Mathematical Programming-Based Sales and Operations Planning at Vestel Electronics

Z. Caner Taşkın*[1], Semra Ağralı[2], A. Tamer Ünal[1], Vahdet Belada[3], and Filiz Gökten-Yılmaz[3]

[1]Department of Industrial Engineering, Boğaziçi University, 34342 Bebek, İstanbul, Turkey {caner.taskin@boun.edu.tr}, {unaltam@boun.edu.tr}

[2]Department of Industrial Engineering, Bahçeşehir University, 34353, Beşiktaş, İstanbul, Turkey {semra.agrali@bahcesehir.edu.tr}

[3]Vestel Electronics, Organize Sanayi Bölgesi, 45030, Manisa, Turkey {vahdet.belada@vestel.com.tr}, {filiz.gokten@vestel.com.tr}

Abstract

We investigate the sales and operations planning (S&OP) problem at Vestel Electronics, a major television manufacturer located in Turkey. The company's product portfolio is very wide due to a large number of configuration options, and changes rapidly due to technological advances. Demand volatility is high and materials procurement requires long lead times. Hence, the S&OP process is critical for efficient management of company resources and its supply chain as well as customer satisfaction. We devise

*Corresponding author

a mathematical programming formulation for Vestel's S&OP problem and describe our experience in implementation of a decision support system (DSS) based on our optimization model. We have fully implemented and deployed our DSS at Vestel, and Vestel has been using it on a daily basis since 2011.

Keywords: Sales and operations planning, decision support system, television industry, mathematical programming

Vestel Group comprises several companies operating in various areas such as manufacturing, household appliances, defense industries and marketing. Vestel Group has approximately $4.2 billion turnover and Vestel Electronics is the flagship company of the group with its revenue and industry-wide market share. Vestel Electronics operates in consumer electronics industry and produces LCD/LED televisions (TV), which is its main product line, and digital set-top boxes. Vestel exports approximately 90% of their products to customers in 140 countries under its own brands as well as various leading Japanese and European brands. Vestel City in Manisa, Turkey is one of the largest industrial complexes in the world operating on a single location, with an area of 1.1 million square meters and annual production capacity of 15 million products [Vestel Electronics, 2013].

A distinctive characteristic of the consumer electronics industry in general, and TV manufacturing industry in particular, is rapid technological evolution [Conlon, 2012, Chang and Chung, 2013]. In the last few years, the mainstream in TV industry has shifted from cathode ray tube (CRT) to plasma and liquid-crystal display (LCD), followed by light-emitting diode (LED) TVs. Recently three-dimensional (3D) and smart TVs have become prevalent, and 4K ultra high definition (UHD) TVs that provide four times as many pixels compared to high definition (HD) TVs have appeared in the market. Moreover, there have been advances in the broadcasting systems. Radical changes such as transition from analog to digital broadcast and Internet protocol television (IPTV) broadcast directly affect the product. Other than these, minor technological improvements, cosmetic changes and changes to reduce costs happen continuously. As a result, product lifecyles are very short and a significant portion of research and development (R&D) effort is spent at the operational level.

LCD/LED TV market is a "buyer's market" where the marketability of a product is very sensitive to its price. Furthermore, customer loyalty is limited and demand volatility is high [Conlon, 2012]. TV demand fluctuates seasonally and special events such as sports organizations heavily affect demand. Television prices tend to decrease over time while prices of input materials fluctuate. This is especially the case for the display (also called panel or screen), which accounts for a significant portion of the total cost [Conlon, 2012]. Price-based competition in the market forces producers to work with low profit margins, and employ opportunistic purchasing of input materials.

Business Model of Vestel Electronics

Vestel Electronics operates in a make-to-order environment, and it allows mass customization of its products. Mass customization is a paradigm in which products are customized in large quantities at low cost rather than standardized [Chen-Ritzo et al., 2010]. Vestel produces approximately 10% of its products under its own brand names while manufacturing the rest under original equipment manufacturer (OEM) and original design manufacturer (ODM) agreements with various customers including well-known Japanese and European brands. For OEM/ODM business model, Vestel follows customer demands and trends in the market, does R&D to design products and produces them under its customers' brand names. This strategy – producing for a large number of customers under hundreds of different brands – requires Vestel's product portfolio to be very wide and products to be diverse in terms of both electronics and cosmetic properties. TV is a heavily customizable product. There are various physical attributes (e.g., size, color), electronic options (e.g., display frequency, USB/HDMI support, 3D support, smart TV capability), cosmetic properties (e.g., front and back cabins), electronic components (e.g., main card, power card, speaker type, remote control type) as well as various software options. When all combinations are considered, the number of products that can be produced at any given time is expressed in tens of thousands, and this number increases as new customization options are added. Due to the rapidly changing technology and the large number of customization options, approximately 5000 new models enter the product portfolio annually. Roughly 60% of the products produced in a month are new products and the entire product portfolio renews almost every six months.

Unlike several of its competitors, which try to create stable operational environments by limiting product variety and limiting customers' flexibility, Vestel's competitive strategy aims to maximize flexibility and responsiveness. To this end, Vestel allows its customers to order any product that can be manufactured from a technical point of view. It also accepts orders of small batch sizes. In particular, 37% of its annual 9.5 million production is for orders of 200 or fewer units, and 66% is for orders 500 or fewer units. Vestel accepts orders with short due dates. It employs no frozen zone in planning horizon, and allows customers to change order quantity, due date and product specifications before actually manufacturing the product. While providing such a level of flexibility to customers is a key component of Vestel's competitive strategy, it increases the difficulty of managing its supply chain.

Vestel works with over 500 suppliers to procure more than 20,000 different stock keeping units (SKUs). Vestel procures a significant number of items from multiple suppliers to decrease costs, resolve supply constraints and due to strategic reasons. These concerns are particularly important for the procurement of displays for which the global supply is limited, costs are significant and prices fluctuate over time. Displays that share similar technical specifications are substitutable to a certain extent. In other words, it is possible to produce a TV unit by using one of several equivalent displays produced by different suppliers. On the other hand, due to some customer requirements, quality concerns or technical reasons, some products cannot be produced by using some of the displays. While exploiting the bill-of-material (BOM) flexibility is crucial for profitability, it also makes material management more difficult because the requirement of several materials (such as power cards and optical materials) depend on the type of the display used. Similarly, usage of a significant number of materials depends on the front and back cabins that customers choose while ordering. Even though cabin choice is mostly cosmetic and does not affect electronic properties of the product, requirement of many materials such as plastic components, speakers, paints depend on the cabin type chosen. Since customers tend to order different cabins in successive orders, and since they tend to delay ordering as much as possible, planning of such materials is particularly difficult.

A unique characteristic of Vestel's supply chain is the result of Turkey's proximity to Europe, which is Vestel's primary market. Vestel sells almost 90% of its products to its customers in Europe. In the meantime, less than one third of its suppliers are located in Turkey, and it procures approximately 90% (in terms of monetary value) of its input materials from Far Eastern countries. Vestel's average order satisfaction lead time is 30 days while its average materials procurement lead time is 90 days. Efficient management of the timing difference between inbound and outbound materials flow is critical for balancing inventory holding costs and order satisfaction performance.

Outputs of Vestel's S&OP process derive long-term material procurement plans. In this sense, S&OP is the most important process in the inventory optimization and demand satisfaction performance at Vestel. Since the flexibility in demand satisfaction is Vestel's main competitive advantage, effective management of the S&OP process carries vital importance in sustaining Vestel's competitive advantage.

