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Convenience food manufacture generates considerable waste due to the planning of production being undertaken based upon forecasted orders. This problem is particularly acute for products that have a very short shelf-life and are subject to considerable volatility in demand, such as ready-meals. Overproduction wastes (OPWs) typically result in finished products being disposed of through commercial waste channels, which is both costly for manufacturers and represents poor and unsustainable use of resources. This paper reports on a hybrid two-stage planning technique for the reduction of OPW by utilizing the advantages offered through both static and dynamic approaches to production scheduling. The application of this planning approach to a case study ready-meal manufacturer through the development of commercially available planning software is also described.

Keywords: Production planning; Food manufacture; Waste minimization; Sustainable manufacture

1. Introduction

Demand for food products varies across the industry, with some foods having fairly steady, easily predictable demand patterns, meaning that consumer demand for the product can be met accurately, without wasteful overproduction or disappointing consumers by not meeting their needs. Other products, for example prepared sandwiches and ready-meals, display a highly volatile demand for which there may be considerable wastage when demand is over-predicted or consumer dissatisfaction when stock-outs occur. The manufacture of many food products cannot be completed under a make-to-stock regime as the short shelf-lives of the ingredients mean that products will spoil if held for long periods before supply to retailers. Current demand management efforts used by retailers for these products are merely an attempt to compensate for the external driving conditions (e.g. weather conditions, holiday seasons, sporting events) that contribute to the unpredictable consumer demand for such products. Manufacturers producing convenience foods for retailers' 'own-labels' however are required to meet short order lead-times, even

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though production lead-times exceed order lead-times by several days. This overlap has previously been identified as a $P:D$ ratio where P is production lead-time and D is the order lead-time, with courses of action being based around improving forecasts and contingencies to correct shortcomings of forecasts (Shingo 1995, Mather 1999). Production of convenience foods begins based upon forecasts in order to meet demands from retailers who have increasing power over their suppliers (Hingley 2005). Previous industrial approaches depended on overestimating demand to provide the flexibility to meet orders, resulting in large volumes of waste, as was indeed found in the initial stages of this research. The increasing importance of sustainable manufacture and the unacceptability of excessive waste mean that pressure is growing on manufacturers from governments and consumers to reduce the burden of wastes they create (DETR 2000, DEFRA 2005).

In this paper a two-stage planning (TSP) approach has been adopted to plan the production of short shelf-life products. This TSP approach is part of a responsive demand management (RDM) framework that aims to support the manufacture of products with short order reaction times without the creation of environmentally unacceptable wastes. The initial sections of the paper provide an overview of relevant research in production planning and scheduling for the food industry, together with a brief description of the RDM framework. TSP of production is then described in greater detail before the paper concludes by outlining the realization of TSP for an industrial case study.

2. Production planning in the food industry

Production planning and scheduling of ready-meal manufacture has been identified as a complex industrial example (Shaw and Fleming 2000) where forecast volatility, drastic production changes and customer demands for flexibility require greater support than offered by standard scheduling rules more common in manufacturing (Sabuncuoglu 1998). Production schedules must meet the constraints of the food industry when sequencing production, for example the particular order certain flavours must be processed as described by Nakhla (1995) and which products have processing precedence due to allergens (for nut-free products for example). Hygiene is of paramount importance and in addition to frequent cleaning activities at changeovers, intensive ‘clean-downs’ of the processing equipment must be scheduled into production at regular (daily) intervals; over the course of the reported research, these were found to take on average one hour per assembly line. The ‘rules of thumb’ and constraints that must be imposed by the production planner are also poorly defined and rarely recorded, and it is often the case that it is only the planner or scheduler that knows when and where to apply these rules (Van Donk and Van Dam 1998). This places great responsibility upon the production planner. A formalized system of identifying these constraints will clearly be of benefit in times of staff illness or turnover, and will aid dissemination of vital production knowledge across the enterprise. Scheduling software has significantly aided the process of schedule generation, both speeding up the process and allowing optimization of the schedules produced to improve production planning. However, Kuo and Hwang (1999) propose the balancing of tasks to remove boring and time-consuming tasks to allow human schedulers ‘thinking space’ as human–computer interactions often require the combination of both to approach complex situations such as those found in convenience food manufacture. Further scheduling complications are evident based on the highly dynamic nature of the food industry (Gargouri *et al*. 2002). Examples of these include when shipments of ingredients from suppliers arrive relative to when orders are placed and how this influences the way a schedule is created. In most cases, fresh-food manufacturers simply back schedule a batch of product from its due date before applying scheduling rules to ensure that the product is processed as late as possible and hence leaves the factory with as great a shelf-life as possible. Scheduling rules that may be used within production may be classified as either static or dynamic rules. Examples of static rules include 'earliest due date' and 'minimum number of operations', which have performance indices that are independent of time and are therefore commonly applied prior to production, resulting in a fixed schedule for that production period (Gupta *et al*. 1989, Vollman *et al*. 2005). Static scheduling rules are often used in a 'predictive production planning and control structure', using off-line planning and control techniques. The utilization of such static rules enables the sequencing, routing and allocation of jobs to be carried out based on an optimization process to satisfy a number of particular manufacturing goals (e.g. minimization of machine set-up times and the number of required tool changeover activities). Dynamic scheduling rules such as 'slack time remaining' or the 'machine with the shortest queue' are time-dependent and must be used in conjunction with real-time data (Vollman *et al*. 2005). As a result, the terms 'real time' or 'on-line' are usually used to refer to planning and control systems with capabilities of incorporating such dynamic rules within a 'reactive production planning and control structure'. Dynamic scheduling postpones loading decisions, thereby preserving routing options for as long as possible in order use the system's flexibility opportunistically.

3. The responsive demand management framework

Production lead-times that exceed order lead-times present a substantial challenge to planning as production cannot be completed through a make-to-order approach as identified by Mather (1999). Short shelf-life products present an extreme case of this challenge as overestimating demand to ensure orders are met results in overproduction and poor utilization of resources, thus creating significant wastes in manufacturing activities. The research reported here began by surveying manufacturing practices in a variety of food sectors with fresh, chilled ready-meals and prepared convenience foods (such as sandwiches) being identified as product sectors where an overproduction regime was most prevalent. The RDM framework proposed to reduce OPWs created by these conflicting demands has been described in greater detail in an earlier paper (Darlington and Rahimifard 2004). In order to effectively reduce the amounts of waste created and to promote greater manufacturing sustainability, the RDM framework was based on three main approaches:

1. reduce manufacturing lead-time through improved production processes and technology;

2. increase order reaction time through effective management of supply chain activities;
3. utilization of an intelligent reactive production planning approach.

The first stage of the RDM framework takes the form of a health-check for review documentation and analysis of the manufacturing activities and supply chain processes before separate consideration of the three approaches described. The overall structure of the RDM framework is shown in figure 1.

Lead-time reductions were the focus of production process improvement, which considered a broad range of improvement tools including process activity mapping (Hines and Rich 1997), value stream mapping (Tapping *et al*. 2002), single minute exchange of dies (Shingo 1995) and other techniques derived from lean manufacture. The improvement of order reaction times was based on supply chain management techniques and approaches developed from quick response initiatives

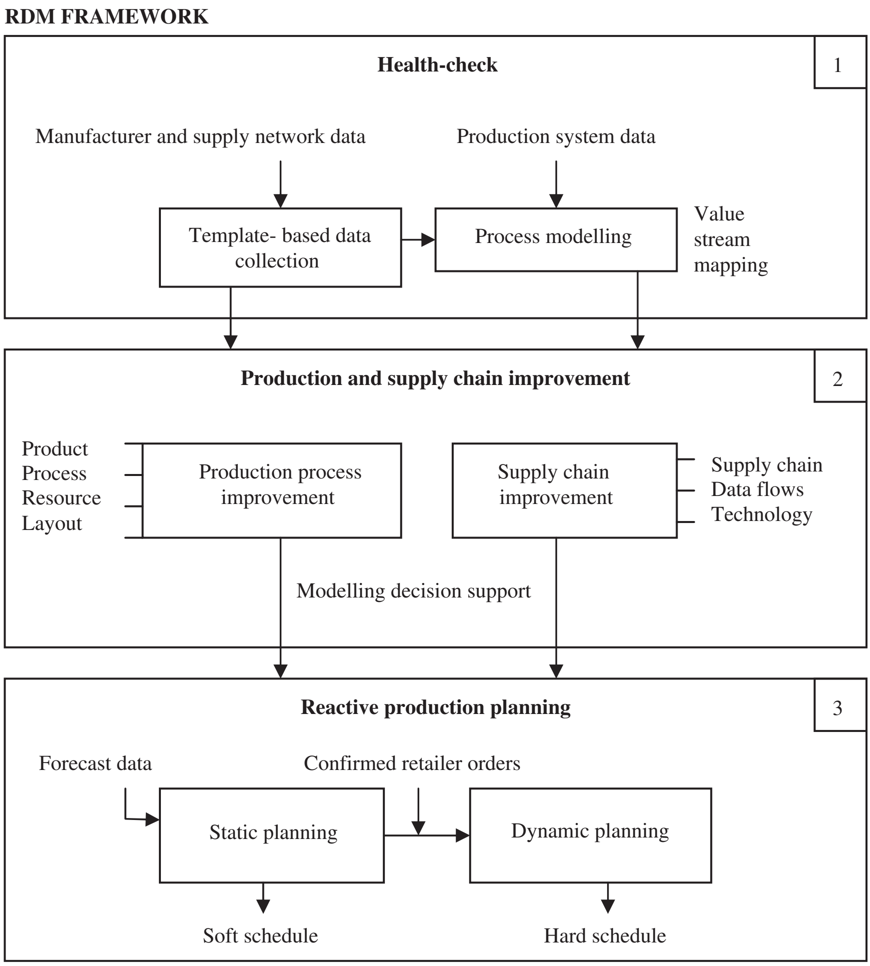


Figure 1. Outline structure of responsive demand management (RDM) framework.

(Lowson *et al*. 1999) and efficient consumer response (Barratt and Oliveira 2001) such as collaborative planning forecasting and replenishment (VICS 2004). The improvement activities associated with order reaction times focused mainly on the streamlining of demand information through the supply chain in the most effective manner (Darlington and Rahimifard 2006).

In the cases where reduction of manufacturing lead-time and improvements to order reaction time fail to create a situation where make-to-order production is possible, the application of the TSP approach is proposed to minimize OPWs. The remainder of this paper describes in greater detail the TSP approach that forms an integral part of the RDM framework.

4. Two-stage planning of production in convenience food manufacturing

Historically, wastes created through overproduction have been preferable to manufacturers in order to ensure retailer orders are met. Retailers in the food industry have grown increasingly powerful (Lowson *et al*. 1999) and the consequences for a convenience food 'own-label' manufacturer not supplying retailer demands are significant, particularly when many manufacturers only serve one customer (retailer). Against this backdrop, the TSP approach utilizes a hybrid of both static and dynamic production scheduling rules to reduce the environmental and economic impacts of production in the convenience food sector. In this approach, operations are divided into two categories, standard and special operations, as shown in figure 2. Standard operations are those that do not give the product identity and are shared among many products. Special operations are those that give identity to a product, such as combinations of particular ingredients

