Business optimization at Nativa Pharmaceuticals

BPJ420 Final Draft

Van Heerden Greeff 25300190 4 October 2010
Project Leader: Mr. O. Adetunji

Executive summary

An optimized business provides management with objectives for guiding long, medium and short term actions.

The project will be conducted at Nativa Manufacturing in Centurion. The plant produces various powder product ranges for Nativa pharmaceuticals and the production line is finding it challenging to meet demand on time due to a fast growing yet fluctuating market.

Discussions with the Nativa's management brought up some issues which are currently impeding the performance of the plant. This project will focus on two different areas where improvements can be made namely production scheduling and resource planning. To achieve these improvements production scheduling algorithms for the production line will be developed.

The aim of the project is to provide the onsite production managers with tools to assist them in making informed and scientifically based decisions.

Table of Contents

List of tables

List of Figures

1.1. Introduction

Nativa Pty Ltd. is a pharmaceutical marketing and sales company that started doing business in the alternative and natural health market in South Africa in April 1999.

Nativa's approach has been to develop quality natural products that target specific conditions or cater for specific consumer needs. To ensure the quality and safety of products, contract manufacturing takes place at GMP approved facilities.

Retail pharmacy constitutes the main client base of Nativa. You can currently find their products in 1700 pharmacies in South Africa, Namibia and Botswana and they are looking to expand their operations internationally. Nativa has grown in net worth from one million rand to over one hundred million rand in less than 10 years.

The company uses various manufacturing plants to produce the 21 different product lines that they offer. These plants are mainly spread around Gauteng and each specialises in a few different products. The plant focused on here is Nativa Manufacturing in Centurion, where all the powder based products are produced.

Recently the company has launched various new products, these will be produced on the powder production line that is presently being used for all other powder products. The demand for these products will place strain on Nativa Manufacturing and they could find it challenging to balance the production of all their products.

This product balancing challenge would clearly have to be solved for Nativa to accommodate the growth that they are experiencing.

1.2. Project Aim

The most important aim of this project is to build a dynamic scheduling tool which must establish the most ideal production order. This schedule will maximize production by minimizing the setup time between production runs while still reaching the demand at the quality level that the customer is expecting.

1.3. Scope

There are numerous different products being produced on different production lines at Nativa manufacturing, but for the purpose of this project the focus will be on the high quality powder production line. The rest of the production lines at Nativa manufacturing will be excluded from this project.

The project will include an in-depth literature study. This entails studying various production scheduling and line optimizing methods used in similar manufacturing environments. The examples that will best accommodate the needs of this project will be chosen and explored deeper. This will assist the student in formulating project specific scheduling algorithms.

Gathering sufficient information will also be crucial and could affect the quality and accuracy of the end solution. The remainder of the project will consist of developing the actual scheduling model and a simulation model to test the scheduling model.

1.4. Deliverables

After completion of the project, the following will be achieved:

- An in-depth literature review.
- Delivery of a dynamic scheduling model.
- A simulation model of the production line which will be used to determine the effectiveness of the scheduling model.

Further deliverables include:

- A detailed description of production process.
- A fully functional scheduling algorithm which can be easily changed as the production process changes or as new products are added or discarded.
- A summary of outputs from the models for different test demands and strategies.

1.5. Project Plan

Research and information gathering

- Research and analysis of existing literature on production lines in a similar environment.
- Gathering information on Nativa's production line, this includes determining production capacity and conducting time studies on all applicable processes.
- Sourcing information with regards to previous order sizes and production history.

Analysis of information and developing of models

This phase of the project will include all activities to accurately model production at Nativa Manufacturing and determine the constraining factors that affect the system. Further, it will include activities to accurately model events such as changeover time between products and also determine the constraints of the change over procedure.

The activities that will be followed comprise of:

- Identifying the constraints and analysing the impact of these constraints in both the above mentioned cases.
- Analysing collected data regarding the aforesaid constraints.
- Use linear programming to determine the following critical decision variables such as:
    - the optimal sequence of product types to minimise changeover time, and
    - the optimal production volume of each product to meet the demand within a specified time.
- Accurately modeling the production line on simulation modeling software such as ARENA or a similar program.
- Testing the scheduling model with the simulation model.
- Documentation and analysis of results achieved by the above mentioned activities.

Final phase integration

- Transform the developed models into usable business optimization tools.
- Present the models and gather feedback from all concerned parties.
- Make alterations according to feedback.
- Finally document and represent findings.

The above listed activities are subject to change as the project progresses. The changes will be kept to a minimum and will be updated and communicated to all parties concerned.

2. Literature Review

2.1. Production Scheduling

Production scheduling is concerned with the allocation of resources and the sequencing of tasks to produce goods or services. Advantages associated with having an effective production schedule includes the ability to determine both whether demand can be met within a certain period of time and the steps needed to meet that demand.

2.2. Production Scheduling Techniques

Single line multiple-product scheduling problems have been widely explored recently. The competition among products sharing the same resources often creates complex scheduling problems. Three methods have been researched to solve these types of problems in a more simple and elegant fashion namely: (1) Operations Research Methods (OR) or Metaheuristical methods, (2) Artificial Intelligence Methods, and (3) Human-machine coordination methods.

2.2.1. Operations Research Methods

Operations research (OR) methods are concerned with finding optimal or near- optimal solutions to scheduling problems using heuristic algorithms or optimal solutions using exact algorithms. Redwine and Wismer (1974) proposed production planning and scheduling models based on mathematical programming to find solutions to hot rolling steel production problems through dynamic programming algorithms (Redwine & Wismer, 1974). The order scheduling models given by them contains many variables and constraints resulting in computational difficulties, none of the models found the optimal solution. Goyal (1974) described a method for determining multi-product single machine schedules on a repetitive basis. However, this method becomes very complex and does not consider setup times (Goyal, 1973).

Wright and Jacobs (1988) proposed a system where orders are selected one at a time based on expected revenue (Wright & Jacobs, 1988). The system does not, however, consider setup time or sequence. A Travelling Sales Person (TSP) model was investigated for the steel rolling industry by Koshiba (1992). Although the model minimizes setup cost, it is only effective for a single production lot. The TSP selects one order at a time from the order pool, this results in a local optimum for the specific order but rarely optimizes the entire schedule (Kosiba, 1992).

Tang et al. (2000) implemented a strategy whereby a TSP model was built based on actual production constraints for the Baoshon Iron and Steel Company of China. The TSP is illustrated below.

(1) $$\text{Minimize} \quad Z, \ \text{with } Z \equiv \sum_{i \in I} W_i \cdot C_i$$

Subject to

(2) $$C_i = \min_{l_{i,\varphi_i(K_i)} + \lceil d_{i,\varphi_i(K_i)} \rceil \leqslant t \leqslant u_{i,\varphi_i(K_i)}} \{t + T \cdot (1 - X_{it})\}, \quad i \in I,$$

(3) $$X_{it} \leqslant x_{i,\varphi_i(K_i),t}, \quad i \in I, \ t = l_{i,\varphi_i(K_i)}, \ldots, u_{i,\varphi_i(K_i)},$$

(4) $$X_{i,t} \leqslant X_{i,t+1}, \quad i \in I, \ t = l_{i,\varphi_i(K_i)}, \ldots, u_{i,\varphi_i(K_i)} - 1,$$

(5) $$x_{i,k,t} \leqslant x_{i,k,t+1}, \quad i \in I, \ k = 1, \ldots, K_i, \ t = l_{i,\varphi_i(k)}, \ldots, u_{i,\varphi_i(k)} - 1,$$

(6) $$x_{i,k+1,t} \leqslant x_{i,k,t-\lceil d_{i,\varphi_i(k)} \rceil + 1}, \quad i \in I, \ k = 1, \ldots, K_i,$$
$$t = \max\left\{l_{i,\varphi_i(k+1)}, l_{i,\varphi_i(k)} + \lceil d_{i,\varphi_i(k)} \rceil - 1\right\}, \ldots, \quad \min\left\{u_{i,\varphi_i(k+1)}, u_{i,\varphi_i(k)} + \lceil d_{i,\varphi_i(k)} \rceil - 1\right\}$$

(7) $$\sum_{i \in H_j} (x_{i,\varphi_i^{-1}(j),t+1} - x_{i,\varphi_i^{-1}(j),t}) \cdot r_{ij} \leqslant R_{jt}, \quad j \in J,$$
$$t = \min_{i \in I}\{l_{ij}\}, \ldots, \quad \max_{i \in I}\{u_{ij}\} - 1,$$

(8) $$t + B \cdot (1 - \lfloor x_{i,k,t} \rfloor) \geqslant l_{i,\varphi_i(k)} + \lceil d_{i,\varphi_i(k)} \rceil, \quad i \in I, \ k = 1, \ldots, K_i, \ t = l_{i,\varphi_i(k)}, \ldots, u_{i,\varphi_i(k)},$$

(9) $$t + B \cdot (1 - X_{it}) \geqslant l_{i,\varphi_i(K_i)} + \lceil d_{i,\varphi_i(K_i)} \rceil, \quad i \in I, \ t = l_{i,\varphi_i(K_i)}, \ldots, u_{i,\varphi_i(K_i)},$$

(10) $x_{i,k,u_{i,\varphi_i(k)}} = 1, \quad i \in I, \; k = 1, \ldots, \; K_i,$

(11) $x_{i,k,l_{i,\varphi_i(k)}} = 0, \quad i \in I, \; k = 1, \ldots, K_i,$

(12) $0 \leqslant x_{i,k,t} \leqslant 1, \quad i \in I, \; k = 1, \ldots, K_i, \; t = l_{i,\varphi_i(k)}, \ldots, u_{i,\varphi_i(k)},$

(13) $X_{it} \in \{0, 1\}, \quad i \in I, \; t = l_{i,\varphi_i(K_i)}, \ldots, u_{i,\varphi_i(K_i)},$ where B is a very large positive integer.

The model consistently found near- optimal scheduling solutions and after one year's implementation showed a significant improvement on the company's previous scheduling system (Tang et al., 2000).

2.2.2. Artificial Intelligence Based Methods

Artificial Intelligence (AI) methods rely on human knowledge to create schedules that are acceptable although not always optimal. The scheduler is viewed as the designer of a production plan and the scheduling tool behaves as a decision support system. Several AI based methods are available for solving scheduling problems, two of these methods have been researched: (1) constraint satisfaction methods and (2) expert system methods.

Constraint satisfaction methods

This method focuses on satisfying the constraints to find any acceptable solution rather than finding the optimal solution (Tang et al., 2000). Additionally, single line – multiple product production scheduling problems comprise complex constraints and it would be hard to find the optimal solution to them using this method.

Expert systems

An expert system is software that attempts to provide a solution to a problem where normally one or more human subject experts would need to be consulted (Ignizio, 1991),. this method has been successfully used in solving scheduling problems.

Henning, et al. (1996) developed a system which generates several alternative production plans and allows the scheduler to get involved in the scheduling process (Henning & Cedra, 1996). The drawback to these systems is that they require a vast amount of knowledge to be stored in the knowledge base.

In the case of a single line- multiple product schedule the amount of stored information would be too large for the active memory of a computer and computational time would be excessive.

2.2.3. Human-Machine coordination methods

The human-machine coordination method allows the scheduler to propose a production schedule which is examined for feasibility by subjecting it to number of constraints. The schedule is displayed on a graphical user interface (GUI) and typically appears in the same format as a Gantt chart. Figure 1 below is a printout from the system previously used by the Ensidesa Steel Plant in Spain (Bruner & Kantor, 1990). Figure 2 is a printout from the system currently being used by Gienow Building Products (Sun & Xue, 2001).

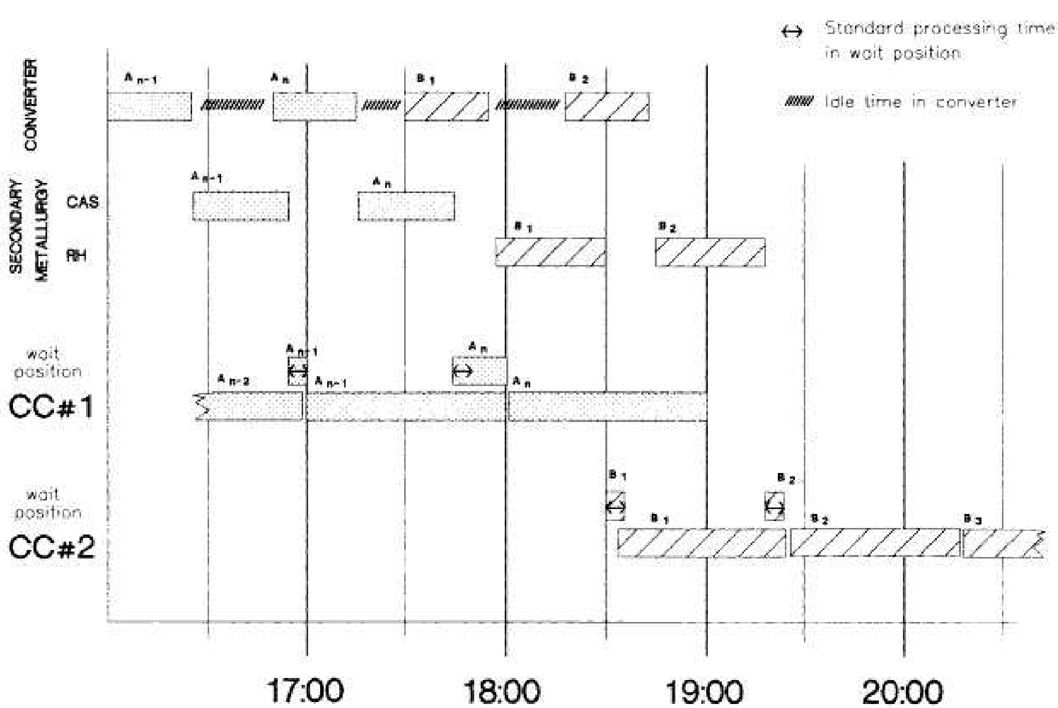


FIGURE 1: HUMAN MACHINE COORDINATION GUI

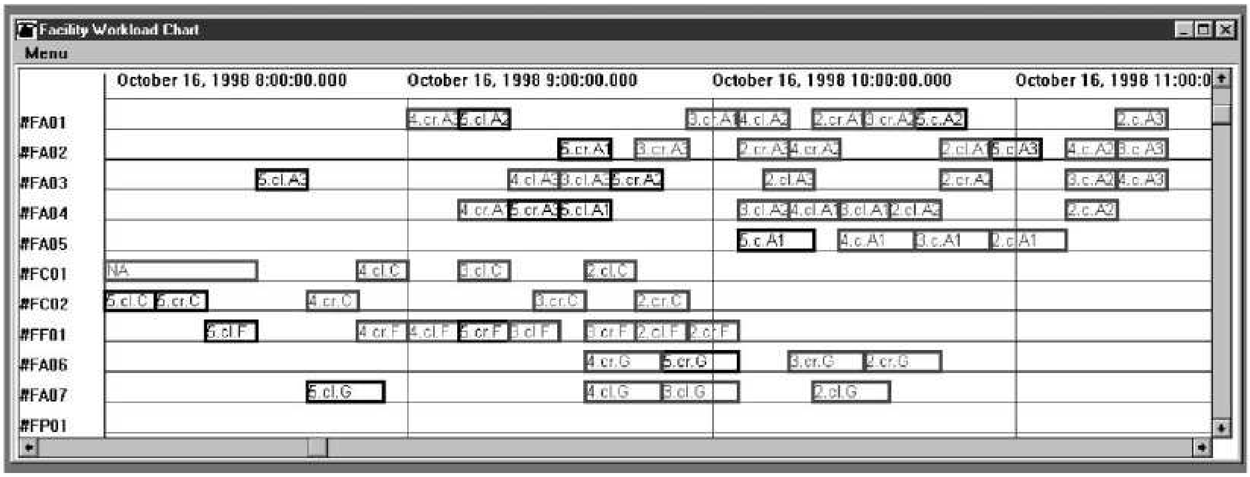


FIGURE 2: PRINTOUT OF MODERN HUMAN-MACHINE COORDINATION GUI

This method is robust and shows flexibility but is aimed at feasibility rather than optimality.

2.3. Selection of solving method for the scheduling problem

As discussed above, AI based methods are effective in mimicking real world scheduling decisions by simulating the human thought process. Human-machine coordination methods are robust and adaptable. Although both methods are capable of providing effective schedules, they tend to be expensive to implement, complex to formulate and they focus on feasibility rather than optimality.

Operations research methods are capable of finding optimal or near optimal scheduling solutions. Some models can find optimal schedules where only one product is produced per production line while other models are formulated to find multi-product single line schedules but only find local optimums to single order production runs or one production lot at a time. By making use of TSP models one can find solutions which optimize the entire schedule rather than just one order at a time.

It is clear from the above literature that a solution to the scheduling problem can be found using the TSP approach.

3. Schedule Formulation

3.1. Production Process

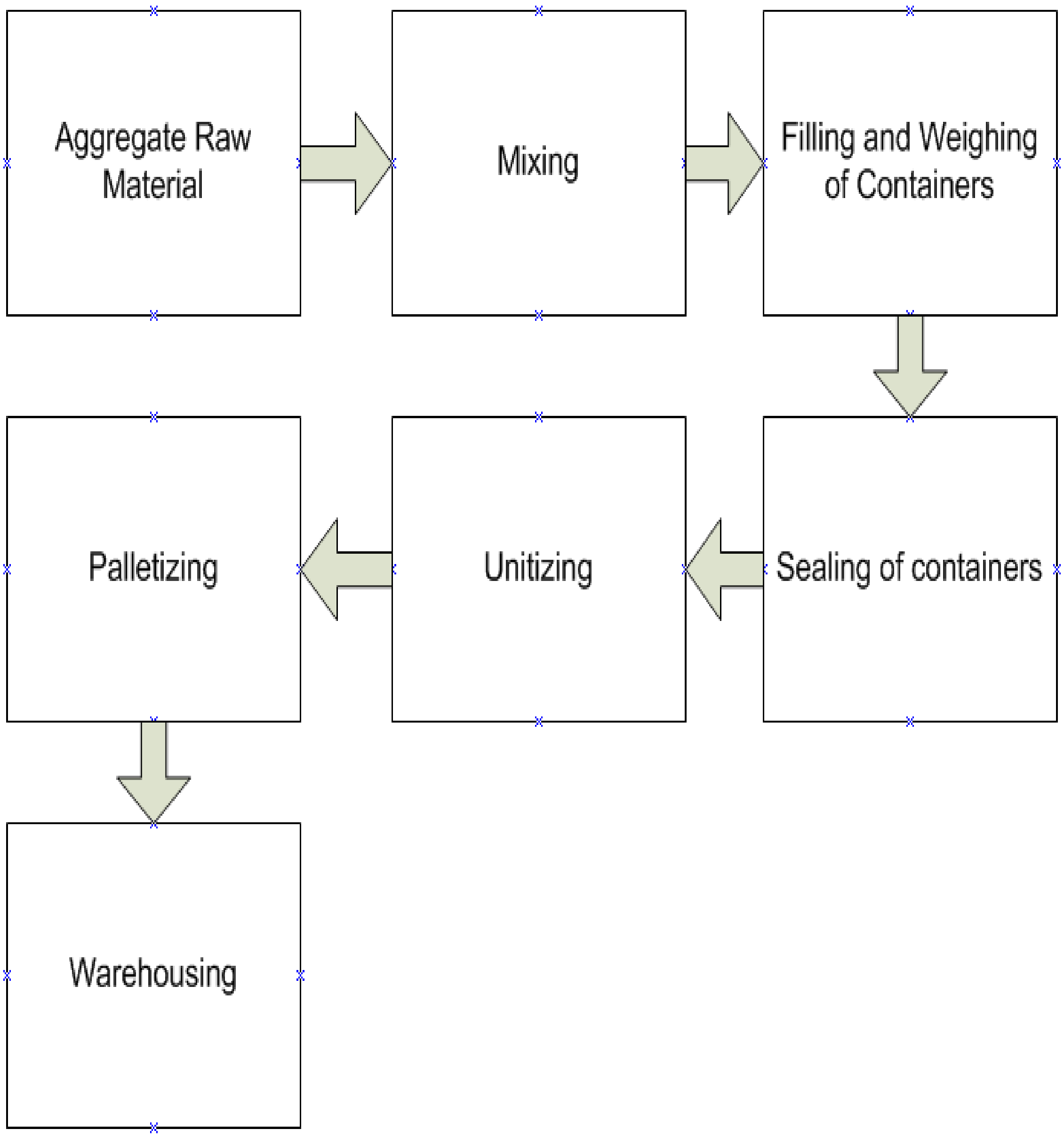


FIGURE 3: NATIVA MANUFACTURING'S PRODUCTION PROCESS

The production process at Nativa Manufacturing is advanced for its size and production output can be assumed to be optimal while a single product is produced. The aforementioned information means that very little time is spent describing the production process as it does not affect the outcome of this project. Nativa currently produces 11 different powdered meal supplements. Due mostly to financial reasons there is a single production line and most production activities are performed in series or sequence rather than in a parallel manner.

