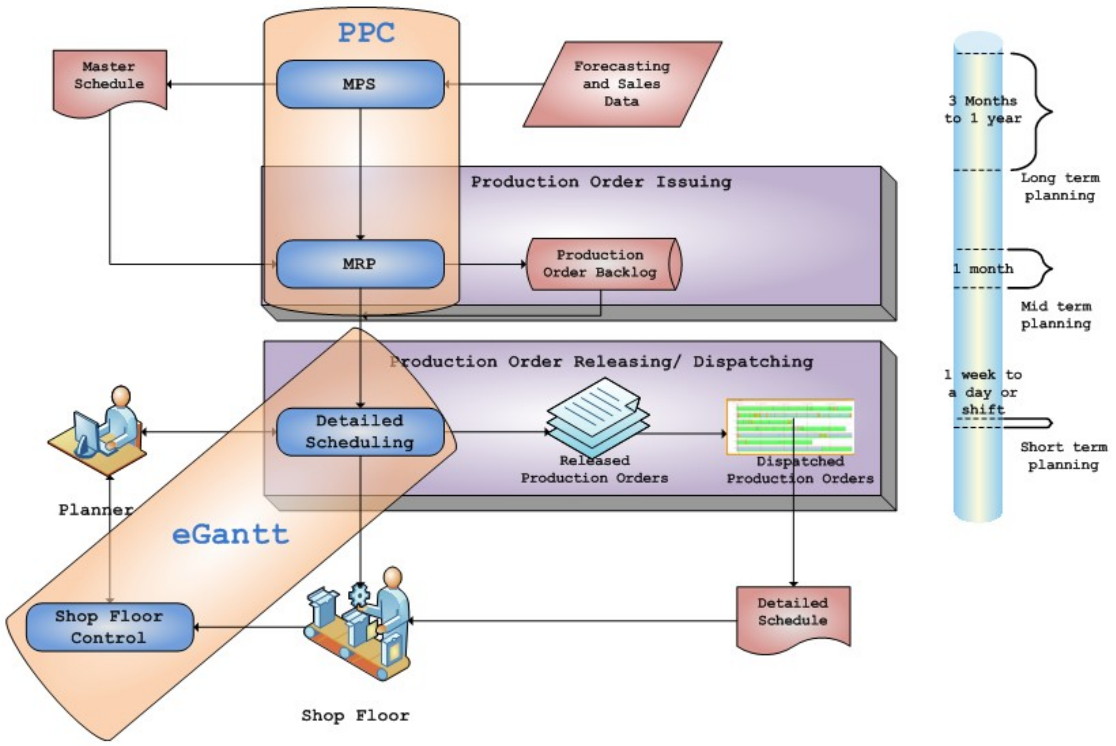

Figure 4: The New Hierarchical Production Planning Framework

Conclusions

Growing consumer demand for variety, reduced product life cycles, changing markets with global competition and rapid development of new products, services and processes have significantly increased the interest of both academia and industry in detailed production scheduling (Williams, 1994). The above economic and social market pressures emphasize the need for a production planning system which requires only small inventory levels, minimizes waste production but is able to maintain customer satisfaction by getting the right product at the right customer and at the right time. Consequently the last three decades have been marked by the advent of manufacturing practices such as make-to-order, cellular manufacturing, group technology, demand management and engineering-to-order. These practices except for process reengineering, alternate plant layouts and a renewed business mentality require facilitation and control of efficient, effective and accurate scheduling (Jain, 1998). Since scheduling is an overly complex operation in all but the simplest manufacturing environments it remained jolted until the mid 90s when the APS systems were first introduced. Those systems combine operational research algorithms and decision support tools for the optimization not just of the shop floor but of the entire supply chain. Although at first heralded as the preferred approach in solving scheduling problems, the high acquisition costs, numerous implementation issues and poor integration capabilities with ERP systems deemed them a prohibitory choice for the majority of SMEs.

Subsequently, customized detailed production scheduling DSS systems became an emerging pattern. Such systems can accurately depict the distinct particularities of a production process and are not overburdened with the functionality of traditional APS systems. That was also the scope of the research project presented in the paper: the development and deployment of a bespoke scheduling DSS in a repetitive make-to-stock SME. Although, the case study does not employ customer oriented manufacturing practices such as make-to-order, the extensive usage of subcontractors, the presence of dynamic events, Make-To-Stock (MTS) functional layout environment, the complex, multi-level manufacturing process and the accumulation of late orders, raise the need for visibility and efficient control of the shop floor.

The needs were addressed via the “eGantt” releaser/ dispatcher which embeds all the necessary functionality and methods that enable the planner in rapidly creating schedules and are made available through a user friendly, visually appealing Gantt chart based GUI. The offered functionality of the DSS consists, but is not limited to a set of priority rules for dispatching, bottleneck identification for capacity planning, production order reallocation to alternative work centers and planning periods, interchangeable scheduling scenarios and work in process availability check according to BOM precedence constraints. The end result is a robust short term production plan capable of incorporating potential shop floor uncertainties such as machine breakdowns and rush orders.

The emphasis was given to the decision support aspect of the system through manual selection in order releasing, transferring and preemption, report generation, what-if analysis and alternative scenarios management. However, additional algorithms such as ATM, priority rules or strict BOM adherence are incorporated for automating the procedures of dispatching, component availability check and precedence constraint satisfaction among others. Furthermore, interoperability of the system with surrounding IT infrastructure, namely the PPC system and the ERP package, is fully facilitated, thus providing an unhampered information flow through a 3-tier planning framework that initiates from calculation of end item needs over long term horizon, advances to disaggregation of those needs over the mid-term and further implodes via the "eGantt" to the component and material requirements of a single day or shift. In conclusion the SME benefited by gaining visibility in its production process, decreasing lead times, avoiding stock outs, increasing flexibility and responsiveness in demand fluctuations and organizing production, maintenance, sales and procurement departments in a collaborative and auspicious manner.

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