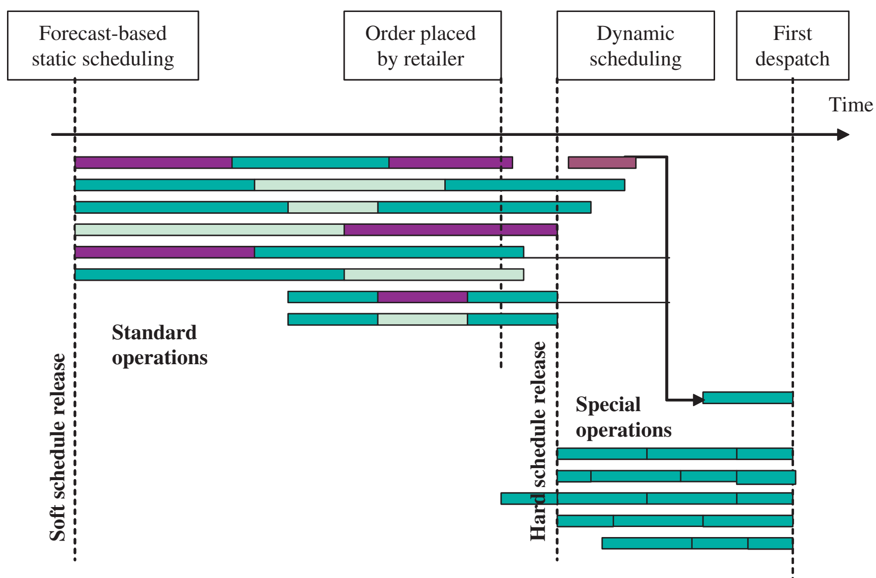


Figure 2. Standard and special operations as part of soft and hard schedule generation.

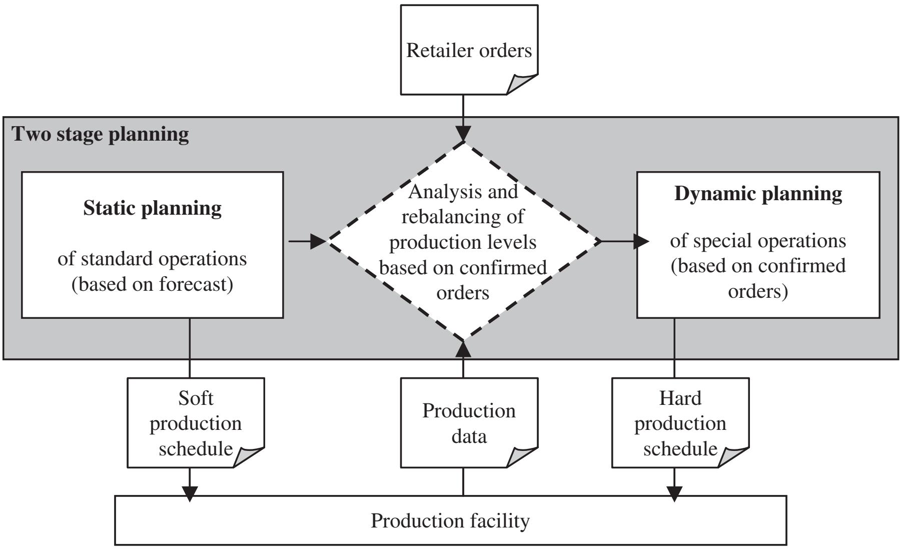


Figure 3. The two-stage planning approach to static and dynamic planning of late ordered products.

or even packaging labels. The main principle of the TSP is to use static planning for standard operations based on traditional forecasting approaches in the first stage to generate a soft schedule; for the second stage a dynamic (real-time) approach for special operations is utilized. The second stage is initiated when customer orders are placed, typically at an agreed time (as depicted in figure 2), which triggers a subsequent planning activity. The confirmed production levels will be used to re-adjust batch sizes for special operations to produce a hard schedule based on confirmed orders. In this TSP framework, the processing of standard operations is initiated based on the soft schedule. The processing of special operations is, however, subject to change, dependent upon confirmed orders and shop-floor data indicating the current state of production (figure 3).

At the point of order confirmation, there are four possible outcomes based on forecasts, actual orders for products and current production volumes as shown in figure 4. These four possible outcomes are as follows.

1. Confirmed orders exactly match forecasts (Order $= F$). All of the required ingredients will be in place, orders will be met and no product will be wasted.
2. Orders are higher than forecasts (Order $> F$). There is a requirement to quickly process extra products to meet the higher than anticipated demand. Additional ingredients may be required with limited available material, and the re-scheduling of standard operations may be required to free capacity for additional processing tasks. This scenario presents several conundrums for the production planner, who must consider the following.
   - Has any other product been overestimated compared with the actual demand? If so are there sufficient ingredients available to meet the additional volumes required for the particular product?

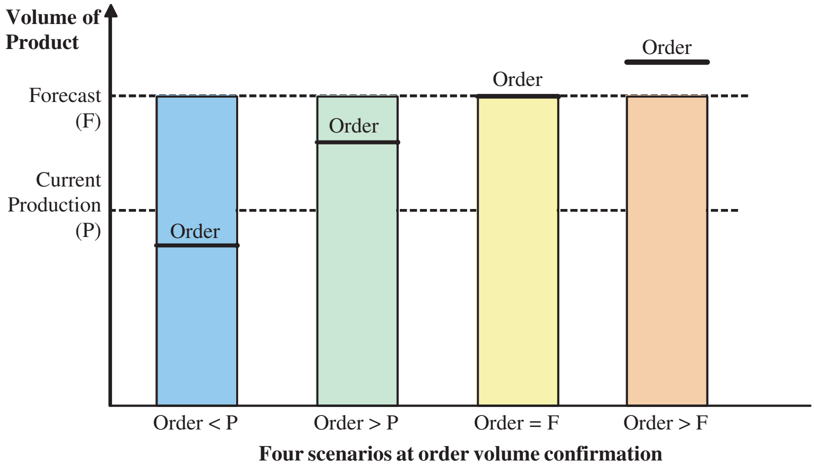


Figure 4. Scenarios at order confirmation point for order volume.