As seen in Figure 1, the production process consists of the following sequence:

1. Adding the aggregate raw material to the revolving mixer.
2. Mixing of all raw materials until an acceptable level of uniformity is reached.
3. Simultaneous filling and weighing of product specific containers.
4. Two stage sealing and capping of containers.
5. Batching and unitizing of containers.
6. Palletizing of containers.
7. Warehousing of palletized products.

Useful information

Crucial information collected before data analysis or modeling could begin is:

- Solutions to have to come at no extra cost to the company, that means that no new equipment is allowed to be bought and no additional staff are allowed to be hired.
- The mixing process is an incremental process and not a continuous flowing process. Products are not allowed to be mixed, this means that no intermediate products such as *a vanilla-strawberry* mix or *a Lifegain-Turbokids* mix may be produced. Previous attempts at this have resulted in the company losing money.

3.2. Data collected

Production Demand and other Information

In Table 2 the production data from March 2010 is used as an example to illustrate production rates, monthly and weekly demand, safety stock and required weekly production volumes.

General Product Data					
Product Type	Throughput Rate (Tins per hour)	Demand for March 2010	Weekly Demand for March 2010	Safety Stock Percentage	Total Required Weekly Production
Life Gain 1kg	218	1700	425	5%	446.25
Life Gain 300g	363	1200	300	5%	315
New You 400g Vanilla	509	2400	600	15%	690
New You 400g Strawberry	509	3400	850	15%	977.5
New You 400g Chocolate	509	2600	650	15%	747.5
Turbokids 400g Vanilla	509	2400	600	10%	660
Turbokids 400g Strawberry	509	2400	600	10%	660
Turbokids 400g Chocolate	509	1800	450	10%	495
Replace 400g Vanilla	436	2400	600	10%	660
Replace 400g Strawberry	436	2400	600	10%	660
Replace 400g Chocolate	436	1800	450	10%	495

TABLE 1: PRODUCTION DEMAND

Changeover Time Between Products

Table 3 depicts the different setup times for the production line between different products. The main constraining factor is the cleanup time between products with different ingredients and flavours.

Changeover Time (in minutes) if production switches from product in row to product in column											
Product Type	Life Gain 1kg	Life Gain 300g	New You 400g Vanilla	New You 400g Strawberry	New You 400g Chocolate	Turbokids 400g Vanilla	Turbokids 400g Strawberry	Turbokids 400g Chocolate	Replace 400g Vanilla	Replace 400g Strawberry	Replace 400g Chocolate
Life Gain 1kg	Not Allowed	60	120	120	120	120	120	120	120	120	120
Life Gain 300g	30	Not Allowed	120	120	120	120	120	120	120	120	120
New You 400g Vanilla	120	120	Not Allowed	30	30	30	30	30	30	30	30
New You 400g Strawberry	120	120	60	Not Allowed	60	60	30	60	60	30	60
New You 400g Chocolate	120	120	30	30	Not Allowed	30	30	30	30	30	30
Turbokids 400g Vanilla	120	120	120	120	120	Not Allowed	30	30	30	30	30
Turbokids 400g Strawberry	120	120	120	120	120	60	Not Allowed	60	60	30	60
Turbokids 400g Chocolate	120	120	120	120	120	30	30	Not Allowed	30	30	30
Replace 400g Vanilla	120	120	120	120	120	120	120	120	Not Allowed	30	30
Replace 400g Strawberry	120	120	120	120	120	120	120	120	60	Not Allowed	60
Replace 400g Chocolate	120	120	120	120	120	120	120	120	30	30	Not Allowed

TABLE 2: CHANGEOVER TIME BETWEEN PRODUCTS

3.3. Travelling Salesperson Problem

The TSP describes the following application: a salesman departs from a given city to visit a number of geographically dispersed customers before finally returning home. The problem is to find the sequence in which he should visit each customer in order to minimize the total distance travelled (Pizzolato & Canen, 1998).In the case of Nativa's production scheduling problem the production lots are seen as cities to be visited and setup time between different production lots as travel distance between cities. Provided in Table 2 and Table 3 is the set of all production orders for the month and the matrix depicting setup times between all pairs of products respectively. The required volume of one lot divided by the production rate for that product represents the visiting time to a city. By finding the optimal production sequence the TSP model will minimize the total setup set-up and production times.

3.4. Production Sequence Modeling

The production sequence model is formulated as a travelling salesman problem. Here the objective is to produce each of the considered products while minimizing the total changeover time of the production sequence. Thus in mathematical terms, the objective function is the minimum of the sum of the changeover times.

Constraints

- A Production run can only be started once, per week, and changeover between production runs of different products can also occur only once.
- The production sequence must contain all the considered products and may not have multiple sub tours.
- All variables must be integer.

Changeover Times

Changeover times are comprised of the total cleaning time of the entire line and the total time of calibration of the respective machines.

Mathematical Representation of Production Sequence Model

$i, j = \{1, .., 11\}$

$$x_{ij} \triangleq \begin{cases} 1 \text{ if changeover occurs from product } i \text{ to product } j \\ 0 \text{ otherwise} \end{cases}$$

$d_{ij} \triangleq$ *the given changeover time if changeover occurs from product i to product j, where*

$$\min z = \sum_{i=1}^{11} \sum_{j=1}^{11} x_{ij} d_{ij} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \text{Total Changeover Time}$$

s.t.

$$\sum_{i=1}^{11} x_{ij} = 1 \ \ (for\ j = 1,2,..,11) \ \ \ldots\ldots\ldots\ldots\ldots\ldots \text{Changeover can only happen once from product } i$$

$$\sum_{j=1}^{11} x_{ij} = 1 \ (for\ i = 1,2,..11) \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Changeover can only happen once to product } j$$

$u_i - u_j + 11x_{ij} \leq 10 \ (for\ i \neq j; i = 1,2,..,11;\ j = 1,2,..,11)$..... Sub-tour prevention

$All\ x_{ij} = 0\ or\ 1, All\ u_j \geq 0$

Please refer to Appendix B for the initial Lingo programmed model.

3.5. Production Volume Model

For the production volume model, the objective is to minimize the total amount of production runs taken. In mathematical terms, the objective is the minimum of the sum of the production runs for all the considered products.

Constraints

- For each of the products considered, the product of the amount of production runs, and the throughput rate must be more, or equal to the product of the estimated demand and the sum of 1 and the safety stock fraction.
- The sum of the amount of production runs per product, may not exceed the total available productive time available.
- The production run variable must be integer.

Production Runs per Product

The amount of production runs that should be run per product. These production runs are measured per hour.

Total Available Productive Time

The total time available to conduct production. This time is the total time available in a working day, subtracting the tea breaks, the lunch break, and the line overall cleanup at the end of each working day.

Mathematical Representation of Production Volume Model

$i = \{1,2,..,11\}$

$p_i \triangleq the\ amount\ of\ production\ runs\ that\ are\ done\ for\ each\ product\ i$

$d_i \triangleq the\ given\ demand, in\ units\ per\ week, for\ product\ i\ for\ the\ following\ month$

$b_i \triangleq the\ given\ batch\ size, in\ units, produced\ per\ hour\ of\ product\ i$

$s_i \triangleq the\ given\ safety\ stock\ percentage\ required\ for\ product\ i$

$$\min z = \sum_{i=1}^{11} p_i \qquad Amount\ of\ production\ runs$$

s.t.

$$p_i b_i \geq d_i(1 + s_i) \quad \forall\ i = \{1,2,..,11\} \qquad Production\ more\ than\ demand\ plus\ safety\ stock$$

$$\sum_{i=1}^{11} p_i \leq 30 - z_{production\ sequence} \qquad Production\ runs\ less\ than\ available\ productive\ time$$

$p_i \geq 0\ and\ integer$

Please refer to Appendix B for the initial Lingo programmed model.

4. Execution and analysis of results

4.1. Production Sequence Model

The production sequence model yielded the following results:

$$Life\ Gain_{1kg} \rightarrow Life\ Gain_{300g} \rightarrow New\ You_{Vanilla} \rightarrow Replace_{Vanilla} \rightarrow Turbokids_{Vanilla}$$

$$Replace_{Chocolate} \leftarrow Turbokids_{Strawberry} \leftarrow New\ You_{Strawberry} \leftarrow Replace_{Strawberry} \hookleftarrow$$

$$\Lsh\ New\ You_{Chocolate} \rightarrow Turbokids_{Chocolate}$$

This optimal sequence yields a total changeover time of 300 minutes per week for the sample month. This is the minimum changeover time.

4.2. Production Volume Model

The production volume model yielded the following results:

Product	# of Production Runs	Total Number of Products Produced
Life Gain 1kg	3	654
Life Gain 300g	1	363
New You 400g Vanilla	2	1018
New You 400g Strawberry	2	1018
New You 400g Chocolate	2	1018
Turbokids 400g Vanilla	2	1018
Turbokids 400g Strawberry	2	1018
Turbokids 400g Chocolate	1	509
Replace 400g Vanilla	2	872
Replace 400g Strawberry	2	872
Replace 400g Chocolate	2	872
Total	21	

TABLE 3: PRODUCTION VOLUME PER PRODUCT FOR THE SAMPLE MONTH

This optimal solution yields that a total of 21 production runs must be done to satisfy the weekly demand.

4.3. Sample Production Schedule

The combination of the above models yields a weekly production schedule as shown below:

Production Schedule of week x of March 2010					
Time/Day	1	2	3	4	5
08:15-08:45					
08:45-09:15					
09:15-09:45					
09:45-10:15					
10:15-10:30	Tea Time				
10:30-11:00					
11:00-11:30					
11:30-12:00					
12:00-12:30					
12:30-13:00	Lunch				
13:30-14:00					
14:00-14:30					
14:30-15:00					
15:00-15:15	Tea Time				
15:15-15:45	Line Overall Cleanup				
15:45-16:15					
16:15-16:45					
16:45-17:30					

TABLE 4: PRODUCTION SCHEDULE FOR WEEK X OF MARCH

Changeover
Life Gain 1kg
Life Gain 300g
New You Vanilla
Turbokids Vanilla
Replace Vanilla
New You Strawberry
Turbokids Strawberry
Replace Strawberry
New You Chocolate
Turbokids Chocolate
Replace Chocolate

4.4. Performance measurement

Schedule performance

When executed on Lingo 8.0 software installed on a 2.4MHz Core2Duo Pentium, the model returned optimal results within 7 seconds. The proposed schedule for the sample month achieves a total changeover time of 300 minutes per week, this is the minimum changeover time and amounts to 18% of active production time. Actual powder production takes place 57% of the factory's total operational time and results in 75% total available production time utilization.

