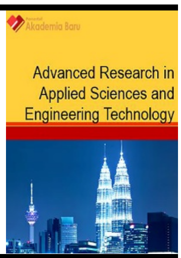
Penerbit Akademia Baru

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage: www.akademiabaru.com/araset.html
ISSN: 2462-1943



Production decision support system for batch processes

Open Access

L.P. Chee [1,2], S.R. Wan Alwi [1,2,*], J.S Lim [1,2]

[1] Process Systems Engineering Centre (PROSPECT), Research Institute of Sustainable Environment, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
[2] Faculty of Chemical & Energy Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia

ARTICLE INFO

Article history:
Received 30 September 2016
Received in revised form 6 November 2016
Accepted 9 November 2016
Available online 14 November 2016

ABSTRACT

Aggregate planning acts as a blueprint for all operational planning activities. Despite the substantial amount of research that has been done in determining methods to improve aggregate planning approaches, the industry is still at a loss when it comes to working on the tactical planning aspect, especially in aggregate production. Therefore, this research work aims to present a comprehensive and generalised framework that will formulate a realistic batch production environment using an interactive Production Decision Support System. This system consists of an aggregate planning framework that combines a simulation model and a Pinch Analysis graphical approach to improve the effectiveness and efficiency of the decision-making process. The target is to allow operational opportunities to be captured at first sight and thus, maximise organisational profit. The simplicity and practicality of this new Production Decision Support System is demonstrated through two illustrative examples where a total of four heuristics were identified and turned into the new strategies to avoid the stock-out scenarios.

Keywords:
Production decision support system (PDSS), Pinch analysis, Grand composite curve (GCC), Aggregate planning, Tactical planning, Capacity planning

1. Introduction

Many industrial companies have to face the strong global competition where challenges come from many ways and aspects [1]. Aggregate planning is such acts as a blue print for all operational planning activities, which in turn, determines the organisational profitability decision at one point. Fluctuating sales demand already poses a very challenging environment to a company. Additionally, aggregate planning could become more complicated with the presence of flexibility in production line setup, different product types, different product grades, different product cycle times, different

* *Corresponding author.*
E-mail address: syarifah@utm.my (S.R. Wan Alwi)

batch sizes, various changeover times, limitation of inventory requirement, and maintenance requirements.

All this makes tactical capacity planning, a very tough task. Oftentimes, due to changes in a scenario such as product mix from the market, sudden breakdown of critical equipment or unplanned prolonged process upset, and/or a sudden change in market need, the operation team might wrongly estimate their production capability due to time pressure and thus cost the company either revenue losses or impaired reputation, abandoning profit maximisation in the process. Nevertheless, it is essential to determine the structure of the problem and explicitly evaluate these multi criteria [2]. The industry cannot afford to remove these complexities and simply neglect flexibility or even make the customer wait considering the highly competitive market nowadays. Thus, obtaining a truly holistic overview and making the right call at the right time can be a tricky matter to execute.

So, how can the plant manager quickly comprehend all possible manufacturing scenarios along the way and decide the next path forward whilst ensuring that operation will always stay on the desired track? In considering this question, the problem statement for this study then becomes: Given a set of production contributory factors such as cycle time, batch size, plant availability, and number of stream and product mixes, a match between production and sales forecast is desired, using a generic framework and assisted with an algorithm tool that can guide decision making.

This paper will start with literature review, followed by the proposed methodology and lastly illustration through examples production strategies.

2. Literature review

According to Anthony's framework [3], a company decision can be classified into three main categories that are based on time horizons, which are long term, medium term, and short term. Strategic planning supports long-term decisions, while tactical and operational planning support medium- and short-term decisions, respectively. These three time-based decisions are essential to the effective management of a manufacturing system, the aim of which is to transform raw material into high quality finished products [4] and to deliver the correct product quantity on time and at an appropriate cost.

Strategic planning involves high-level overall business planning where a company's mission, vision, objective, and value are considered. In the context of production, strategic planning relates to the long-term impacts of decisions such as expansion of facilities, plant acquisition, building of new plants, and development of new product types. All these decisions usually require a huge investment and are affected by both internal and external information [5]. Tactical planning involves allocating resources such as facilities, work force, as well as logistic resources in such a way that the costs are minimised. Decision-making at this stage includes balancing between plant capacities and market demand via changing of product mix, accumulation level of inventory, utilisation of labour, and alternative ways of distribution. Operation planning deals with daily resource allocation e.g., scheduling, lot sizing, processing and assignment of customer order to the respective machine, daily inventory control, and dispatching.

Aggregate planning is a form of tactical planning, and acts as a bridge between strategic and operation planning. With this type of planning, the best way to meet demand forecast is determined by adjusting production, inventory, labour, as well as other resources over the next period of typically 2-18 months [6].

Being able to accurately estimate capacity is a critical step in ascertaining the success of aggregate planning. To ensure a continuous process, capacity is derived from the amount of primary feedstock or refined product per unit of time that a plant can process, while for batch and semi-continuous processes, capacity is derived from the number of batches that a plant can process, which is solely governed by the cycle time of a batch [7].

To match demand with capacity, three types of approaches are used, namely proactive, reactive, and mixed approaches. Proactive strategies alter demand and match it with capacity, whilst reactive approaches alter capacity to match demand. The mixed strategy is a combination of both.

Operational management is responsible for meeting current and future customer demand. Thus, it is important to balance capacity and demand with the correct cost to ensure business sustainability.

2.1 Estimating Capacity for a Batch Plant

Plant capacity analysis is a crucial tool to ensure improvement in manufacturing and accuracy in planning. Subsequent analyses such as asset utilisation, asset efficiency, overall equipment effectiveness, process bottlenecks, as well as types of planning i.e. aggregate production planning, production scheduling, and resource planning, can only be rationalised at the correct capacity estimation.

As pointed out that plant capacity of the batch plant is a function of cycle time (Ct^{min}) [7, 8]. Hence, the shorter the cycle time, the higher the plant capacity. The derivation of cycle time and plant capacity is well-established in the literature. Brigler [9] explained the determination of cycle time on multiple identical equipment case whilst Manganaro [10] demonstrated the cycle time derivation for multiple non-uniform equipment and in year 2011, Koulouris [11] extended the cycle time determination on the shared equipment basis.

2.2 Aggregate Planning Techniques

Numerous formal techniques have been suggested for aggregate planning since the early 1950s started with Hott et al. [12] who introduced aggregate planning using a Linear Decision Rule. These works are summarised in some of the review papers [13, 14].

Despite the growing number of research in this area, Buxey [15, 16] pointed out that the industry often does not adopt any of these formal aggregate planning models, as they are too complicated or because there are gaps between theoretical and practical managerial planning considerations. This can be attributed to the lack of theoretical technical knowledge of the managers as well as other needs or other aspects of a firm’s business considerations including managing brands and the positioning of the firm against its competitors. Imprecise, inherent data has also added to the difficulty in planning. Ramezanian [17] also emphasised that researchers have yet to present a comprehensive and generalised model to formulate real production environments despite the many methods that have been introduced to address the Aggregate Production Planning problem. This is mainly due to the researches whose main focus is on solution algorithms rather than on the creation of a general model. Chakrabortty et al. [11] again underscored this gap in their research.

In 2009, Ludwig [18] pointed out that the graphical Pinch Analysis introduced by Singhvi and Shenoy [19] can act as an alternative new approach for aggregate planning. This process integration is indeed a breakthrough approach in aggregate planning [20]. