RESOURCE PLANNING ALGORITHMS FOR PERSONALIZED MANUFACTURING

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ABSTRACT

A growing trend in industry is to offer highly personalized products. Customers are constantly seeking products that are fitted to their needs with regards to physical features and service. Manufacturers wanting to enter the personalization market expect to capture higher margins, but they are also aware of the increasing competition in this market. A necessary factor of success is a manufacturer's capability to minimize resource needs while satisfying complex market offers.

In response to this strategic problem, a systematic approach is presented that estimates resource needs that will sustain a manufacturer's complex personalized offer. The methodology discussed proposes an algorithm that evaluates a network configuration by determining resource requirements. Adaptations of the algorithm permit users to find minimum and maximum resource requirements when altering delivery delays and service levels. The methodology being implemented in a software tool that can model a multilevel demand and supply network, which takes into account key factors for personalized manufacturers such as lead time, service levels, the complex product structure, and inventory.

The paper first presents the challenge of offering personalization offers and the general resource planning problem using the golf club industry. Secondly, the core of this paper presents the resource planning algorithm and how it could be adapted to improve resource needs. The paper concludes with avenues of research for improving the resource planning algorithms.

KEYWORDS

Personalized Offers, Supply and Distribution Network Design, Estimation Algorithms, Decision Support Systems, Iron Golf Club Manufacturing Industry

1 INTRODUCTION

The motivation for research in resource planning for personalized manufacturers stems from lack of planning tools on the manufacturing side and an increase in customer demand for personalized products and services. Manufacturers have been offering certain levels of customization over the past decade but not enough to fulfill customers' growing needs. Although manufacturers are quite aware of these market changes, manufacturing networks become extremely difficult to organize. Manufacturers realize that offering personalization has major implications on their value creation network since resource needs could escalate quickly when one offers short delivery delays (Christopher, 1998). Offering many personalization levels is quite complex due to the number of final products, the number of service levels and variable lead times, as well as the resource options available (Poulin, Montreuil, 2003).

The golf industry is chosen as the test bed for the methodology for important reasons. First, there is a growing demand for personalized golf clubs which is similar to many other industries that involve personalized offers. Second, the manufacturing process is simple to comprehend in comparison to other industries such as the semi-conductor industry that are faced with personalized demand. Third, the number of potential combinations of iron clubs is substantial enough to reflect the size complexity caused by personalized offers. Lastly, the authors have considerable understanding and experience in the golf club industry which is central to our methodology that relies on detailed modeling and comprehension of personalization in the golf club industry.

1.1 Defining and positioning personalization

It is important to briefly explain our definition of 'personalization' since there are many ideas on personalization and mass customization in scientific and industrial literature. Personalization is often limited to the process of personalizing customer interaction (Aaronson, 2003). Introduced by Davis (Davis, 1987), mass customization refers to levels of customization that can be offered with prices and delivery delays that closely resemble those found in mass production. This paper defines personalization as developing an offer that closely matches the evolving personalized expectations of customers in the targeted segments and by having the capability to profitably deliver the offer on a reliable basis. Our definition of personalization involves a wider spectrum of offers than standard mass customization definitions in the literature in terms of customer involvement, product variety and service levels (Montreuil, Poulin 2002). In our personalized manufacturing philosophy, in each of its targeted market segments, an enterprise has to specify its value proposition in terms of product personalization, delivery personalization and pricing personalization.

1.2 General resource planning problem

The general resource planning problem addressed is a strategic decision for resource requirements in a personalization context. This section briefly states the variables and parameters of the general problem that is addressed by our methodology.

The variables of the problem describe the offers between centers and the resources required in each center. For each center offer, the methodology determines the volume offered for a generic product, the response time and the service level. In terms of resources, the methodology determines the technology used, the quantity of resources required, and the inventory levels required within each center for each product and personalization offer.

The parameters required can be categorized in a network's structure, resource options, market offer, demand forecast, and management policies. The structure of the network consists of the centers and their relationships. For each center, basic information is required such as location and responsibilities that indicate the processes and products it can offer. The links reflect client-supplier relationships. The resource options required include one or more resource groups of machines, workers and methods that can fulfill one or more processes. These options contain the performance measurements such as process rate, rejection rate, variability factors, etc. The market offers are the network's personalization offers for each region where each offer includes one or more personalization level, with a specific response time and service rate. Each personalization level may include one or more generic product. Demand forecasts state the expected demand of each market offer with a variation factor. The forecast periods are relatively large periods such as months, quarters or years as is done in industry. Lastly, the management policies indicate the potential inventory, scheduling, and lot sizing policies to investigate by the methodology.

1.3 The iron golf club industry

Due to advances in technology and increased popularity of the sport of golf, the demand for personalized golf clubs has increased significantly over the past decade and it is continuing at an increasing rate (SRI International, 2002). This section briefly describes the golf club industry in order to better understand the resource planning methodology proposed. It describes the key actors, the manufacturing process and some key issues.

1.3.1 Key actors

The key actors in the golf club industry are golfers (final customers), suppliers of components, original equipment manufacturers (OEMs), assemblers, distributors and retailers. The demand for customized products comes from three groups of golfers: world class professionals, regular professionals and amateurs. Although the large majority of demand comes from amateurs, professionals have an impact on the product image and many world class pros participate in R&D activities for OEMs. Amateurs could be further subdivided into three groups: recreational players, friendly competitors, and serious amateur competitors. The majority of amateurs value low to medium levels of personalized products but there is an increasing demand for personalized golf clubs.