Schedule modification and time extension

Currently the factory has a daily 9 hour shift and production is divided into a week by week approach. Considering the daily overall line cleanup and minimum changeover times for all products while assuming all available products are produced every week, the system is currently able to achieve a maximum productivity of 67%.

Basic Arena simulation models were developed to compare results obtained by different schedules and production strategies. Arena simulates each strategy 20 times to obtain an acceptable average.

By running 12 hour shifts the maximum system productivity increases by 11%. This option results in increased overtime labor expenses, however, it is feasible under higher demand circumstances.

By producing in a month-by-month instead of the currently preferred week-by-week approach the system achieves a maximum productivity increase of 13%. This has no additional direct labor- or raw materials costs but could result in hidden or indirect cost under fluctuating demand. This approach is also sensitive to situations where raw materials shortages occur and could result in the system being idol for extended periods of time.

5. Conclusion

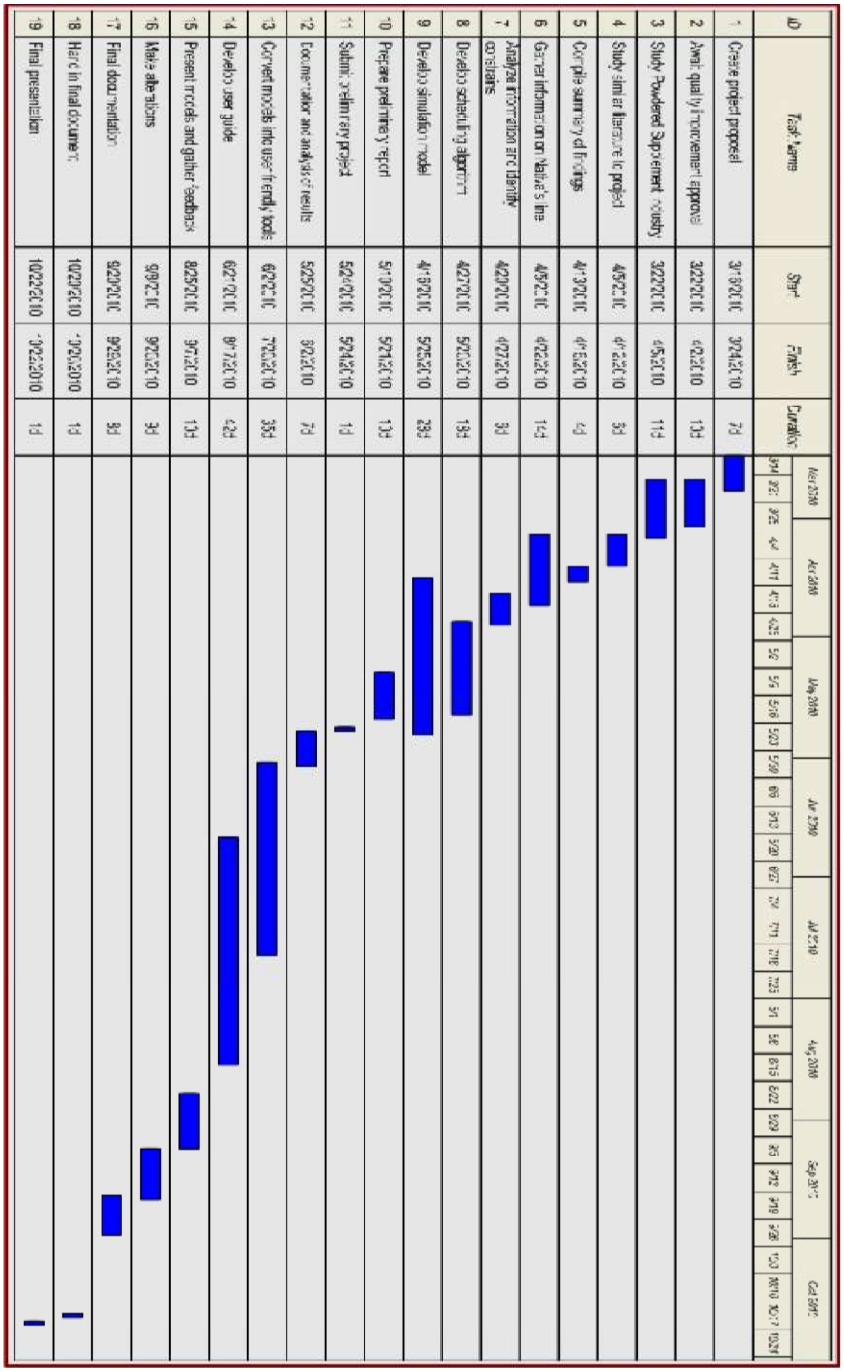
Production schedules for the months of March, April and May were created by the *sequence* and *volume* models by executing them in Lingo 8.0. The outcome of the models executed provided optimal solutions for March and April. The production time available per week was not sufficient to meet the production volume required for the month of May although this problem could be solved by running overtime or by producing in a month-by-month approach.

Given enough production time, the models produce both feasible and optimal solutions. However, this does not guarantee that production demand will always be met given that the production line is constantly running at close to full capacity utilization.

Nativa Manufacturing is currently in the process of acquiring a new facility to address their production capacity needs. The simulation model created for comparative schedule testing will furthermore be beneficial in providing valuable information regarding capacity requirements planning and opportunities for improvement in numerous areas.