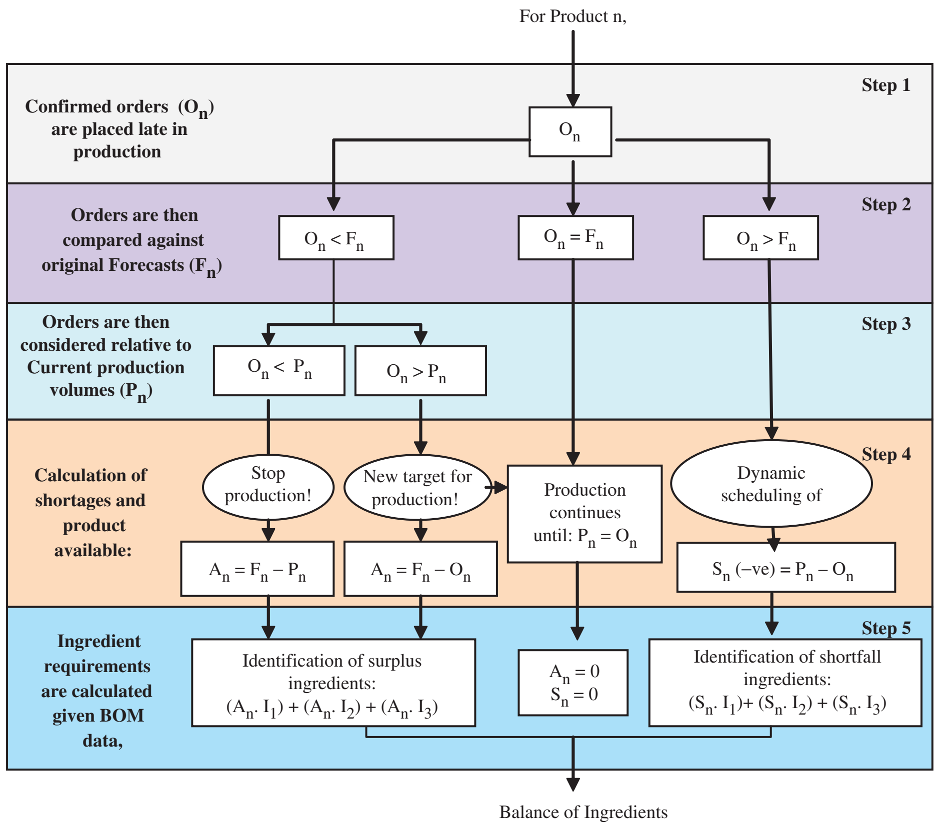
- Are adequate raw materials on hand to meet the additional demand?
- Is capacity available within the production system for the additional processing required?
- Does the processing lead-time of the product's additional volume allow manufacture to be completed before delivery?

3. Orders are below the forecast but above the current production (Order $< F$, Order $> P$). When orders fall below forecasts the volumes are then compared against current production data. This means that there will be component ingredients prepared but not committed to products and OPW can be reduced by redirecting these ingredients to alternative products having suitable interchangeability.
4. Orders are below forecasts and below current production (Order $< F$, Order $< P$). It is intended that through improving the forecast method used as part of static scheduling, such situations will be minimized as, at this stage, products are already committed in excess of the orders and wastes will be unavoidable.

Given these potential outcomes, swift feedback to production is required regarding those specialized operations that have been over-forecasted and are in danger of creating OPW. This has been achieved through the application of a heuristic to establish the shortages and OPWs of products, based on the newly confirmed order volumes and current-state manufacturing data.

4.1 *TSP scheduling heuristic*

Based on the above four possibilities depending on actual order volumes, there is a need to rebalance ingredients that were planned into production at the soft schedule stage. A heuristic has been proposed and assessed by this research that establishes ingredient requirements across the production range and changes to the soft schedule required. This TSP heuristic is outlined in figure 5. For the purposes of describing



Key

I	Ingredient. Each product is comprised of a number of ingredients
n	Product n. Distinct unit comprising a number of specific ingredients e.g. Product x = I1 + I2 + I3
F_n	Forecast n. Estimated volume of product n required for certain due date.
O_n	Confirmed Order volume of product n. The volume of product n that will be required by customer for despatch
P_n	Current Production volume of product n. The volume of product n that has been manufactured up to the current point
A_n	Available ingredients of product n at order confirmation point. This indicates the amount of product and ingredient that was forecasted to be produced, and is no longer required. For $F_n > P_n > O_n$ then: $A_n = F_n - P_n$ For $F_n > O_n > P_n$ then: $A_n = F_n - O_n$
S_n	Shortages of Product n at order confirmation point. This occurs where orders are greater than forecasts $S_n = P_n - O_n$

Figure 5. Flow diagram indicating ingredient requirement determination.

the course of action to be followed when confirmed orders arrive late in the manufacturing lead-time, the figure is accompanied by a list of definitions. The first stage of the heuristic considers the confirmed volume for each particular product; for the purposes of this explanation *product n* is identified. The order volume is then compared against the forecast volume, the outcome from this comparison is to assign *product n* either exactly as forecasted, or having an order greater than or less than forecasted. Most straightforwardly, those products being correctly forecasted ($O_n = F_n$) need no further action, the targets set for production through the soft schedule may remain and no wastage will be generated.

The next stage of the heuristic utilizes production system data in order to differentiate between those orders that are below forecasted volumes and above production ($O_n > P_n$) and those that are also below the current production volumes ($O_n < P_n$), which means that waste products have already been created. At this point a number of orders to the production facility are executed either to stop production immediately (for cases where $O_n < P_n$) to prevent further waste, or where new production targets are required ($O_n > P_n$) so that production can carry on until the order volume is attained. The 'available ingredients' are calculated differently as ingredients already committed to specific products ($O_n < P_n$) are no longer available to other products. This stage also identifies the shortfall of ingredients to fulfil orders that have exceeded forecasts (where $O_n > F_n$). The final stage of the heuristic is used to balance ingredients between the shortages created and the available ingredients left over when manufacture runs to lower order volumes.