S&OP Process at Vestel Electronics

S&OP is a tactical level integrated business process through which companies aim to keep demand and supply in balance and achieve synchronization among different functions of the organization [Wallace, 2004, Sheldon, 2006]. S&OP has received a significant research interest recently. In particular, Feng et al. [2008] propose several integer programming formulations that represent different levels of cross-functional integration. They compare these models on data obtained from a firm operating in oriented strand board industry to estimate potential financial impact of S&OP before actual implementation. Chen-Ritzo et al. [2010] investigate S&OP problem in configure-to-order systems with configuration uncertainty. They propose a stochastic programming approach, and test the efficacy of their approach on data obtained from IBM System and Technology Group. Oliva and Watson [2011] report their experience on organizational alignment and business processes perspectives of S&OP gained through a set of interviews at a consumer electronics firm. Affonso et al. [2008] propose a simulation model to investigate the effect of lead times and level of collaboration between different entities on S&OP performance. We refer the reader to Thome et al. [2012] for a recent review of the literature on S&OP. While several authors have performed studies on various aspects of S&OP, to the best of our knowledge there is no existing study that addresses S&OP challenges such as imbalance between inbound and outbound flow lead times, rapid technological evolution, BOM and process flexibility in a mass customization and make-to-order environment comparable to Vestel.

Figure 1 provides an overview of the S&OP process employed at Vestel Electronics. Executive Management leads S&OP meetings to align Sales & Marketing, Manufacturing, Procurement and Research & Development (R&D) functions. Since the lead time of some critical materials supplied from Far Eastern countries is up to 16 weeks, planning horizon length is at least 4 months. On the other hand, customers tend to order late. As shown on Figure 2, as of the beginning of month t, fewer than 80% of forecasted sales for month t

Figure 1: The diagram shows organizational functions participating in the S&OP process at Vestel Electronics along with main inputs and outputs of the process.

have turned into firm customer orders. Similarly, as of the beginning of month t, fewer than 30% of forecasted sales for month $t+1$, fewer than 10% for month $t+2$, and fewer than 5% for month $t+3$ have been realized as customer orders. Customer orders, sales forecasts, market preferences and trends are very important inputs for the S&OP process. Vestel Group has several subsidiary companies for sales and marketing worldwide, and these companies are responsible for generating sales forecasts. They consider and closely monitor various factors including past sales, country-based pricing policies of competitors, screen size and technological preferences of customers, important sports events in the world (such as UEFA European Championship, FIFA World Cup, Olympics), and agreements with ODM/OEM customers. Sales companies make most forecasts at screen size and main technology level (e.g., 32" LCD TV, 40" LED TV). However, they provide more specific forecasts for certain market segments and customers. This implies that Vestel needs to work with sales forecasts containing different levels of detail.

Manufacturing department provides information regarding production capacity, current inventory levels of materials and manufacturing costs of semi-finished components and end products. By analyzing the effect of capacity bottlenecks on sales targets and taking corrective actions, S&OP process increases coordination between production and sales activities. Furthermore, knowledge about production costs and bottlenecks can be used to guide sales activities towards a more profitable product mix.

Another important goal of the S&OP process is the management of demand and supply of displays and other critical materials having long lead times. As discussed earlier, global supply of displays is limited and display prices are subject to fluctuations. Procurement department provides information about display procurement capability, supplier capacities, procurement lead times and scheduled receipt quantity/timing of critical materials along with material costs. S&OP process facilitates coordination between procurement and sales activities by investigating the effect of procurement problems on sales targets. Furthermore,

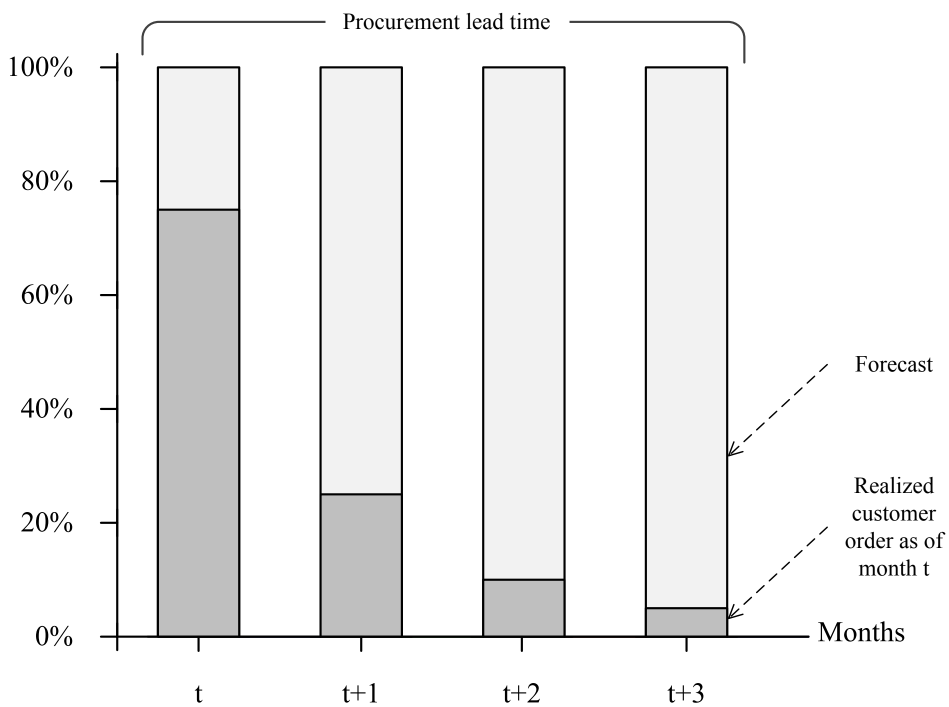

Figure 2: The chart illustrates ratio of firm customer orders (dark area) to total forecast (light area) as of the beginning of month t for time periods within the procurement lead time.

since many end products can be produced with different displays having equivalent technical specifications, BOM flexibility can be utilized to improve profitability.

R&D department is an important contributor to Vestel's S&OP process since product life cycles are very short and new products enter the market continuously. R&D shares information about various projects in their pipeline to increase BOM flexibility of existing products (such as adding new display options), new product introduction plans and engineering changes to existing products or replacing certain components with new ones. Timing of these projects needs to be aligned with Sales & Marketing to improve customer satisfaction and Manufacturing and Procurement departments to decrease operational costs.

In S&OP meetings Executive Management gets together with representatives of the corresponding functions to formulate a consensus plan given the input from various functions and financial and strategic goals. The consensus plan represents the constrained forecast for Sales & Marketing, high level production plan for Manufacturing, high level procurement plan for Procurement and provides target project timings for R&D. Executive Management holds S&OP meetings regularly and as needed (such as in case of major supply disruptions, manufacturing problems or changes in market conditions).

Given unique characteristics of TV manufacturing, Vestel's business model and its organizational structure, Vestel's S&OP process presents some challenges that we address in our study:

- *How to plan for products that do not yet exist*: Since product life cycles are quite short, new products replace a significant portion of currently existing products by the end of the planning horizon. This implies that long-term production and material requirement plans have to incorporate products that do not yet exist.
- *How to identify and resolve inconsistencies between various targets and constraints*: Since there are various functions involved in the S&OP process with their own goals and constraints, there can be conflicts between them. Furthermore, since different sales

companies make sales forecasts at different levels of detail at different times, there can be internal inconsistencies between those.

- *How to identify a least costly/most profitable operations plan*: While customer orders are associated with specific products, Sales & Marketing makes forecasts at a high level, and there are many products that can be used to satisfy each forecast item. However, manufacturing and material costs of these products are typically different (due to being compatible with different displays, using different kinds of electronic components, whether or not their required components are already in inventory or need to be ordered, etc.). This flexibility can be exploited to guide Sales & Marketing towards a more profitable sales plan.
- *How to put the consensus plan into action*: Vestel uses an enterprise resource planning (ERP) system for its operations. Once the functions reach an agreement, the consensus plan needs to be integrated into the ERP system so that it provides an input for materials requirements planning (MRP) and long term capacity planning processes. Furthermore, it needs to be communicated to various employees within the organization rapidly so that actions taken in other processes are in alignment with the decisions made at S&OP process.

Planning Materials (PM)

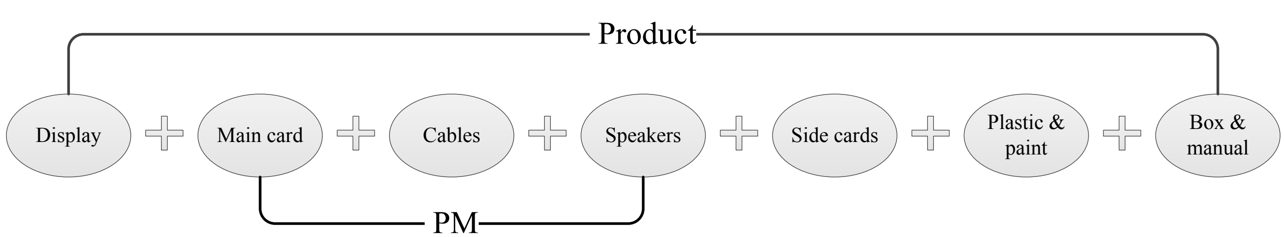

Figure 3: The figure shows main components of products and planning materials (PM), which comprise components that are relevant for the S&OP process.

Figure 3 shows main components of an LCD/LED TV. A product contains various mechanical and electronic components, a remote control, possibly an integrated DVD/DVR unit, printed documents, packaging materials and software. As discussed earlier, there are various customization options (such as size, color, display frequency, USB/HDMI inputs, integrated DVD/DVR units, 3D/smart TV capability, speaker and remote control type etc.), and Vestel allows mass customization of its products. The number of products that the customers can order is on the order of tens of thousands, and the product portfolio changes rapidly due to technological advances. Therefore, it is not possible to create a long term operations plan based on existing products. On the other hand, various components are manufactured in-house (e.g. plastic materials such as front and back cabins), have relatively short procurement lead times (e.g. side cards, boxes and manuals), or are purchased in bulk quantities and used commonly in a diverse range of products (e.g. paint). Such materials are out of the scope of S&OP process, and operational-level MRP calculates their requirements.

In order to provide a basis for the S&OP process Vestel has defined high level products called Planning Materials (PM). PMs are representative virtual products that i) capture basic product attributes (e.g. size, display type, power card type, customer group), and ii) have a simplified BOM consisting of components having long procurement lead times (e.g. main card, cables, speakers) (see Figure 3). PMs provide a grouping of products having common attributes and common components that are relevant for long term procurement planning. Hence, each existing product corresponds to a single PM, but a PM can have several corresponding products. Furthermore, each PM has a corresponding set of displays that are compatible with it considering technical specifications and customer preferences. Similarly, each display can be used by several PMs. PMs capture the information needed for long term sales, manufacturing and procurement planning, and are the main building blocks of Vestel's S&OP process.

Table 1 demonstrates a simplified example to illustrate dynamics of the problem. For this

Goal/ Constraint	Attribute	Quantity	PM1	PM2	PM3	PM4	PM5	PM6	PM7	PM8
			MPEG2	MPEG4	DVD, MPEG2	DVD, MPEG4	MPEG4 Customer 1	MPEG2 Customer 2	MPEG2 Smart TV	DVD MPEG4 Smart TV
F1	TOTAL	50,000	1	1	1	1	1	1	1	1
F2	DVD	20,000			1	1				1
F3	MPEG2	25,000	1		1			1	1	
F4	MPEG4	25,000		1		1	1			1
F5	Customer 1	10,000					1			
F6	Customer 2	10,000						1		
F7	Smart TV	25,000							1	1
Initial PM assignments			1,250	1,250	1,250	1,250	10,000	10,000	12,500	12,500
Realized customer orders			2,000	1,000	1,000	500	5,000	7,500	4,000	8,000
Revised PM assignments			2,000	1,500	1,000	500	10,000	10,000	12,000	13,000

Table 1: The table shows a simplified example that illustrates main dynamics of the problem. Given a set of PMs and their attributes, "Initial PM assignments" row shows a solution that satisfies all goals/constraints. Later, customer orders are realized as given in row "Realized customer orders." "Revised PM assignments" row shows an alternative solution satisfying all goals/constraints that is also consistent with realized orders.

example we assume that there are eight PMs (columns "PM1", . . . , "PM8"). The second row of each column shows attributes of the corresponding PM. Columns "Goal/Constraint," "Attribute" and "Quantity" represent various goals and constraints of stakeholders of the S&OP process. In particular, F1 corresponds to the executive management's goal of manufacturing and selling a total of 50,000 products (corresponding to all PMs). F2 represents the procurement capability of DVD units and indicates that the total quantity of products having integrated DVD units (PM3, PM4 and PM8, marked with 1 in the corresponding grid cells) cannot exceed 20,000. Similarly, F3 and F4 indicate manufacturing capacity restrictions on products supporting MPEG2 and MPEG4 (PM1, PM3, PM6, PM7 and PM2, PM4, PM5, PM8, respectively). F5 and F6 represent sales forecasts for products specialized for Customer 1 and Customer 2 (PM5 and PM6, respectively), and finally F7 indicates forecasted sales quantity on products having Smart TV capability (PM7 and PM8). Note that this simplified version of the problem does not contain i) displays and compatibility of displays with PMs, ii) the multi-period nature of the problem, iii) R&D inputs such as new product introduction and engineering changes, iv) BOM, current inventory levels and scheduled receipts of upstream materials. However, it demonstrates that goals and constraints of the various stakeholders partially overlap with the others.

As discussed in earlier sections, different people prepare inputs of the S&OP process at different levels of detail, and there can be inconsistencies between them. As an example assume that sales forecast for Smart TVs (F7) were 35,000. This would create an impossible situation because sales forecasts for Customers 1 and 2 (F5 and F6, respectively) imply that the total sales of PM5 and PM6 is at least 20,000. Furthermore, since only PM7 and PM8 have Smart TV capability, F5–F7 would imply that the total number of forecasted product sales of PM5–PM8 would be at least 55,000. However, since PM5 and PM8 support MPEG4, their total manufacturing quantity is bound by 25,000. Similarly, since PM6 and PM7 support MPEG2, their production quantity is limited to at most 25,000. Hence, total production quantity of PM5–PM8 is at most 50,000, meaning that forecasted sales would be inconsistent with the manufacturing capacity. While this particular example demonstrates an under-capacity problem, in practice we have observed that sales forecasts are often inconsistent among themselves and realized sales.

Assume that there are no realized customer orders when the S&OP process takes place. The row “Initial PM assignments” represents a feasible assignment of PM quantities that meets all sales forecasts, satisfies capacity and procurement constraints, and ensures that total assigned quantity is in alignment with the goal set by executive management. Assigned PM quantities represent the consensus plan. ERP system uses these quantities to calculate material requirements at lower levels via the MRP process. Note that PM assignments are based on the information available at the time, and may need to be revised in case of changes in market conditions or supply disruptions. As new customer orders materialize during the month, no action is needed as long as all realized customer order quantities do not exceed assigned PM quantities. Assume that "Realized customer orders" row represents actual customer orders received within the month. Since the realized customer order quantity for PM1 (2,000) exceeds its initial assignment (1,250), assignment of PM1 needs to be increased to at least 2,000. Since this change affects goals and constraints that PM1 participates in (F1 and F3), other PM assignments also need to be adjusted. "Revised PM assignments" row shows a revised assignment of PMs that are in alignment with original goals/constraints and realized customer orders. Note that without such an adjustment, MRP would overestimate lower level materials' requirements, resulting in accumulation of unnecessary inventory. We will further discuss this issue in Benefits section.