8. Appendices

Appendix A: Gantt Chart



ID	Task Name	Start	Finish	Duration
1	Create project proposal	3/18/2010	3/24/2010	7d
2	Await quality improvement approval	3/22/2010	4/2/2010	10d
3	Study Powdered Supplement Industry	3/22/2010	4/5/2010	11d
4	Study similar literature to project	4/5/2010	4/7/2010	3d
5	Compile summary of findings	4/13/2010	4/15/2010	4d
6	Gather information on Nativa's line	4/5/2010	4/22/2010	14d
7	Analyze information and identify constrains	4/20/2010	4/22/2010	3d
8	Develop scheduling algorithm	4/27/2010	5/20/2010	18d
9	Develop simulation model	4/19/2010	5/25/2010	23d
10	Prepare preliminary report	5/10/2010	5/21/2010	10d
11	Submit preliminary project	5/24/2010	5/24/2010	1d
12	Documentation and analysis of results	5/25/2010	6/2/2010	7d
13	Convert models into user friendly tools	6/2/2010	7/20/2010	35d
14	Develop user guide	6/21/2010	8/17/2010	42d
15	Present models and gather feedback	8/25/2010	9/7/2010	10d
16	Make alterations	9/8/2010	9/20/2010	9d
17	Final documentation	9/20/2010	9/29/2010	8d
18	Hand in final document	10/20/2010	10/20/2010	1d
19	Final presentation	10/22/2010	10/22/2010	1d

Appendix B: Programming of Models

Lingo™ Code

Production Sequence

```
MODEL:
SETS:
PRODUCT/1..11/:U;
LINK(PRODUCT,PRODUCT):DOWN,X;
ENDSETS
DATA:
DOWN=5000 30 120 120 120 120 120 120 120 120 120
60 5000 120 120 120 120 120 120 120 120 120
120 120 5000 30 30 30 30 30 30 30 30
120 120 60 5000 60 60 30 60 60 30 60
120 120 30 30 5000 30 30 30 30 30 30
120 120 120 120 120 5000 30 30 30 30 30
120 120 120 120 120 60 5000 60 60 30 60
120 120 120 120 120 30 30 5000 30 30 30
120 120 120 120 120 120 120 120 5000 30 30
120 120 120 120 120 120 120 120 60 5000 60
120 120 120 120 120 120 120 120 30 30 5000;
ENDDATA
N=@SIZE(PRODUCT);
MIN=@SUM(LINK:DOWN*X);
@FOR(PRODUCT(K):@SUM(PRODUCT(I):X(I,K))=1;);
@FOR(PRODUCT(K):@SUM(PRODUCT(J):X(K,J))=1;);
@FOR(PRODUCT(K):@FOR(PRODUCT(J)|J#GT#1#AND#K#GT#1:
U(J)-U(K)+N*X(J,K)<N-1));
@FOR(LINK:@BIN(X););
END
```

Production Volume

```
MODEL:
SETS:
PRODUCTS/1..11/:AMOUNT, DEMAND, BATCH, SAFE;
ENDSETS
DATA:
DEMAND= 425 300 600 850 650 600 600 450 600 600 450;
BATCH=218 363 509 509 509 509 509 509 436 436 436;
SAFE=0.05 0.05 0.15 0.1 0.1 0.15 0.1 0.1 0.15 0.1 0.1;
ENDDATA

MIN = @SUM(PRODUCTS(I):AMOUNT(I));

@FOR(PRODUCTS(I):
      AMOUNT(I)*BATCH(I) >= DEMAND(I)*(1 + SAFE(I));
);

@SUM(PRODUCTS(I): AMOUNT(I)) <= 21;

@FOR(PRODUCTS(I): AMOUNT(I)>=0);

@FOR(PRODUCTS(I):
      @GIN(AMOUNT(I));
);

END
```

9. References

Bruner, R.W. & Kantor, T.A., 1990. Intergrated Process Control -A means to survive. *Steel Times*, pp.15-19.

Goyal, S.K., 1973. Scheduling a Multi-Product Single Machine System. *Operations Research Quaterly Vol.24*, pp.261-69.

Henning, G.P. & Cedra, J., 1996. *A Knowledge Based Approach to Production Scheduling for Batch Processes*. Universidad Nacional del Litoral.

Ignizio, J., 1991. Computers and Operations Research Vol 17. pp.523-33.

Kosiba, E.D., 1992. Discrete event sequencing as a traveling salesman problem. *Computers in Industry 9*, pp.317-27.

Pizzolato, N.D. & Canen, A.G., 1998. Improving Industrial Competiveness: A case study. *Logistics Information Management Vol 11*, pp.188-91.

Redwine, C.N. & Wismer, D.A., 1974. A mixed integer programming model for scheduling order in steel mill. *Journal of Optimization Theory and Applications 14*, pp.305-18.

Sun, J. & Xue, D., 2001. A dynamic reactive scheduling mechanism for responding to changes of production orders and manufacturing resources. *Computers in Industry*, pp.189-207.

Tang, L., Lui, J., Rong, A. & Yang, Y., 2000. A multiple traveling salesman problem model for hot rolling scheduling in Shanghai Baoshan Iron & Steel Complex. *European Journal of Opewrational Research 124*, pp.267-82.

Wright, J.R. & Jacobs, T.L., 1988. Optimal inter-process steel production scheduling. *Computers and Operational Research 15*, pp.497-507.