Golfers can purchase golf clubs through retailers, clubmakers, component distributors, refurbishers or other golfers. Retailers can be classified in three categories. General sports stores offer bottom line products at low prices. Although they differ in size and location, both, specialty golf stores and pro-shops offer mid to high end products. Delivery delay, price and personalization offers vary significantly within the last group. Clubmakers offer low to high end products, built to order at lower prices but with longer delivery delays. Customers can also build their own clubs by purchasing from component distributors. Refurbishers offer high end, refurbished products at reduced prices – but there are fewer choices and longer delays. Lastly, golfers can obtain low-priced used clubs from other golfers in their area, but the difficulty lies in matching a buyer and a seller. Intermediaries such as Ebay and Golfclubexchange.com have facilitated this process. Retailers are supplied from regional and national distributors, or directly from OEMs. Retailers offering mid to high end products usually buy a large quantity of products to be delivered at the beginning of the season and re-order a few times during the season. Highly personalized products are usually ordered as they are demanded and delivery time varies from 3 to 14 days, where some take several months for highly personalized clubs. Distributors usually hold inventory of popular products and components to increase service during season. Final products are assembled by clubmakers, component-supplier distributors and brand-named OEMs. Major brand name OEMs fabricate their major components and assemble the final products, but those that do outsource major components are usually supplied by the Orient.

A key issue for manufactures wanting to offer personalized golf clubs is fitting the customer. Although manufacturers are improving rapidly, there is a lack of proper fitting tools and processes to find the appropriate product for a customer. In fact, in Franke and Piller`s (2003) paper on Configuration Toolkits in Mass Customization, they stated that although manufacturers in their study indicated customer interaction and fitting is the most crucial success factor, half of them thought they fitted improperly. With golf clubs, getting properly fitted implies that golfer's needs are stable from the time of purchase until they receive their product. With golf clubs, there is an additional problem of inconsistency of golf swings on a daily basis thus making it difficult to have appropriate fitting and hence, order the properly parametered golf club. Besides economic reasons, this is a key reason why demand for highly personalized golf clubs is not as popular with amateurs as with competitive amateurs or professionals. Some manufacturers have developed solutions to address this problem such as online questionnaires, software and fitting equipment, yet there is much to be done. Hence, resolving the fitting complexity should be at the forefront of golf manufacturers aiming to offer high levels of personalization.

Delivering personalized golf clubs within the quoted delivery time on a reliable basis is also critical to remain competitive. Many leading OEMs are experiencing back orders due to inadequate resource planning or lack of capacity. Standard relationships with suppliers from the orient currently make it difficult to order components in small quantities frequently. Furthermore, manufacturers have difficulties forecasting demand that lead to not having the right products during periods of high demand, or it causes them to have high inventory levels to protect against back orders.

High levels of product variety and quick introduction of new technology impedes the resource planning process. The number of options per product parameter creates an enormous number of final product combinations. Companies have difficulties forecasting which will be in demand, especially for higher levels of personalization. Secondly, the speed at which new products are introduced leaves little room for error. Leading OEMs such as Tileist and TaylorMade introduce two product versions per year which imposes a short market window to capture early and valuable sales. This results in price drop-offs of 30% - 50% in the same year when the new versions are introduced.

1.3.2 Manufacturing process of golf clubs

Their exists four types of golf clubs: ‘woods’, ‘irons’, ‘wedges’ and ‘putters’. A typical set of golf clubs, which is limited to fourteen clubs by the rules of golf, consists of three woods, eight irons, two wedges and one putter. Manufacturers sell each club individually or in sets. In fact, it is now common for golfers to buy these four types of clubs separately. That is, a player often has clubs from four different manufacturers in his set of fourteen clubs and is fitted separately for each.

To illustrate the personalization challenge in the golf club industry, it is sufficient to focus on the iron golf club industry. Figure 1 depicts both the general fabrication process and the main components of a golf iron. As every other type of golf club, it is constructed by assembling three principal components: a club head, a shaft and a grip. The main processes involved in fabricating and distributing a golf iron club are: club head design, production of components, component assembly, packing and distribution to retailers.
In past offers, leading OEMs have traditionally offered a limited number of products off-the-shelf supported by make-to-stock supply chain strategies. Most OEMs also offered some options on the major components such as custom shafts or grips but this would be considered a special order that involved considerable delays and extra costs which was not accepted favorably by consumers desiring personalized products.

Recently, leading OEMs are offering much more variety and the customer involvement occurs earlier in the manufacturing process. In contrast to previous special orders where customers selected components to be assembled, some customer choices can no affect processes prior to the assembly process. In addition to offering more product variety some are also personalizing their service offer by varying delivery delays and service rates. In contrast to research done by Piller (Rautenstrauch, 2002) that indicates that customers are only willing to pay 10% - 15% more for mass-customized products and that they are not willing to accept longer delays, this is not the case in the golf club industry. Note that this client service sensibility is a key difference between mass customization and our view of personalization where offers could imply large price ranges and delivery delays. For instance, many golfers will pay 30%-75% more for personalized products and wait several weeks from OEMs such as Titleist and Taylor Made, rather than buy popular products off-the-shelf.

In order to support the change in their personalization offers, many have incorporating different management policies and strategies such as: make-to-order policies, late differentiation and modularization strategies, quick response and lean manufacturing strategies. Nevertheless, many OEMs are struggling with the transition and have difficulties promising there quoted delivery delays while limiting total costs.

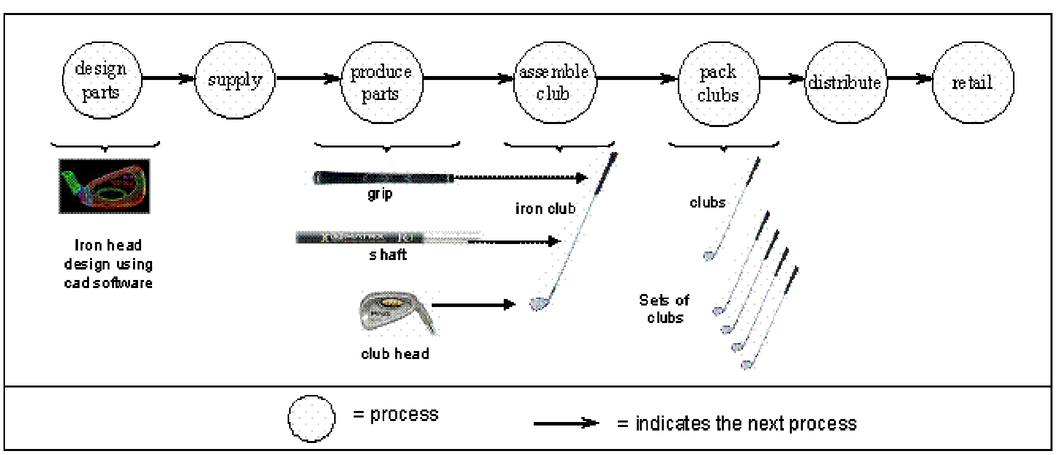

Figure 1: Demand and supply processes for golf irons

2. NETWORK RESOURCE PLANNING ALGORITHM

In order to address the general resource planning problem discusses previously, this section presents an algorithm that plans resource requirements for a network configuration offering personalized offers. The algorithm is composed of three main parts. The first part translates a firm's aggregate market forecasts into detailed demand scenarios. The second part determines resource requirements by simulating production schedules, and the third part synthesizes resource configurations. Next, by making minor adaptations to the input data, it is shown how the general algorithm can be used to improve resource requirements by bounding its lower and upper limits. Lastly, the possibility of integrating the algorithm into a metaheuristic is discussed.

2.1 Algorithm Key Input

To apply the resource planning algorithm, the firm needs to provide the following key input: its value creation network, personalization offers for each center comprised of products offered within a specific delivery delay and service level, center responsibilities, and market forecasts. Furthermore, the firm must provide classic resource planning information such as its product network, resource characteristic, and processes.

Value Creation Network

The first key input a firm needs to provide is a description of its value creation network, which is composed of centers and the client-supplier relationships (links) between each center. Figure 2 reveals an example of a firm's value creation network. There are five types of centers where each have fundamentally different responsibilities. However, some centers of the same type may have different personalized offers with regards to products, response times, or service rates. A stage refers to a group of centers of the same type (retailers, fulfillers, assemblers, producers, suppliers) where the first stage begins with retailers.

Depending on the level of resource planning required, a firm will also provide internal networks within each center. Figure 3 shows an example of three network levels for the head producer HP1 center. The upper level is referred to as level 1, whereas the third level is the cellular level. In this example, a key resource of the Head Producer center is the Filled Mold Producer.

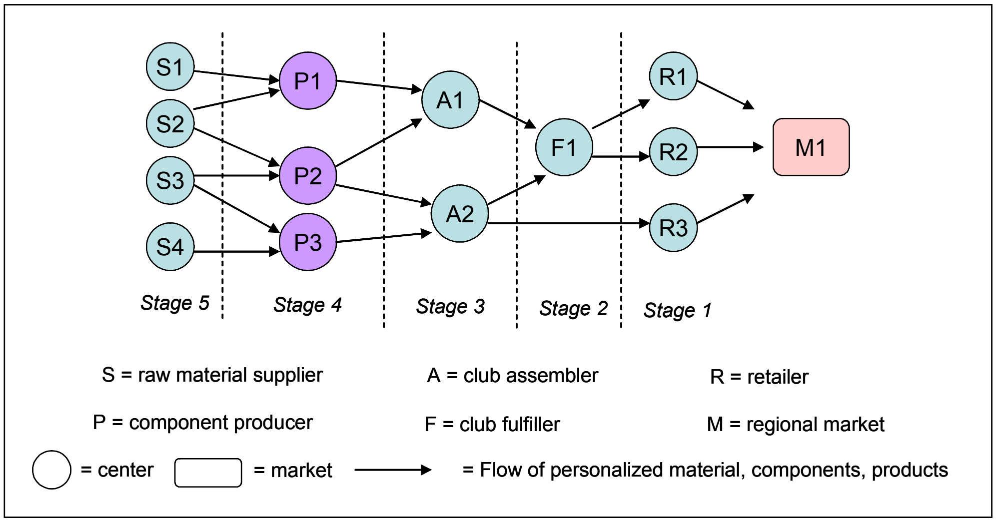

Figure 2: Example of value creation network

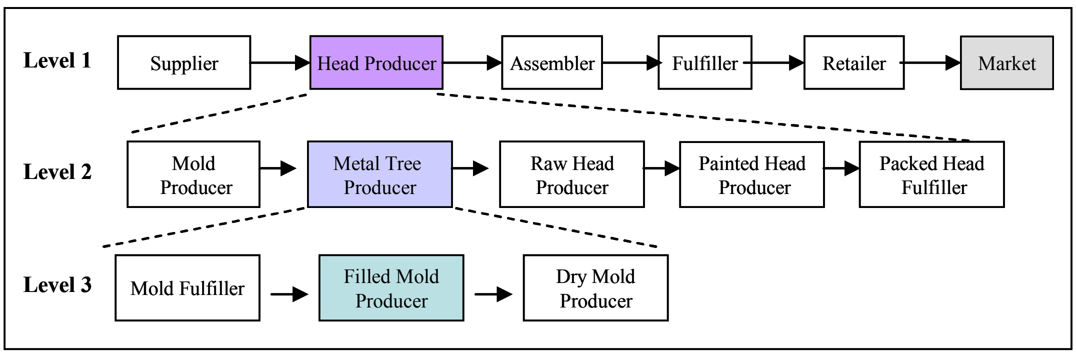

Figure 3: Example of center levels in the demand and supply network

Response Time input

Key to resource planning for personalized offers is the response times between centers. To execute the planning algorithm, the firm needs to predetermine the response times (synonymous to delivery delays in this paper) between each center for every personalization level. Figure 4 shows an example of response times for the Parametering offer for the Head Producer center HP1. The top portion of the figure shows the client-supplier links where the HP1 center is filled in purple. In this offer, the regional market response time offered by the firm is 5 days and products are made-to-order from center HP1. As input, the firm indicates that the internal response times are 2, 1, 2, and 0 days respectively for centers HP1, A2, F1, and R7, and the client response times are 2, 3, 5, and 5 days respectively.

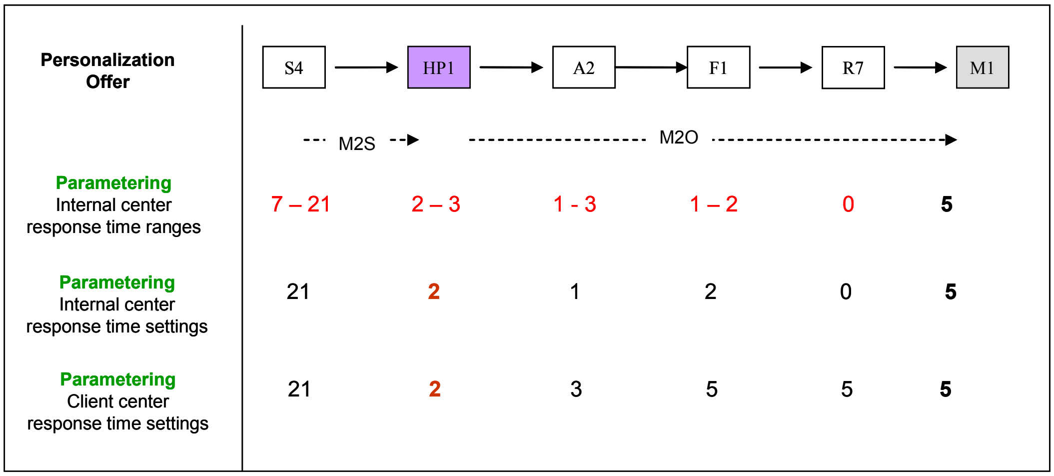

Figure 4: Example for determining minimum internal center response time of HP1

Personalization Offers

Figure 5 reveals an example of a firm's partial personalization offer that must be given as input. The top table in the figure indicates the expected demand as a percentage for each generic product in a personalization level. It also indicates the delivery delay and service level it wants to offer the market. Furthermore, for each generic product offer, it indicates the parameter options that are offered. For some personalization levels, the parameter options offered are described by a function since there are too many possibilities to list distinctively. For instance, the function for types of material in the Tailoring offer could include three variables that are set by the user within a certain range, which provides the exact material to make the club head. Since listing the endless possibilities, a function is used.

Canadian Market Offer

	Product Offer						
Percent Demand	Personalizatin Level	Iron Club	Head Offer	Grip Offer	Shaft	Delay days	Service
40%	Popularizing	IronClubOffer2	HeadOffer3	GripOffer5	ShaftOffer1	0	90%
25%	Varietizing	IronClubOffer6	HeadOffer7	GripOffer11	ShaftOffer7	2	95%
20%	Accessorizing	IronClubOffer8	HeadOffer9	GripOffer19	ShaftOffer15	3	95%
10%	Parametering	IronClubOffer12	HeadOffer15	GripOffer22	ShaftOffer24	5	90%
5%	Tailoring	IronClubOffer19	HeadOffer26	GripOffer24	ShaftOffer39	14	90%

Personalization Level	Club head offers	Club Head Models	Types of Material	Number of available sides	Number of lie angle options	Number of Weight Distibution	Sole Grinds per Model
Popularizing	HeadOffer3	2	1	1	1	1	1
Varietizing	HeadOffer7	2	1	2	3	1	1
Accessorizing	HeadOffer9	2	2	2	5	2	2
Parametering	HeadOffer15	2	4	2	function	6	4
Tailoring	HeadOffer26	3	function	2	function	function	function

Figure 5: Example of Canadian market offer

Market Forecasts

Market forecast provide the basic input to generate demand scenarios. For each market, the forecast provides an average quarterly demand and standard deviation with a certain probability distribution. In the methodology presented, these forecasts are referred to as aggregate forecast. Figure 6 provides an example of a Canadian market forecast which also includes percent market shares for each personalization level offered.