Implementation

Before our study planning experts were manually executing the S&OP process using spreadsheets. They were using several interlinked spreadsheets to investigate the plan from various perspectives including sales, manufacturing, procurement and R&D. Data used in these spreadsheets were manually downloaded from several tables on the ERP. Planners were manually making PM assignments on spreadsheets and uploading results back to the ERP. This process was time consuming and prone to errors at various levels. Furthermore, the large amount of data involved made it difficult for planners to investigate and analyze inconsistencies and identify a least costly/most profitable operations plan. To this end, Vestel had made various attempts to automate the process by implementing spreadsheet macros and heuristic procedures in the ERP system. However, these approaches proved to be insufficent for a company that produces over 9.5 million TV units in over 5,000 different models annually, and procures approximately 20,000 different materials because they did not provide the required flexibility, speed and solution quality.

Our study started in December 2010 with the goal of developing a decision support system to support Vestel's S&OP process. In the analysis and design phase, together with all stakeholders of the S&OP process, we identified main system requirements as follows:

- Rapidly generate high-quality plans,
- Determine inconsistencies between sales forecasts, realized customer orders, supply constraints, R&D plans and managerial goals,
- Choose among alternative plans that can satisfy given goals and constraints to increase operational efficiency and reduce costs,
- Work with Vestel's ERP software bidirectionally in an integrated manner,
- Perform scenario analysis on forecasts, procurement capability, production capacity,
- Revise the plan automatically to align with realized customer orders,
- Store plans and compare previous plans within themselves and with realized orders, and facilitate analysis of differences between forecasts and realized customer orders,
- Serve as the "single source of truth" regarding the S&OP process, and eliminate the need of multiple spreadsheets.

.

After an initial investigation of the problem and the required functionality, we chose to build a decision support system (DSS) based on mathematical programming as the solution direction. Our reasons for choosing an optimization-based approach instead of heuristics or metaheuristics can be summarized as follows:

- Our investigation revealed that the problem structure is suitable for the development of a mixed-integer programming model based on linear programming formulations used in aggregate planning problems (see e.g., Pochet and Wolsey [2006]).
- If a linear or mixed-integer programming problem is infeasible, an irreducible infeasible subsystem (IIS) of constraints can be calculated [Gleeson and Ryan, 1990, Guieu and Chinneck, 1999]. Such a subset is infeasible by itself, but if any constraint is removed from the subset, the remaining set of constraints is feasible. Thus, an IIS provides a

precise “reason of infeasibility” of the formulation, and can be used to identify conflicts between various inputs of the S&OP process.

- Planning horizon in S&OP process is at least 4 months, during which Vestel produces and sells over 3 million TV units and procures all related materials. Therefore, solution quality has a significant impact on operations costs, customer satisfaction and profitability.

Given the requirements that became clear during the analysis and design phase, we carried out our study in three phases:

1. Designing the optimization model
2. Developing a DSS based on the optimization model
3. Expanding the usage of the DSS within Vestel, and enabling stakeholders of the S&OP process to benefit from the system directly

In the first stage we formulated the planning problem in the S&OP process as an optimization model given in the Appendix. Our model minimizes procurement and production costs while satisfying customer orders and sales forecasts, and meeting operational constraints. In the second stage we developed a DSS based on the optimization model on ICRON Advanced Planning and Scheduling system [ICRON Technologies, 2013]. ICRON provides an object-oriented and visual algorithm modeling environment. It also has extensive support for database and ERP systems integration and interfaces to several mixed-integer programming solvers such as GLPK, Cbc, CPLEX and Gurobi. Main functionalities and use cases of our DSS can be summarized as follows:

- Our DSS downloads up-to-date data about realized customer orders, current inventory levels and scheduled receipts of critical materials, PM definitions, BOM and so on from the ERP software.
- It validates input data and reports data problems via a number of validation reports. It also allows the user to investigate input data and make changes before running

optimization.

- Once the user initiates optimization, our DSS constructs and solves the optimization model in memory.
- If the model is infeasible, it performs infeasibility analysis by computing an IIS. It then identifies the business objects (such as PMs, displays, sales forecasts) that are associated with the constraints and variables in the IIS. Thus, it automatically translates a mathematical description of infeasibilities to a business description of inconsistencies. It reports such inconsistencies in the graphical user interface (GUI) in a manner that allows the user to rapidly resolve the infeasibility by directly interacting with the objects taking place in the inconsistency. As an example, assume that an infeasibility is caused by the shortage of a display within its procurement lead time. In this case our DSS lists the display along with all customer orders and sales forecasts that require the display in a window dedicated to infeasibility analysis. The user can then resolve the infeasibility by increasing the supply (after aligning with Procurement) or decreasing the demand (after aligning with Sales & Marketing). The user can also manually enable or disable some constraints.
- The user can also instruct our DSS to automatically relax some constraints to resolve infeasibility. When the user executes this functionality, our DSS first converts demand constraints to soft constraints by adding an auxiliary variable to each customer order and sales forecast. These variables represent the quantity of the corresponding demand item that cannot be satisfied, under the given constraints. Our DSS, then, solves an auxiliary optimization model whose objective function minimizes the sum of unsatisfied demand quantity variables subject to constraints in the original model. An optimal solution of this auxiliary model represents minimum-unsatisfaction solution, and the demand items whose unsatisfaction variable takes nonzero values indicate the reason of infeasibility. We then fix each demand item's unsatisfaction variable to its current

level, switch back to the original objective function and re-solve the problem. The user can identify the demand items that are affected by the infeasibility in the original model, and also can evaluate the plan that will be generated once infeasibilities are resolved.

Note that this functionality complements the IIS detection functionality. Users regularly use IIS detection to identify root causes of infeasibility. However, since the number of constraints that can take place in an IIS can be relatively large and since there can be multiple IIS sets associated with an infeasible model, the automated infeasibility resolution functionality is also needed. We have observed that over time users have gotten more and more comfortable with interpreting IIS sets from a business point of view. They now often prefer to use IIS detection functionality so that they have an active role in infeasibility resolution and have more control over the system.

- Once an optimal solution is found, our DSS reports the solution in various reports, pivot tables, etc., so that users can easily understand and interpret the solution.
- It also allows users to manually add, remove or modify constraints. We have integrated these use cases into a pivot table that allows the users to dynamically filter and group PMs with respect to their product attributes. Each cell in the pivot table represents a subset of PMs to be produced in a particular month sharing similar attributes. The user can see the current result of the optimization model associated with that subset and month, and can add a new constraint (6) to change it in the next optimization run.
- It also stores results of the optimization in database for future reference, and updates the ERP system as needed.