The TSP heuristic has been implemented using commercial software (Preactor International 2002). Figure 6 outlines the data transfer through the TSP PREACTOR schedule system as part of the TSP approach.

The flexibility to reallocate materials to other jobs at the point of dynamic scheduling required the development of a bespoke configuration of the scheduling software to enable ingredients to be redirected rather than pegged to one particular product after initial processing. For this reason, the bill of material (BOM) and product data were held externally from the scheduler, as can be seen in figure 6. Confirmed orders received via an electronic data interchange (EDI) or other such communication are presented to the decision heuristic along with data from production.

4.2 *Soft and hard schedules*

The release of soft schedules considers shelf-lives, capacity constraints, resource availability and changeovers at that stage. Priority, however, is give to planning based on the knowledge that orders will be confirmed at a later stage and production volumes will need to be rebalanced. Given these complexities, the support provided by historical data simplifies the scheduling process and enables further support to reduce wastes created by orders being overestimated. An example of the soft schedule is represented in figure 7, identifying the order of operations, ingredients, volumes and operational details required for groups of resources as found in the production environment.

Hard schedules for the production environment are generated through dynamic scheduling after data are passed from the decision heuristic. As shown in figure 8, icons representing jobs to be scheduled are presented in the sequencing environment

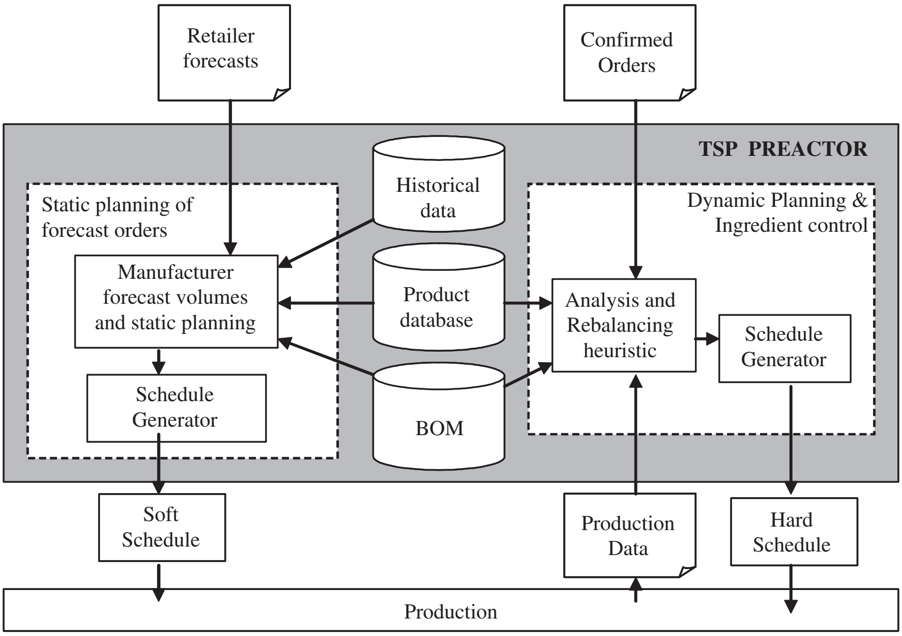


Figure 6. Data flows through schedule generation within industrial scheduling software.

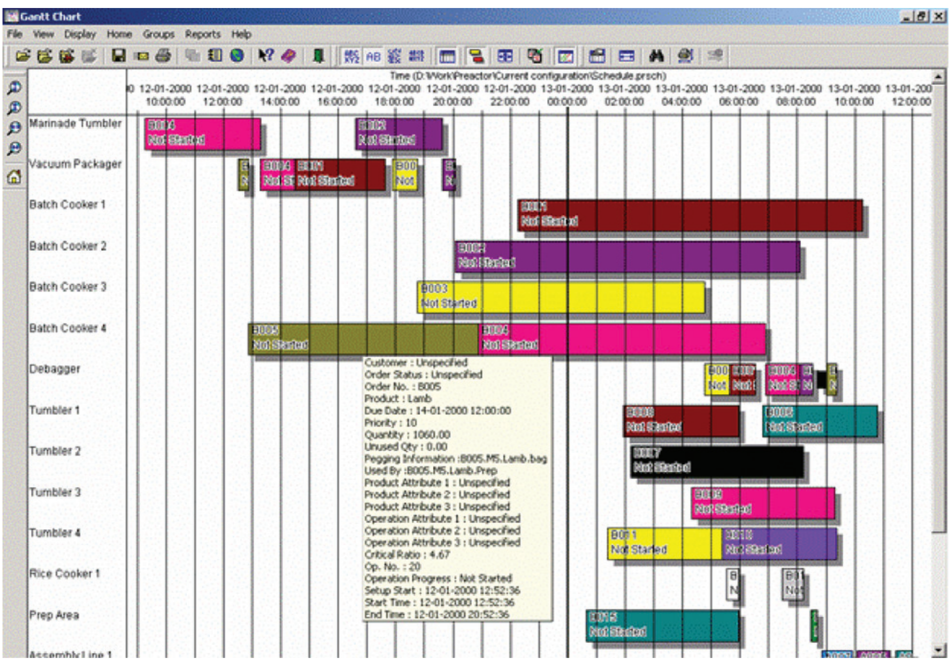


Figure 7. Static scheduling—example of a soft schedule.

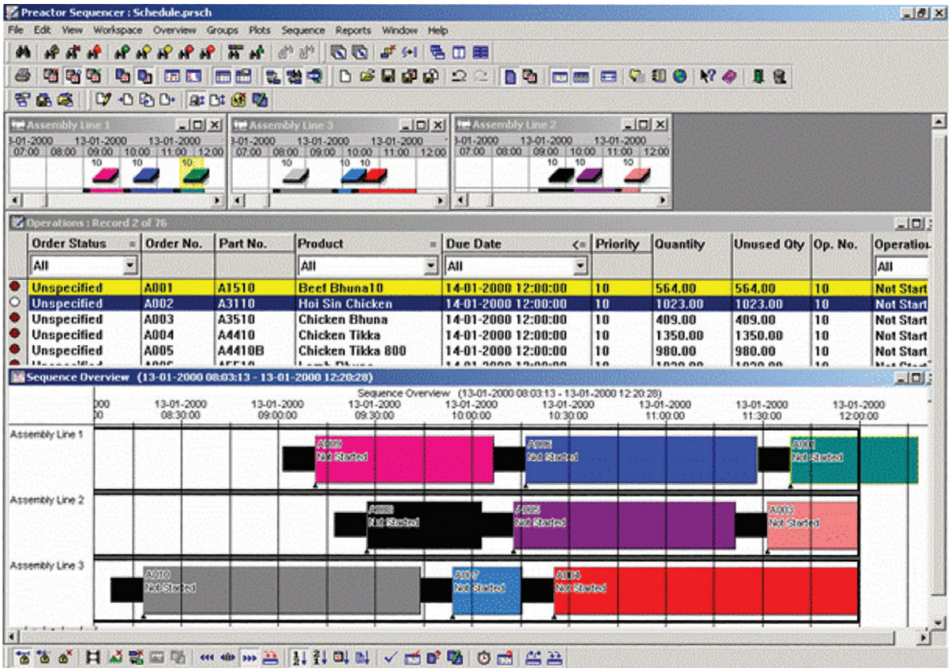


Figure 8. Dynamic rescheduling of jobs on the planning board.

and dynamic scheduling of specialized operations can be achieved through manual ‘drag and drop’ of those jobs into the planning board based on the production planner’s experience. Given an integrated production and planning data system, the sequencing environment will continually update on the availability of real-time data, the scheduler being set up to dynamically reallocate materials to resources taking into account changes of production presented by the real-time data.

5. The TSP system case study application

After an initial survey of manufacturing practices, a company was selected for involvement in the research as a case study; this company typifies the demands placed on manufacturers in this sector. The company produces in excess of two million ready-meals per week, with current manufacture consisting of around 130 of retailer X’s own-label products, 80 of which are core lines with greater production volumes. Orders for all products are placed by retailer X at 09:00 each day. These orders frequently differ to the forecast demand available from the retailer (which is provided for ten days ahead); this volatility is a key driver in the levels of waste created by the manufacturer. The orders placed at 09:00 are for despatch to regional distribution centres (RDCs) from 19:00 hours on the same day through to 12:00 on the following day. Ten RDCs are served in this way, with the RDC furthest away from the company site requiring despatch at 19:00, while the closer RDCs have their despatch times delayed until later in the order cycle. Planning and scheduling of production was completed manually via a system of spreadsheets at the time of the initial research visit and data gathering. The planning efforts took 12 man-hours daily, with production runs confirmed at 13:00 each day (and often later, sometimes 16:00–17:00) after orders were received.

The initial stages of the RDM framework were completed for the case study manufacturer and have been described in an earlier paper (Darlington and Rahimifard 2004). Detailed health-check and process modelling, lead-time reduction analyses and reaction time improvement activities were all completed before planning system considerations were undertaken, as described in the remainder of this section.

The resource databases within the scheduler were set up to reflect the production facility, which is staffed by 1000 personnel, operating 24 hours a day, 7 days per week (night work mainly consists of hygiene teams and cook cycles). The main facility is split over three floors, each of which manufactures a different family of products. Each floor consists of 'low-risk' preparation and cooking areas that are separate to the 'high-risk' filling area, which in turn is separated again from another low-risk area for packing and despatch. These separate areas prevent personnel and equipment from easily moving between low- and high-risk zones of the factory without passing through the necessary hygiene procedures. The flexibility of the equipment used on each floor means that several products can often be assembled on lines on other floors, should demand require it. The products database (as shown in figure 9), BOM and product orders were maintained through external Excel files.

As mentioned previously, a key driver in the creation of OPWs is high levels of order volatility; in order to minimize the effects of production beginning upon forecasts, greater use was made of historical data. Records were kept and used regarding maximum and minimum experienced forecast and order volumes

	A	B	C	D	E	F	G	H
1	Part Numb	Product Name	Operation	Operation	Resource	Required R	Icon Name	Foreground
91	C10270	Carrots and peas for Beef	10	Cook	Filling Roo	Select fron	Sauce	lime
92	C10615	Beef in Pot Sauce	10	Cook	Filling Roo	Select fron	Sauce	Violet
93	C10170	Braised Beef Bagging	10	bag	Filling Roo	Bag Seale	Beef	Maroon
94	C10170	Braised Beef Bagging	20	cook	Filling Roo	DD oven	Beef	Olive
95	C30740	Kedergee Sauce	10	cook	Filling Roo	Select fron	Sauce	Purple
96	C10260	Kedergee rice	10	cook	Filling Roo	Select fron	Rice	White
97	C14723	Kedergee Egg	10	cook	Filling Roo	Select fron	Sauce	Silver
98	C10169	Coriander Rice	10	cook	Filling Roo	Select fron	Rice	Black
99	C30284	Coriander chicken sauce	10	cook	Filling Roo	Select fron	Sauce	Yellow
100	C30490	Pesto Chicken Beans	10	cook	Filling Roo	Select fron	Rice	Green
101	C10100	Pesto Chicken	10	bag	Filling Roo	Bag Seale	Beef	Green
102	C10100	Pesto Chicken	20	cook	Filling Roo	DD oven	Beef	Teal
103	C10430	Pesto Pasta	10	cook	Filling Roo	Select fron	Rice	Olive
104	C30870	Pesto Chicken Sauce	10	cook	Filling Roo	Select fron	Sauce	Fuchsia
105	C30820	Salmon and Tarragon Sau	10	cook	Filling Roo	Select fron	Sauce	Azure
106	C10070	Cooked Salmon	10	Bag	Filling Roo	Bag Seale	Fish	Salmon
107	C10070	Cooked Salmon	20	cook	Filling Roo	DD oven	Fish	Green
108	C30850	Chicken provencal sauce	10	cook	Filling Roo	Select fron	Sauce	Red
109	C10435	Provencal pasta	10	cook	Filling Roo	Select fron	Rice	Purple
110	C30590	Pork Meatball Gravy	10	cook	Filling Roo	Select fron	Sauce	lime

Figure 9. Case study products database.