Canadian market forecasts Demand per quarter per personalization offer

		annual	annual	annual	Qrt 1	Qrt 1	Qrt 1	Qrt 2	Qrt 2	Qrt 2	Qrt 3	Qrt 3	Qrt 3	Qrt 4	Qrt 4	Qrt 4
	% Dmd	Qt	Avg/dy	Std dev	Qt	Avg/dy	Std dev	Qt	Avg/dy	Std dev	Qt	Avg/dy	Std dev	Qt	Avg/dy	Std dev
Popularizing	**45%**	**37 125**	155	6%	11 250	125	5%	16 875	188	5%	6 750	75	5%	2 250	25	10%
Varietizing	**22%**	**18 150**	76	10%	5 500	61	10%	8 250	92	5%	3 300	37	10%	1 100	12	15%
Accessorizing	**20%**	**16 500**	69	14%	5 000	56	15%	7 500	83	10%	3 000	33	10%	1 000	11	20%
Parametering	**10%**	**8 250**	34	20%	2 500	28	20%	3 750	42	15%	1 500	17	20%	500	6	25%
Tailoring	**3%**	**2 475**	10	40%	750	8	40%	1 125	13	30%	450	5	40%	150	2	50%
total	**100%**	**82 500**	344	18%	25 000	417	18%	37 500	625	13%	15 000	250	17%	5 000	83	24%

Figure 6: Canadian market forecast

2.2 Algorithm Pseudo-Code

The Pseudo-code below describes the essence of the resource planning algorithm. Although it attempts to show a relatively high level of detail it obviously does not contain all the verification variables and iteration counters to precisely conduct and exit functions. The words in bold represent the coded language and words in italics are functions in our algorithm.

BEGIN
  Generate Demand Scenarios
  Simulate Center Production Schedules
    For each network Stage, (beginning with the Stage closest to the market, which are Retailers)
      For each Center
        Initialize Resources
          Calculate Average Demand
          Calculate Resource Requirements

        Schedule Demand Orders

          While Resource Level **Is** Sufficient **And** Periods **Exist**
            While Periods **Exist And** Service Level of All DemScenarios **Is Satisfied**
              While DemScenarios **Exist And** Service Level of All DemScenarios **Is Satisfied**
                Schedule Orders
                  While Orders **Exist And** Service Level of DemScenario **Is Satisfied**
                    Identify Order
                    Make Tentative Production Schedule
                      Begin *Update Production Schedule*
                        If *Tentative Production Schedule* **Is** non-feasible **Then**
                          Update Service Level of DemScenario

Update Service Level of All DemScenarios
Else
Confirm Tentative Schedule
EndIf
End *Update Production Schedule*
Increment Orders Counter
DoWhile Orders
Increment DemScenario Counter
DoWhile DemScenarios
Period = Period + 1
DoWhile Periods
If Resource Level **Is** Non-Sufficient **Then**
Increase Resource Level
EndIf
DoWhile Resource Level
Next Center
Transfer Demand Peaks
Next Network Stage
Analyze Resource Configurations
END

2.3 General Resource Planning Algorithm

This section explains the logic behind the pseudo-code of the previous section. It explains each function and illustrates them through the golf club industry. The Demand Scenario generating function is first clarified followed by the simulation of production schedules. The section ends with a synthesis and analysis of the results.

2.3.1 Generate Demand Scenarios

This function translates market forecasts supplied by a firm into detailed demand scenarios that serve as key input to run the algorithm. In most industries firms generate monthly or quarterly forecasts while delivery delays are usually measured in smaller periods such as weeks, days or hours. In the case of the iron golf club industry, quarterly forecast are used and delivery delays are measured in days.

As shown in Figure 7, the function begins with the Aggregate Regional Forecast supplied by the firm. For each period, personalization level and generic product, the forecast provides a quarterly mean value with a variation measure, for a specific probability distribution (ex. Normal). Figure 8 is used to illustrate all the steps involved in generating demand scenarios.

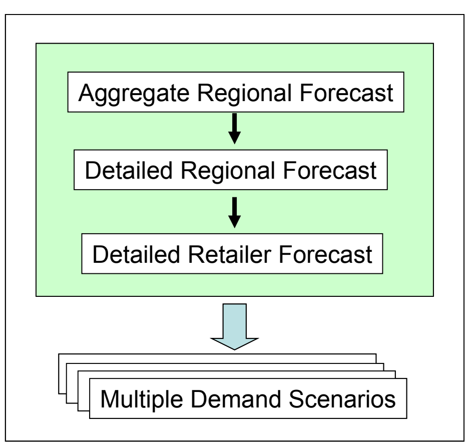

Figure 7: Translating Aggregate Regional Forecasts to Multiple Demand Scenarios

Create Detailed Regional Forecast

Detailed Regional Forecasts are created from an Aggregate Regional forecast. This involves translating the aggregate forecast to a detailed forecast as indicated in Figure 7. Precisely, each period forecast for a product is disaggregated into forecasts for a number of smaller periods. The number of periods is equal to the number of response time units that fit into the aggregate demand period. For instance, if demand forecasts are in months and center response times are measured in days, then monthly forecast quantities are disaggregated into daily forecasts for the number working days that are in a month. Depending on the information supplied by the firm concerning the characteristics of demand, the monthly market forecasts may or may not be equally disaggregated amongst each day. For instance, consider the case where there are 20 working days in a month and the aggregate forecast for one month has a mean of 100 units. If no other information is given by the firm concerning demand patterns, then the algorithm could disaggregate the monthly mean demand to daily mean demands of 5 units. Alternately, the firm could indicate that half of the customer orders in a week are made between Friday and Saturday while the remaining orders are made equally between Sunday and Thursday. For the latter situation, the algorithm would assign a mean demand of 25 units on both Fridays and Saturdays, and 10 units on all days between Sunday and Thurday inclusively.

Figure 8 shows an example of how the Aggregate Regional Market for Montreal which is a segment of the Aggregate Canadian Market Forecasts, translates quarterly forecasts to daily forecasts. Due to space constraints, Figure 8 only shows four days of forecasts that reflect the essence of the desegregation process.

Create Detailed Retailer Forecasts

Creating detailed retailer forecasts consists of assigning a portion of each daily regional forecast to the retailer. The proportion of demand or the market share of a retailer in a specific region is provided by the firm. Figure 8 shows an example of a Detailed Retailer Forecast is the Montreal Region. Like the previous forecast, it has a mean demand value and variation value. Note that in this example, the Retailer does not support Tailored offers since it is not in his responsibilities.