Our DSS keeps the optimization model and its solution "alive" in computer memory. This capability allows our DSS to reflect any changes that the user makes to goals and constraints immediately to the optimization model instead of building and solving the model from scratch each time the user triggers optimization. Specifically, when the user executes optimization for the first time our DSS builds the mathematical model in memory. It communicates the resulting model to the solver component, which solves the optimization problem and returns an optimal solution along with additional information such as optimal basis. Our DSS stores the mathematical model and its optimal basis in memory, and reflects it in the GUI. If the user makes a change to the model, our DSS changes the corresponding mathematical model objects incrementally. For instance, if the user creates a new constraint, our DSS adds a new constraint to the mathematical model after calculating its variable coefficients and right-hand-side value. Note that this approach is significantly faster than re-building the model from scratch on each optimization request since it saves on model generation time and also allows the solver to utilize its warm start capabilities. As a result, this re-optimization capability enables scenario analysis within a few seconds and significantly enhances usability of the system.

User tests for our DSS started in June 2011. We identified three test phases together with users:

1. *Data accuracy tests*: Users compared data seen on ICRON with up-to-date data on the ERP software and made necessary corrections as needed. At this stage data quality on the ERP improved significantly, and various checks for data consistency were implemented. In particular, during this phase we observed that purchase orders for various components on ERP were not being updated promptly to reflect changes on inbound ship schedules. Vestel updated relevant business processes to solve this issue. This phase took approximately six weeks, until mid-July 2011.
2. *Model accuracy tests*: We generated small-sized data sets together with the users, and executed the DSS over these data sets to check results of the optimization model. We specifically analyzed extreme scenarios (such as no demand, very high demand, no materials procurement capability, etc.), and made necessary corrections until the

system successfully produced correct and explicable results for these situations. This phase was executed in parallel with the first phase, and allowed identification and resolution of various "corner cases" before they appeared on real data.

3. *Parallel usage test*: After the problems encountered in the first two stages were fixed, S&OP planners thoroughly tested the DSS in parallel with their manual planning process using spreadsheets. During these tests, planners checked the plan that our DSS generated on the same data with the manually generated plan, and confirmed that our DSS produces high quality plans and is able to explicitly consider some criteria that were not included in manual planning. This phase started in the beginning of July 2011 and took approximately six weeks. Our main challenge in this phase was expectation management of planners. In particular, planners initially expected our DSS to generate a very similar plan to their manually generated plan. After several discussions, they started focusing on evaluating the plan generated by our DSS independently, and eventually gained trust by observing that our DSS consistently generated high quality plans.

At the end of the second phase of our study, our DSS became operational for use of S&OP planners in August 2011.

In the third phase of our study, we designed web-based reports so that a large number of users in various departments can easily reach the up-to-date plan. These reports take up-to-date plan directly from ICRON, and allow comparing the current plan with previously saved plans and realized customer orders. The entire system became operational in November 2011, and Vestel has been using our DSS on a daily basis since then.

Figure 4 represents the architecture of our DSS in relation to Vestel's information technology landscape. The system consists of various components. Vestel uses SAP as its ERP software, which stores master data (such as product and PM definitions, BOM, cost information) and transactional data (such as customer orders, inventory levels, scheduled

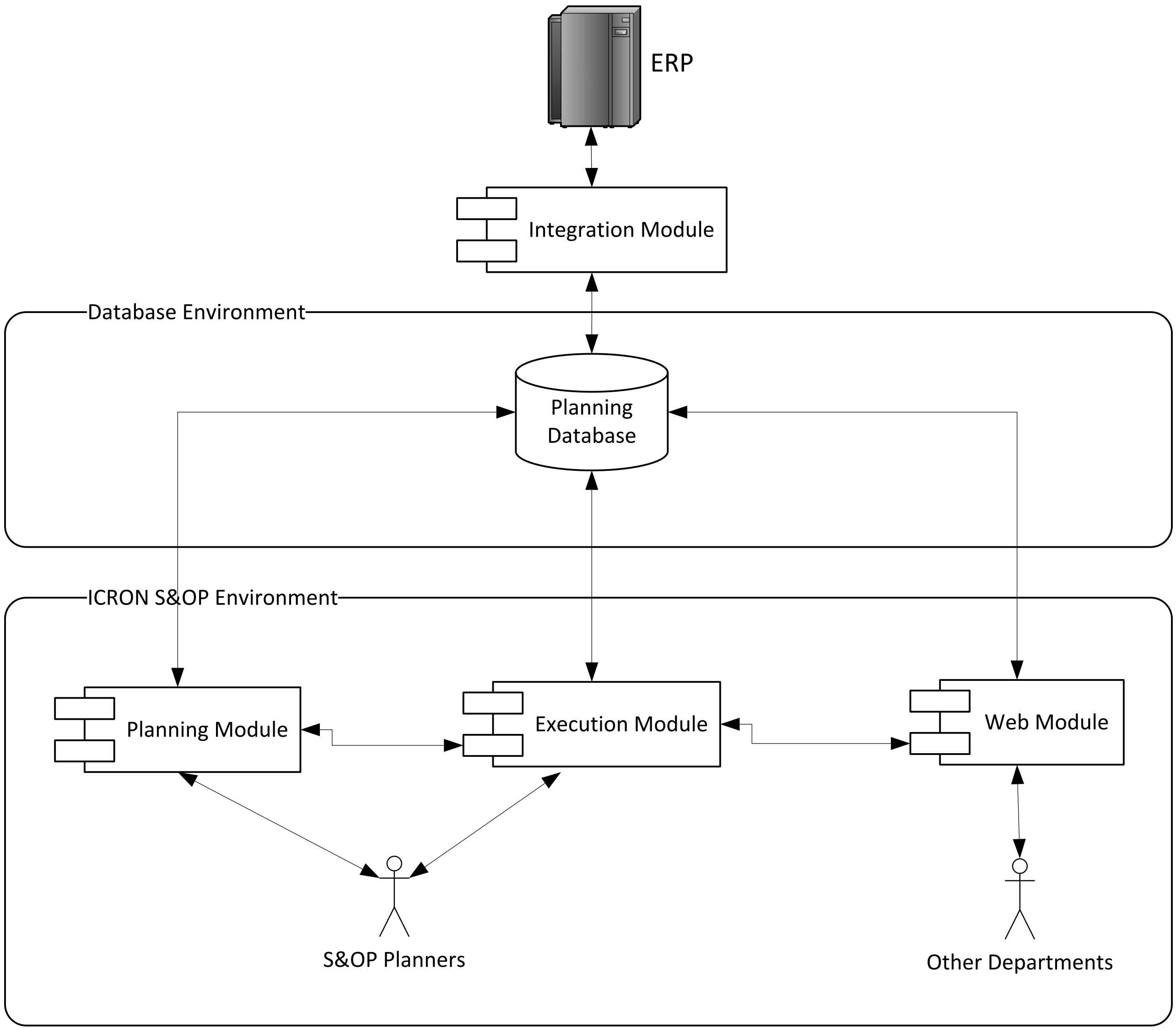

Figure 4: The figure shows main components and users of our DSS in relation to Vestel's information technology (IT) architecture.

receipts). Planning Database, which is a Microsoft SQL Server database, stores required planning data that is not available on the ERP along with scenarios and plans generated in planning sessions. Integration Module, which is implemented in ICRON, transfers data between the ERP and Planning Database, and ensures data consistency via several validation checks. Planning Module, which is also implemented in ICRON, is responsible for planning and scenario analysis. Execution Module, also implemented in ICRON, is responsible for tracking realization of customer orders, inventory levels and scheduled material receipts, and adjusting PM assignments of the current plan as needed. We implemented these modules, which are primarily used by S&OP planners, during the second phase of our study. Finally Web Module, which is an ASP.NET application, provides web-based reporting functionality and is responsible for disseminating up-to-date plan to other departments. This module was implemented during the last phase of our study.

Benefits

We have observed various benefits of our DSS since it became operational in August 2011. We will first discuss tangible benefits measured throughout years 2012 and 2013, followed by intangible benefits.