(along with soft and hard schedule volumes and OPW incurred for those orders) for each particular product relative to previous seasonal, holiday and weekly trends. The improved confidence in knowing the extremes of order fluctuations for each product enabled planning of standard operations (ingredients) to prioritize those ingredients subject to the greatest changing demand earlier in the production schedule, thus leaving more stable components and smaller order volumes for later. This focus for planning provided flexibility for production to best act when orders were confirmed so that components could be redirected and small volumes manufactured quickly to meet orders more accurately. Figure 10 shows an example of the Gantt chart soft schedule that was generated for the case study manufacturer.

Once orders are placed, production volumes are loaded into the heuristic to determine the production requirements for ingredients and to provide instant feedback for those instances where demand has been over-predicted. The TSP heuristic, when populated with data, outlines the waste ingredients and the shortages of specific ingredients relative to the production situation across all products. Through improved soft schedules, ingredient availability for confirmed orders results

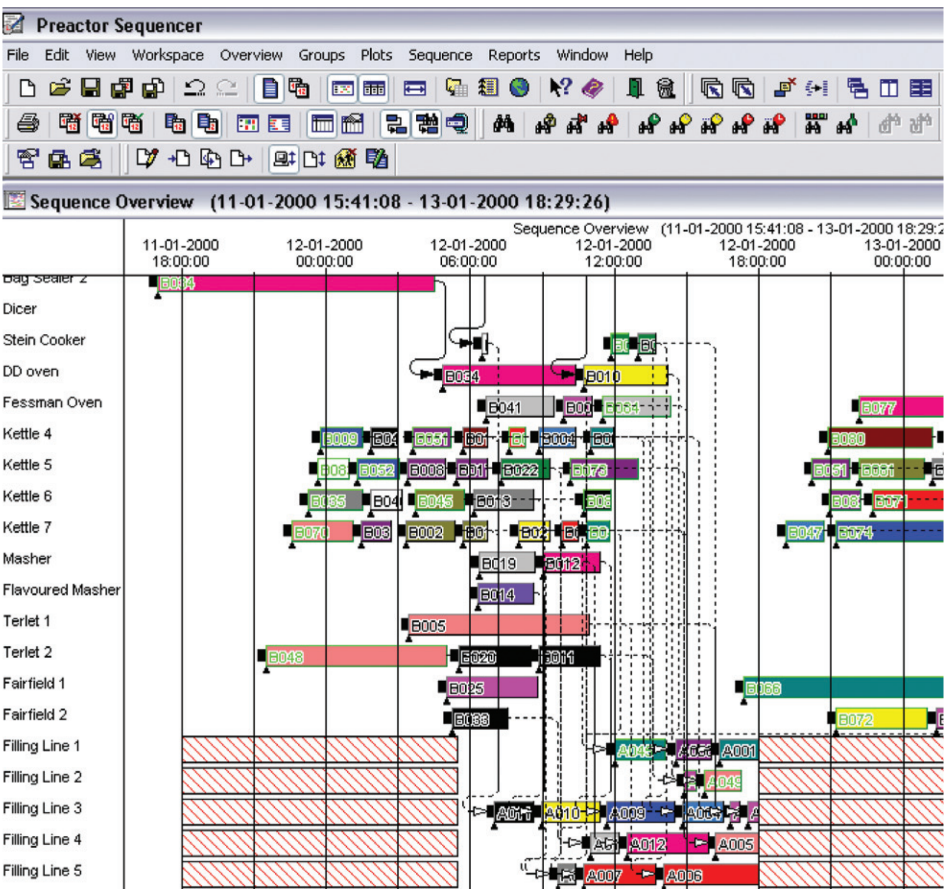
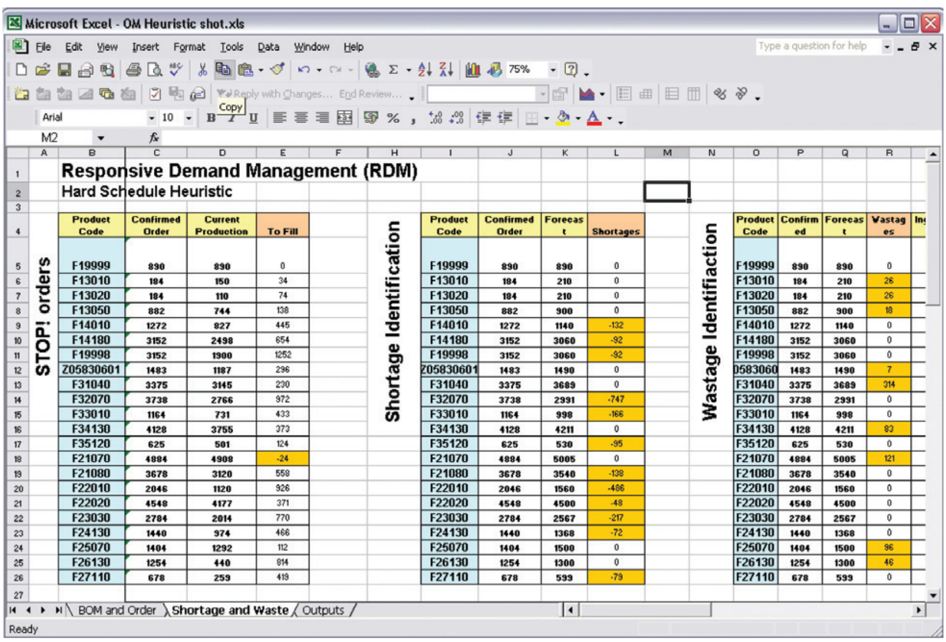