Create Multiple Demand Scenarios

Lastly, the Detailed Retailer Forecasts are used to generate the demand scenarios that will be used as input in our algorithm. This Monte Carlo based function randomly generates a demand order for each generic product, personalization level, and demand period in the Detailed Forecast. This is done by using the probability distribution, mean and variance of the retailer forecasts. Figure 8 illustrates this step through the three demand scenarios in blue.

Aggregate Canadian Market Forecasts

	Qrt 1	Qrt 1	Qrt 2	Qrt 2	Qrt 3	Qrt 3	Qrt 4	Qrt 4
	Qt	Std dev	Qt	Std dev	Qt	Std dev	Qt	Std dev
Popularizing	16 000	5%	12 000	5%	7 000	5%	14 500	10%
Varietizing	8 600	10%	8 000	5%	3 300	10%	9 000	15%
Accessorizing	3 200	15%	7 500	10%	3 000	10%	4 000	20%
Parametering	2 500	20%	4 000	15%	1 500	20%	2 000	25%
Tailoring	200	40%	500	30%	500	40%	350	50%

Aggregate Regional Market Forecast for Montreal

	Qrt 1	Qrt 1	Qrt 2	Qrt 2	Qrt 3	Qrt 3	Qrt 4	Qrt 4
	Qt	Std dev	Qt	Std dev	Qt	Std dev	Qt	Std dev
Popularizing	3200	5%	2400	5%	1400	5%	2900	10%
Varietizing	1720	10%	1600	5%	660	10%	1800	15%
Accessorizing	640	15%	1500	10%	600	10%	800	20%
Parametering	500	20%	800	15%	300	20%	400	25%
Tailoring	40	40%	100	30%	100	40%	70	50%

Detailed Regional Market Forecast for Montreal

	Day 1	Day 1	Day 2	Day 2	Day 3	Day 3	Day 4	Day 4
	Qt	Std dev	Qt	Std dev	Qt	Std dev	Qt	Std dev
Popularizing	40	5%	30	5%	18	5%	36	10%
Varietizing	22	10%	20	5%	8	10%	23	15%
Accessorizing	8	15%	19	10%	8	10%	10	20%
Parametering	6	20%	10	15%	4	20%	5	25%
Tailoring	1	40%	1	30%	1	40%	1	50%

Detailed Retailer Forecast in Montreal Region

	Day 1	Day 1	Day 2	Day 2	Day 3	Day 3	Day 4	Day 4
	Qt	Std dev	Qt	Std dev	Qt	Std dev	Qt	Std dev
Popularizing	13	5%	10	5%	6	5%	12	10%
Varietizing	11	10%	10	5%	4	10%	11	15%
Accessorizing	6	15%	14	10%	6	10%	8	20%
Parametering	6	20%	10	15%	4	20%	5	25%
Tailoring	0	0	0	0	0	0	0	0

Demand Scenario for Retailer in Montreal

Demand Scenario for Retailer in Montreal

Demand Scenario for Retailer in Montreal

	Day 1	Day 2	Day 3	Day 4
	Qt	Qt	Qt	Qt
Popularizing	17	12	6	12
Varietizing	14	8	4	8
Accessorizing	4	11	5	3
Parametering	4	7	1	7
Tailoring	0	0	0	0

Figure 8: Example of stages involved in translating market forecasts to demand scenarios

2.3.2 Simulate Center Production Schedules

This function evaluates the resource level of a center by simulating production schedules over the horizon of the demand scenarios. If the initial level of resources can satisfy daily demand for a number of days corresponding to its service level, then the resource level is sufficient and a feasible solution is obtained. Contrarily, if the level of resources can not satisfy enough daily demand to respect the service level offered, then the level of resources is not sufficient and the function raises the resource level and restarts the simulation process.

Initialize Resources

The function begins by evaluating a center in the first stage, which corresponds to a Retailer in our example. It first initializes the resource level which involves setting the minimum quantity of resources using a classic resource planning such as Equation (1) found in many productions management books such as Factory Physics (Hopp, 1996). Precisely, the equation determines the quantity Q_{rt} of resource r required in period t to satisfy a center's service processing time requirement. Demand is measured in processing time P_{rt} rather than product volume. Each resource r has an availability of A_{rt} per time period t, with S_{rt} of setup time for resource r per period t. The available time minus the setup time is affected by the efficiency rate E_{rt} and the reliability rate R_{rt} for each resource.

$$Q_{rt} = \frac{P_{rt}}{(A_{rt} - S_{rt}) * E_{rt} * R_{rt}} \quad (1)$$

Schedule Demand Orders

Once initialized, the algorithm simulates all demand scenarios in parallel day after day. For each day and for each demand scenario, the algorithm attempts to schedule each order into a tentative production schedule. Scheduling demand involves a simple scheduling algorithm that schedules a group of orders that are know but not yet produced. The function uses the client ordering and due date, supplier delays, management policy (Make-to-order or Make-to-Stock) to schedule products. The schedules produced provide supplier order date, production dates, delivery dates and resource utilization.

If it can make a feasible production schedule after having planned all orders then the resource level was sufficient and the algorithm moves to the next day. In the case where the center did not have enough capacity to schedule all orders, the algorithm notes this as a day of demand where demand was not satisfied and saves the number of orders not satisfied. This process is continued for each day until all days are treated or until the center had insufficient capacity for too many orders. The number of orders a center is permitted to not satisfy all demand is determined by the service level set by the firm. For instance, if there are 50 days in the demand scenario containing 5000 orders and a center has a service level of 95%, then it is permitted to have insufficient capacity for 5 % of those orders. Furthermore, if there are too many demand scenarios that are not satisfied by the resource level of the center, then the resource level is insufficient and if creates an infeasible solution. Once the resource level is considered insufficient, the algorithm increases the quantity of resources in that center and restarts the simulation process for all demand scenarios. These simulation iterations continue until a sufficient resource level for the center is found. Once the first center is done, the algorithm continues with all other centers in the same stage.