Tangible Gains

Decrease in planning time: While new PMs are introduced continuously and some PMs become obsolete due to changes in product portfolio, the number of PMs that are active in planning sessions is approximately 700. The total number of active processes is approximately 5000 since each PM has a number of alternative compatible displays. The time horizon of S&OP process at Vestel is at least four months. Since S&OP planners were manually generating the plan prior to our study, it was taking them at least two days to analyze inconsistencies and calculate PM assignments after obtaining inputs from all functions. After the implementation of our DSS, this time has decreased to 3 hours. Our DSS spends approximately 30 minutes of this time while reading data from the ERP, and 3-4 minutes on constructing and solving the optimization model for the first time. Planners use the remaining time to define and analyze scenarios. Since our DSS stores optimization model and its optimal solution in memory for efficient re-optimization, solution of each scenario takes a few seconds. Automatic infeasibility analysis and infeasibility relaxation functionalities execute under one minute in case our DSS identifies an optimization model as infeasible. Therefore, most of the time is used for defining and analyzing alternative scenarios.

Increase in efficiency of the S&OP process: Prior to our study S&OP meetings with the participation of all functions and the executive management could only be made once per month. After our DSS became operational, Vestel has increased the frequency of S&OP meetings to weekly, and on-demand when a major change in supply or demand conditions occurs. Furthermore, since rapid scenario analysis and inconsistency detection became possible, it is now possible to execute our DSS during the S&OP meeting to investigate ad-hoc scenarios. Thus, the overall effectiveness of the S&OP process has improved significantly.

Improvement in planning accuracy: Discrepancy between the initial PM assignments made and the actual production has decreased by 20% once our DSS became operational compared to manually made PM assignments since i) our DSS makes better use of available information on existing customer orders and supply state compared to manual planning, and ii) our DSS generates an optimal solution, which is communicated to Sales & Marketing to guide sales efforts. Recall that our DSS revises PM assignments automatically as needed. As a combination of these factors, the gap between planned and realized operations has significantly reduced. Furthermore, our DSS has replaced empirical rules used by planners with an optimization model that provides a consistent solution quality.

Decrease in inventory level: As discussed in Planning Materials section, our DSS transfers assigned PM quantities to the ERP system to derive MRP and other relevant processes. Before our study planners were manually adjusting PM assignments with respect to realized customer orders biweekly. Hence, MRP was running with up-to-date data only once every two weeks and producing correct results in terms of long-term materials requirement. This was causing some issues in MRP results as we will describe on our illustrative example given in Table 1. Assume that the row "Initial PM assignments" represents initial assignments with no customer orders yet realized. MRP calculates requirements of upstream materials by using only PM assignments, and total requirement quantity that drives MRP calculations is 50,000 (sum of all PM quantities). Assume that some customer orders have materialized during the month as given in "Realized customer orders" row before PM assignments are revised on ERP. Since PM1 has an assignment of 1,250 but 2,000 realized customer orders, MRP calculates requirements based on 2,000. For other PMs assigned quantity drives calculations since realized order quantity is less than the assigned quantity (reflecting the anticipation of more customer orders in the future). Thus, total requirement quantity that drives MRP calculations is 50,750 even though there is no corresponding change in sales forecasts or management goals. The excess quantity disappears once PM assignments are updated in alignment with realized customer orders as given in row "Revised PM assignments."

Figure 5 illustrates the situation graphically. The x-axis represents time, and the y-axis shows total forecasted demand quantity for a particular month. The dark area marked as "Forecast" represents how Sales & Marketing revise total demand forecast as time passes. The light area ("MRP") in the figure shows the total quantity that drives MRP calculations before our study, in which planners manually revised the plan based on up-to-date realized orders and sales forecasts once in every two weeks. As explained earlier, when realized customer orders correspond to PMs that are different than expected MRP calculations overestimate the actual requirement until PM assignments are revised. Hence, the area between the two curves represents the overestimated requirement quantity and it increases as the

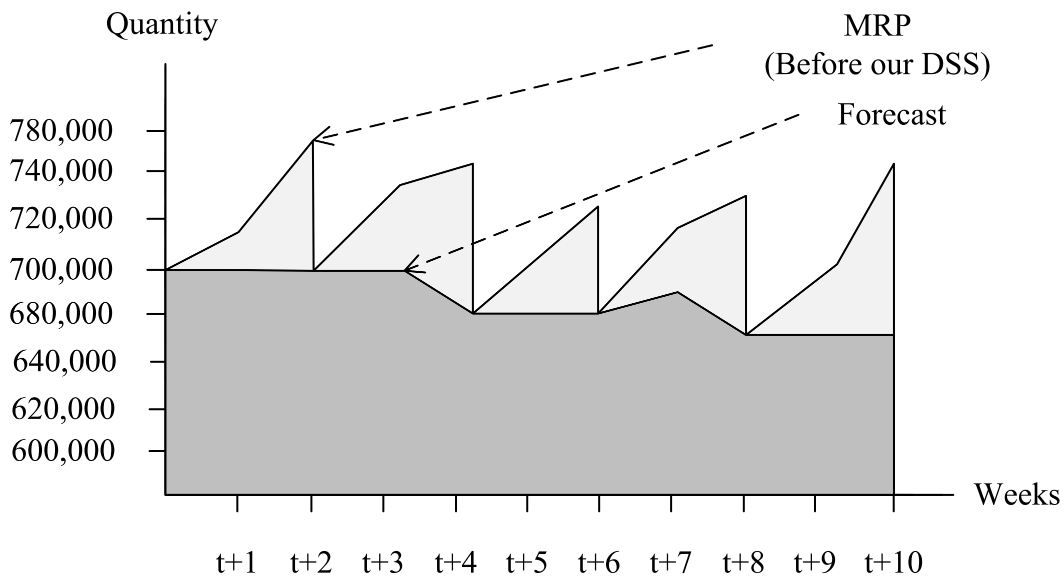

Figure 5: The figure illustrates how total forecast evolves over time (dark area), and how biweekly PM adjustment cycle used before our DSS became operational caused MRP to overestimate material requirements (light area). The Execution Module in our DSS automatically revises PM assignments to ensure that the two curves overlap on a daily basis.

synchronization time increases. Our system's Execution Module has reduced the synchronization time from two weeks to one day since it adjusts PM assignments based on realized customer orders every day, and ensures that the two curves overlap daily. Improving synchronization time has resulted in approximately 5% decrease in inventory levels of components having long lead times.

Intangible Gains

Reduction in MRP nervousness: As illustrated in Figure 5, the total quantity driving MRP calculations had a saw-like pattern before our study with a cycle length of two weeks. This pattern was causing radical changes in calculated requirement and timing of upstream materials. Thus, it was creating nervousness in the MRP results, and required working with high safety stocks. Nervousness in the materials requirement plan was also affecting procurement plan, and hence Vestel's upstream supply chain. Our system's Execution Module has eliminated the root cause of this nervousness.