Figure 10. Soft scheduling at the case study manufacturer for a subset of products.

in fewer incidences of OPW; however, there are increased numbers of jobs where ingredients are below forecasted volumes. In these cases it was found that production processing times were significantly shorter for small volumes of ingredients, meaning that orders could be met exactly in these cases through hard scheduling a small number of standard operations. The uploading of ingredient requirements is completed from the heuristic directly into the case study scheduler planning board, from which the hard schedules are then generated (figure 11).

Hard schedules at the case study company were released as printed job cards to the production environment indicating sequences of production and 'stop' instructions to prevent the creation of further OPWs. The case study manufacturer could not support the electronic transmission of data to or from the production environment so formal planning meetings were timed to coincide with retailer order placements to provide cost-effective communication of immediate production demands. Priority orders are highlighted to production, but material availability is still dependent upon operators indicating when there are shortages—a practice that could be significantly improved upon through improved IT communications.

By the latter stages of the research, forecasting communication had improved from the retailer with durations of promotions, details of offers (percentage savings, buy one get one free, etc.) and new product launches being provided for each product up to 15 weeks in advance. While order volatility still persists, the company continues to work towards implementation of a visual planning system for production sequencing and improved operator support. The possibilities highlighted through this research have demonstrated the cost savings, lead-time improvements, layout implications and waste reductions possible through the TSP approach.



Product Code	Confirmed Order	Current Production	To Fill
F19999	890	890	0
F13010	184	150	34
F13020	184	110	74
F13050	882	744	138
F14010	1272	827	445
F14180	3152	2498	654
F19998	3152	1900	1252
Z05830601	1483	1187	296
F31040	3375	3145	230
F32070	3738	2766	972
F33010	1164	731	433
F34130	4128	3755	373
F35120	625	501	124
F21070	4884	4908	-24
F21080	3678	3120	558
F22010	2046	1120	926
F22020	4548	4177	371
F23030	2784	2014	770
F24130	1440	974	466
F25070	1404	1292	112
F26130	1254	440	814
F27110	678	259	419

Product Code	Confirmed Order	Forecast	Shortages
F19999	890	890	0
F13010	184	210	0
F13020	184	210	0
F13050	882	900	0
F14010	1272	1140	-132
F14180	3152	3060	-92
F19998	3152	3060	-92
Z05830601	1483	1490	0
F31040	3375	3689	0
F32070	3738	2991	-747
F33010	1164	998	-166
F34130	4128	4211	0
F35120	625	530	-95
F21070	4884	5005	0
F21080	3678	3540	-138
F22010	2046	1560	-486
F22020	4548	4500	-48
F23030	2784	2567	-217
F24130	1440	1368	-72
F25070	1404	1500	0
F26130	1254	1300	0
F27110	678	599	-79

Product Code	Confirmed	Forecast	Vastages
F19999	890	890	0
F13010	184	210	26
F13020	184	210	26
F13050	882	900	18
F14010	1272	1140	0
F14180	3152	3060	0
F19998	3152	3060	0
0583060	1483	1490	7
F31040	3375	3689	314
F32070	3738	2991	0
F33010	1164	998	0
F34130	4128	4211	83
F35120	625	530	0
F21070	4884	5005	121
F21080	3678	3540	0
F22010	2046	1560	0
F22020	4548	4500	0
F23030	2784	2567	0
F24130	1440	1368	0
F25070	1404	1500	96
F26130	1254	1300	46
F27110	678	599	0

Figure 11. Two-stage planning heuristic.

In addition, the other RDM framework methods concerning supply chain and lean manufacturing improvements and the measurement and analysis of production wastes led to reductions in weekly waste costs to around £15 000–£20 000—a reduction of around £10 000 per week.

6. Conclusions

Current supply chain relationships between retailers and food manufacturers make production planning and control of some food products very complex. Make-to-order of convenience foods is not possible due to the length of production lead-times relative to order reaction times; given the short shelf-lives of the food ingredients, the products cannot be produced under a make-to-stock regime without the creation of substantial wastes. As a result, manufacturers have adopted OPW generation as a tactic by which orders can be satisfied at the expense of available resources and the environment.

This paper has presented an intelligent planning approach to solve this complex planning problem through improved redirection of component ingredients to finished products once orders are confirmed. The authors would like to highlight the difference between the TSP approach and postponement approaches suggested and adopted for products with relatively lengthy shelf-lives such as consumer electronics, clothing and paint (Fisher *et al*. 1994, Feitzinger and Lee 1997, Pagh and Cooper 1998). Postponement requires separate stages where components, modules or otherwise unfinished products are manufactured based on a make-to-stock regime before that stock is then assembled or configured based on orders at a later time after logistical differentiation (Pagh and Cooper 1998). The TSP approach considers production as a single activity planned in two stages as components in production cannot be held as stock and will create wastes if production is not balanced for ingredients over every order cycle due to the short shelf-life of ingredients.

The application of the TSP approach has shown to reduce OPWs and improve utilization of resources for convenience food manufacture. Wasteful practices and the creation of material wastes have not been entirely eliminated, however. Relationships within the food industry between retailers and manufacturer suppliers need to be evaluated and further improved to eliminate sources of environmentally unsustainable practices that have evolved to solve the complex problems that the food supply sector has posed.

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