Transfer Demand Peaks

After the resource level of each center in a stage is validated, the algorithm verifies the resource levels for each center in the stage to see if there are any unusual capacity or resource utilization peaks. When a peak is found, the algorithm transfers demand to alternate centers that can produce the same products. The idea is to smooth out as many demand peaks as possible in order to reduce total resource costs. The firm pre-determines which centers can transfer demand and on which terms.

This transferring process begins by analyzing a center’s daily process requirements in order to identify the daily demand peaks to transfer. Although the process verifies the processing time to identify demand peaks, it will transfer actual product demand to alternate centers rather than processing time. This step conducts many network iterations until the centers’ processing times are stable. The transferring process begins with Retailers in the first stages and then proceeds with the other stages working its way to suppliers. It is important that several network iterations are done since transferring demand from one center to another might create other demand peaks that must also be transferred. After several iterations, demand peaks will be smoothed out at their maximum.

2.3.4 Synthesis and analysis of resource configurations

Once the algorithm has determined resource requirements for all centers in every stage, it creates several reports to synthesize key performance measurements such as: daily resource needs, ranges of resource needs, resource utilization, stock levels, products made, non-satisfied demand, etc.. A few reports are shown in this section. These synthesized reports are quite helpful in analyzing resource needs and where there are the most at stake.

Figure 9 shows an example of a of resource utilization over 10 periods for three demand scenarios. Suppose the service rate of the center was 95% and the center only had 10 production days to plan, then resource level has to be at about level 12 so that at least 95% of orders are satisfied.

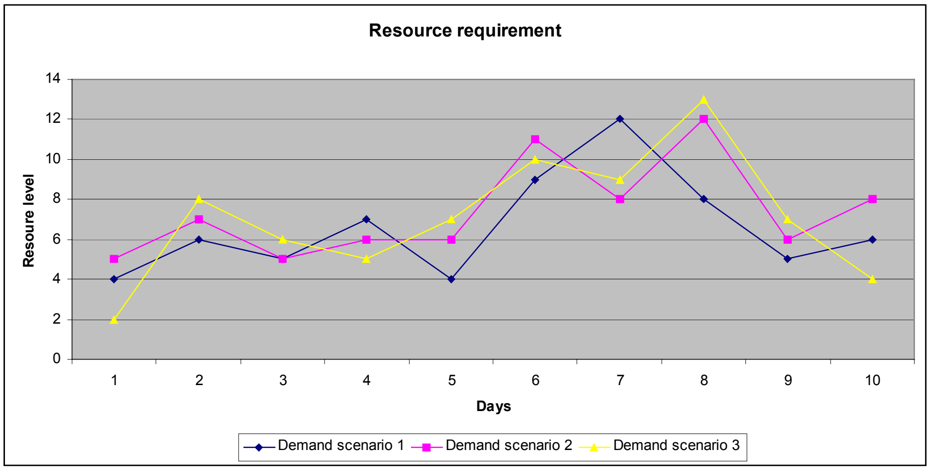

Figure 9: Resource requirements for demand scenarios

Figure 10 shows the ranges of resource requirements on a daily basis. This clearly points out which centers are most affected by varying response times, service rates and variation from daily demand.

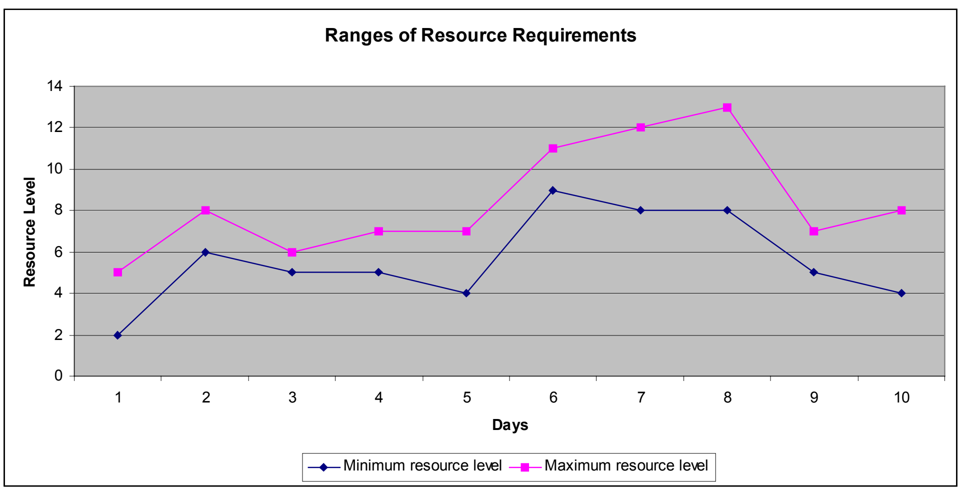

Figure 9: Ranges of resource requirements

The last example of a synthesis report are the space requirements resulting from inventory levels required in each period. Similar to resource requirements, space requirements also have an impact from service levels offered to clients since space requirements correspond to inventory levels which are direct result from the production schedule.