Since our model simultaneously considers Vestel's sales, procurement and manufacturing operations, effect of changes in one part of the system may propagate to other systems due to our model's holistic approach. We note that increased frequency of planning may result in frequent changes to PM assignments, thus potentially contributing to "planning nervousness." To mitigate this effect we initially incorporated a term to our model's objective function that penalizes changes from previously released PM assignments in our DSS's Execution Module. However, planners challenged this approach during testing phase since i) the additional term caused the model to deviate from cost-optimal solutions, ii) it reduced the system's ability to react rapidly to changes in supply and demand conditions, iii) it created differences between PM assignments of Planning Module and Execution Module that were not easy to interpret. Thus, we took a different approach. After several joint sessions with representatives of Sales & Marketing, Manufacturing and Procurement functions, the need for differentiation between PM assignments and firm commitments became clear. Firm commitments were identified as customer orders (Sales & Marketing), production orders (Manufacturing), and purchase orders (Procurement). Furthermore, all functions agreed to interpret PM assignments as temporary calculated values that are needed to ensure consistency of the overall plan, rather than committed decisions. This interpretation also complies with the fact that absolute values of PM assignments are not directly used in operational decisions. We modified our DSS so that it downloads up-to-date information about firm commitments from the ERP, treats them as "frozen," and optimizes PM assignments in alignment with firm commitments. In practice this approach has successfully created a good balance between adaptability and stability of the plan.

Increase in data visibility and correctness: Before our study the S&OP process was based on data kept in several ERP tables, spreadsheet files and pivot reports in different places. These were manually updated and were not integrated, and it was not possible to ensure that analyses were made on up-to-date data. Our DSS has become the single source of truth regarding the S&OP process, and now it is possible to present up-to-date consolidated views of data to all stakeholders in a unified and consistent form. The increased data visibility, combined with improvements in data correctness obtained by automated validation algorithms has enabled a structure that allows guidance of sales efforts, indicates procurement problems before they appear and facilitates analysis of deviations between sales forecasts and realized customer orders.

Providing a basis for further studies: Up-to-date information about long-term operational plan and sales forecasts has become available electronically since our DSS became operational. Availability of this information has enabled automation of other processes that require this data. In particular, Vestel's management identified the capable-to-promise (CTP) process as the next highest priority. Vestel's CTP process is very important in customer satisfaction because the main output of the process is promised delivery dates before customers finalize their orders. Existing customer orders and forecasted sales need to be analyzed with respect to their capacity and material requirements in order to calculate a reliable delivery date. After our DSS for the S&OP process, we developed a system for the CTP process that has become operational recently. Thus, our DSS described in this paper has provided a solid basis for further studies to improve Vestel's operations and supply chain performance.

Conclusion

Operating in TV manufacturing industry, which is highly competitive and has a high rate of change, Vestel is in a unique location where it is geographically close to Europe (where majority of its customers are located), but is quite far away from Far East (where majority of its suppliers are located). While Vestel uses its proximity to Europe as a competitive advantage to satisfy customer demand on short notice, it has to manage long lead times in material procurement and exploit flexibility in manufacturing processes to decrease costs. The rate of technological advances in end products as well as upstream components make it difficult to generate a realistic long-term plan. To this end Vestel's S&OP process is critical for its operational efficiency. In this study we investigated the S&OP process in detail and designed an optimization model that captures dynamics of Vestel's S&OP process. We built a decision support system around our optimization model, which has replaced manual planning. Our system has become an integral part of Vestel's S&OP process, and the process itself has improved by making better use of our system. Our DSS has been in continuous use since 2011 and in addition to benefits that can directly be attributed to it, it also has enabled development of systems for related processes to improve Vestel's competitiveness.

Acknowledgments. This research was partially supported by Boğaziçi University Research Fund Grant No: 6540 and TÜBİTAK TEYDEB grant no 3100682. We would like to thank Çağlar Çakır Tunç (CMA Consulting), Z. Melis Teksan, Noyan Ekici, Uğur Sönmez (ICRON Technologies), Şeref Hamarat, Bora Pilavcı, Engin Ergör (Vestel Electronics) for their valuable contributions to the implementation project.

Appendix

Mathematical Model

Table 2 shows the symbols used in our mathematical model along with their brief descriptions. We model each PM, display and upstream material as a part (set I). Each part has an associated set of processes, where we model each production and procurement option of a part as a different process (sets J and J_i). In particular, since each product can be

Set	Description
I	set of parts
J	set of processes
T	set of planning periods
R	set of resource groups that present a capacity restriction
J_i	set of processes of part i
F_t	set of sales forecasts for period t
I_f	set of PMs that can be used to satisfy sales forecast f
C_t	set of user-defined constraints for period t
U_{ct}	set of PM-process pairs associated with user-defined constraint c in period t

Parameter	Description
q_{ft}	quantity of sales forecast f at period t
o_{it}	total realized customer order quantity of PM i in period t
y_{i0}	initial inventory of part i
v_r	available capacity of resource group r
u_{ijr}	unit usage of process j of part i on resource group r
$b_{i'ji}$	unit usage of process j of part i' on upstream part i
r_{it}	scheduled receipt quantity (due to production/purchase orders) of part i in period t
c_{ijt}	unit cost of process j of part i in period t
$\bar{x}_{ijt}$	upper bound on process j of part i in period t
$\bar{y}_{it}$	upper bound on inventory level of part i at the end of period t
d_{ct}	right-hand-side value of user-defined constraint c in period t

Variable	Description
x_{ijt}	production/procurement quantity of part i via process j in period t
y_{it}	ending inventory of part i at the end of period t

Table 2: The table shows definitions of sets, parameters and decision variables used in our mathematical model.

manufactured by using a number of displays, we model each alternative as a process of the corresponding PM. Our DSS automatically generates such processes by applying a number of business rules regarding compatibility of displays with PMs. In particular, there are business rules regarding i) technical specifications (e.g. display's dimensions must match the PM's dimensions), ii) customer preferences (e.g. agreements with certain customers only allow for displays manufactured by certain suppliers), iii) international laws and legislations (e.g. displays manufactured in certain countries cannot be used in products that will be shipped to certain other countries) iv) managerial preferences (e.g. low-cost displays should be used in low-end products), v) R&D and quality concerns (e.g. certain displays do not perform well on products using certain electronic components). Our DSS keeps these rules in a database, and executes them to create PM processes. Our DSS also links PMs with sales forecasts (sets F_t and I_f), and calculates the total realized customer order quantity for each PM in each period (parameter o_{it}) by aggregating detailed customer order information downloaded from ERP. We model the fact that requirement of some upstream materials depends on the display used by defining a process-dependent BOM (parameter $b_{i'ji}$). We use upper bounds on process quantities (parameter $\bar{x}_{ijt}$) to model procurement capability and R&D issues such as new product/process introduction. Finally, we use upper bounds on inventory levels ($\bar{y}_{it}$) to model end of life for obsolete components and to ensure that production of PMs is planned only to satisfy customer orders and sales forecasts, but not to inventory.

$$\text{Minimize} \quad \sum_{i\in I}\sum_{j\in J_i}\sum_{t\in T} c_{ijt}x_{ijt} \tag{1}$$

$$\text{subject to} \quad \sum_{i\in I_f}\sum_{j\in J_i} x_{ijt} = q_{ft} \quad \forall t\in T, f\in F_t, \tag{2}$$

$$\sum_{j\in J_i} x_{ijt} \geq o_{it} \quad \forall t\in T, i\in I, \tag{3}$$

$$\sum_{i\in I}\sum_{j\in J_i} u_{ijr}x_{ijt} \leq v_r \quad \forall t\in T, r\in R, \tag{4}$$

$$y_{i(t-1)} + r_{it} + \sum_{j\in J_i} x_{ijt} - \sum_{i'\in I}\sum_{j\in J_{i'}} b_{i'ji}x_{i'jt} = y_{it} \quad \forall t\in T, i\in I, \tag{5}$$

$$\sum_{(i,j)\in U_{ct}} x_{ijt} \odot d_{ct} \quad \forall t\in T, c\in C_t, \tag{6}$$

$$0 \leq x_{ijt} \leq \bar{x}_{ijt} \quad \forall t\in T, i\in I, j\in J_i, \tag{7}$$

$$0 \leq y_{it} \leq \bar{y}_{it} \quad \forall t\in T, i\in I. \tag{8}$$

The objective function (1) minimizes the total production/procurement cost. Note that we don't allow backlogs, which is in alignment with Vestel's business policy. Constraints (2) ensure that sales targets are satisfied. Constraints (3) ensure that assignments for each PM are at least as much as its realized customer orders. Constraints (4) force capacity restrictions on resource groups. Constraints (5) are inventory balance constraints. Constraints (6) are user-defined constraints. Users generate such constraints on-the-fly for ad-hoc scenario analysis. The symbol $\odot$ represents the constraint's type, and is one of $\{\leq, =, \geq\}$. Note that in our DSS user-defined constraints are in the form of sum of process quantities in sets selected by user. The reasons why we chose this specific form of user-defined constraints instead of more general ones such as weighted sums are: i) the corresponding sets can be selected by the user via the GUI by simple filtering and grouping on pivot tables, where a more general constraint definition mechanism would require additional complexity at the GUI level, ii) our observation that most constraints needed for ad-hoc scenario analysis at Vestel can be written as sum of a set of process quantities. Finally, constraints (7)–(8) enforce non-negativity and upper bound restrictions on variables. Note that since Vestel's monthly production and procurement quantities are on the order of several hundred thousands, solving the problem as a linear programming problem and then rounding quantities to integral values does not introduce a significant error. Hence, we do not impose integrality restrictions in our DSS.

We note that bucket-based modeling of time in our model and inventory balance equations (5) are similar to linear programming formulations used in aggregate production planning problems (see e.g., Pochet and Wolsey [2006]). Our approach extends basic models in two aspects: i) modeling of alternative processes, possibly with different BOMs, and ii) Vestel-specific constraints (2)–(4), (6)–(8).

Business Implications of Our Mathematical Model

We next discuss how our model handles some of Vestel's challenges described in earlier sections. As discussed in Introduction, in addition to long term agreements with its suppliers, Vestel also employs opportunistic purchasing of input materials, especially displays. We model input materials as parts, which have their own "buy" processes. Hence, optimal values for x-variables corresponding to buy processes answer time-to-buy and quantity-to-buy questions. Furthermore, the r_{it} parameter corresponding to input materials represents the existing purchase order quantity, which our model treats as fixed. Planners can use our DSS to create dummy purchase orders to perform what-if analysis on the values of the r-parameters, and investigate the impact of material purchase opportunities. Note that some large suppliers in the high tech sector sometimes offer complex procurement schemes to manufacturers. Those schemes could involve non-linear discounts based on total volume or purchase quantity of a set of components aggregated across multiple periods. Even though modeling such schemes is not within the scope of our study, we note that Vestel uses our

DSS to analyze long-term procurement requirements by extending the planning horizon to at least 12 months while making annual contracts with its suppliers.

Our model contains $\bar{x}$-parameters that provide an upper bound on x-variables. Our DSS reads R&D project timings regarding new product/material introduction or phase-out as input, and uses the project timing information to calculate values of $\bar{x}$-parameters of parts/processes subject to engineering changes. In particular, if a new product is planned to be introduced at time t, our DSS sets the $\bar{x}$-parameters of the corresponding part's processes before t to zero. We also handle end-of-life planning of existing products/materials in a similar fashion.

Our DSS also allows planners to simulate what-if scenarios on R&D project timings. Thus, planners can propose target timings for R&D projects using our DSS. Another use of $\bar{x}$-parameters is in regard to material procurement capability and lead times. Since Vestel allows late changes to customer orders, it is possible that changes in customer orders affect material requirements within procurement lead time. In this case, our DSS calculates the additional procurement need since our model treats realized customer order quantities as fixed due to Constraints (3), and since the x-variables represent the time/quantity-to-buy decisions. If an x-variable for a buy material takes nonzero value within the corresponding material's lead time, expedited procurement is needed. If additional procurement is not possible within the material's lead time, then the planner can re-execute the model after setting the corresponding $\bar{x}$-parameter to zero, and create an alternative plan (if the model is feasible) or identify which particular demand items are affected by investigating the corresponding IIS (if the model is infeasible).

Note that our model does not contain any terms for setup minimization. Reasons for this are: i) Vestel's manufacturing environment is highly optimized to minimize setup in alignment with their business strategy of accepting orders of small batch sizes (recall that batch size of 66% of orders are for 500 or fewer units, where annual production quantity is over 9.5 million TV units), and ii) setup times and costs are insignificant in relation to the monthly time buckets used in planning. Finally, we note that since our model's parameters are set so that: i) manufacturing costs decrease over time (due to continuous process improvements, this assumption holds in real life), ii) while prices of input materials such as displays fluctuate in the short term, input material costs decrease over time throughout the planning horizon, and iii) backlogs are not allowed; our model plans production and procurement as late as possible to satisfy demand/forecast on time. Therefore, we do not explicitly model inventory holding costs. Our DSS contains reports that show material requirements, proposed purchasing timings/quantities and projected inventory levels in the GUI to aid planners in inventory planning.

References

R. Affonso, F. Marcotte, and B. Grabot. Sales and operations planning: the supply chain pillar. *Production Planning & Control*, 19(2):132–141, 2008.

S. Chang and J. Chung. Optimization models for production planning in LG Display. *Interfaces*, 43(6):518–529, 2013.

C-H. Chen-Ritzo, T. Ervolina, T. P. Harrison, and B. Gupta. Sales and operations planning in systems with order configuration uncertainty. *European Journal of Operational Research*, 205(3):604–614, 2010.

C. T. Conlon. A dynamic model of costs and margins in the LCD TV industry. *Unpublished manuscript, Columbia University*, 2012. URL `http://www.columbia.edu/~cc3264/conlonjmp.pdf`. Accessed 25/01/2014.

Y. Feng, S. D'Amours, and R. Beauregard. The value of sales and operations planning in oriented strand board industry with make-to-order manufacturing system: Cross functional integration under deterministic demand and spot market recourse. *International Journal of Production Economics*, 115(1):189–209, 2008.

J. Gleeson and J. Ryan. Identifying minimally infeasible subsytem of inequalities. *ORSA Journal on Computing*, 2(4):61–64, 1990.

O. Guieu and J. W. Chinneck. Analyzing infeasible mixed-integer and integer linear programs. *INFORMS Journal on Computing*, 11:63–77, 1999.

ICRON Technologies. *ICRON 3.0 Technical Documentation*, 2013.

R. Oliva and N. Watson. Cross-functional alignment in supply chain planning: A case study of sales and operations planning. *Journal of Operations Management*, 29:434–448, 2011.

Y. Pochet and L.A. Wolsey. *Production Planning by Mixed Integer Programming*. Springer Series in Operations Research and Financial Engineering. Springer, 2006.

D.H. Sheldon. *World Class Sales & Operations Planning: A Guide to Successful Implementation and Robust Execution*. J. Ross Pub., 2006. ISBN 9781932159530.

A.M.T. Thome, L.F. Scavarda, N.S. Fernandez, and A. J. Scavarda. Sales and operations planning: A research synthesis. *International Journal of Production Economics*, 138(1): 1–13, 2012.

Vestel Electronics. *Vestel Elektronik Annual Report 2013*, 2013. URL http://www.vestelinvestorrelations.com/en/_assets/pdf/AnnualReport_2013.pdf. Accessed 27/08/2014.

T.F. Wallace. *Sales & Operations Planning: The "How-to" Handbook*. T. F. Wallace, 2004. ISBN 9780967488448.