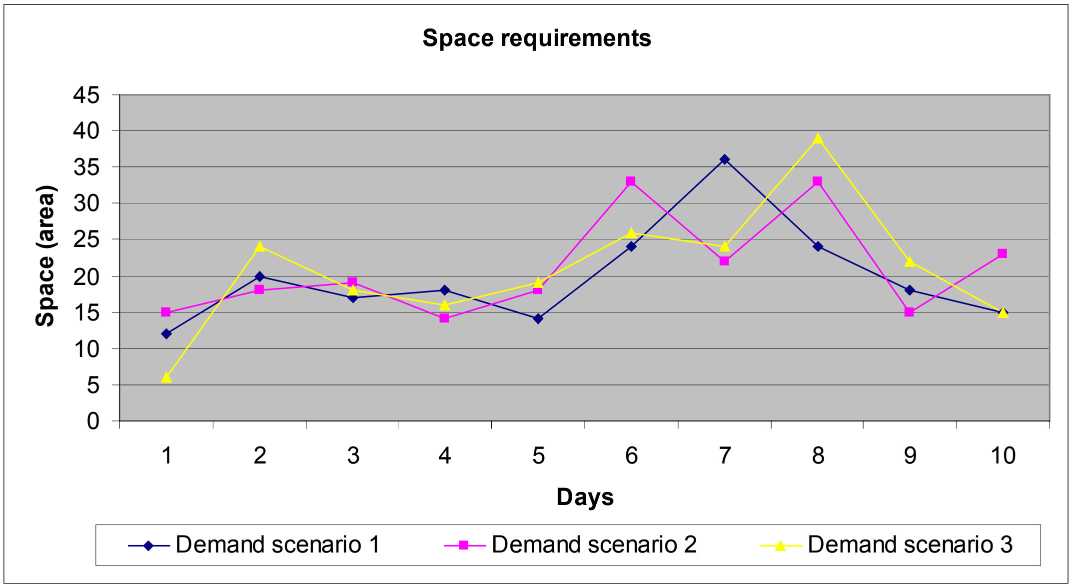

Figure10: Space requirements for inventory

2.4 Adaptations of the Resource Planning Algorithm

The resource planning can be used on its own to assess resource needs in each center but it can serve as a key component for more detailed resource planning algorithms. The first adaptation made is to vary key parameters hence permitting the algorithm to determine lower and upper bounds on resource needs for a firm's personalization offer. Secondly, the algorithm can be used as an evaluator within a resource planning metaheuristic that addresses the more general problem in a design perspective rather than in a configuration approach for a given network.

Bounding Resource Requirements

The algorithm can be adapted to identify minimum and maximum resource requirements. Since response times and service levels are crucial in personalized offers, the algorithm could be used to plan resources for a center when response times and delivery delays are in their worst and best case scenario.

For the best case scenario, the algorithm conducts resource planning by increasing the internal response time of the center and reducing its service level. Note that the overall delivery delay of the firm to the client remains the same but the distribution of delivery delays within the value creation network is varaiable. The assumption made is that having a greater response time permits a center to smooth demand production which translates into fewer resource needs. Similarly, when service levels are lower, the center does not have to satisfy as many demand peaks and again, requires less resources. To obtain the resource bounds, the user simply has to apply the same algorithm but varies the internal response times and service levels depending if the lower or upper bound is sought.

Integrating the Resource Planning Algorithm in a Network Design Metaheuristic

The resource planning algorithm presented in this paper can play an important role in solving the general resource planning problem in the design perspective where response times and service rates are variables.

Specifically, it can be used iteratively to evaluate resource configurations where key variables are set by a metaheuritic.

The algorithm presented in this paper adjusted the resource level for each center until they could be sufficient to satisfy demand scenarios but where the response times and service rates between centers were parameters set by the firm. However, most firms seek methods that can find the optimal response times and service rates in order to satisfy its service offer for each market offer. Developing the present algorithm is a first step in this direction since it could be integrated to serve a resource configuration evaluator.

3. CONCLUSION

The growing need for personalized offers such as in the golf club industry have forced manufacturers to adapt their personalized offers in terms of product, service and price personalization. To fulfill this need, manufacturers are adjusting their demand and supply network and consequently their resource requirements. A considerable challenge for OEMs is the process of designing and evaluating value creation networks that support a personalized offer. There is a need for models that will represent the personalization context realistically, but that can be used to provide solutions in a timely manner.

The research presented addresses these challenges faced by personalized manufacturers. Prior to the current algorithm, data and object models were developed to capture important elements of personalized offers that which were lacking in scientific literature. The resource planning algorithms presented in this paper represents initial steps towards developing solutions for upper management addressing personalized manufacturing. The algorithm's main objective is to give an initial sizing on the resource needs in each center. The most important contribution is that it evaluates resource configurations with detailed, stochastic demand scenarios that include individual products, personalization levels, and delivery delays and service. Only by modeling demand precisely can a firm see how demand peaks are proliferated through its value creation network, and what is the real impact on capacity requirements.

The algorithm could also be adapted to determine limits on resource needs when internal response times and service levels are changed. These bounds reduce the solution space for future optimization techniques that will demand more resolution time. Furthermore, the first sizing and the bounds permits a firm to point out where there is the most at stake in terms of resource costs when considering a personalization offer. The resolution process and general view of the network will also permit a firm to rely on their experience and intuition to set values for key variables before executing further algorithms that will seek good solutions for the network.

The algorithms presented are the initial steps towards resource planning methodologies for personalized manufacturers. Current research focuses on a metaheuristic that will be developed to build on the resource planning algorithm presented. Following the metaheuristic, there will be a need to incorporate a multi-agent simulation tool that could provide more accurate performance measurements. We feel this research will aid upper management determine resource requirements for a proposed personalized offer as is reflected by the local managers in the golf club manufacturing industry.

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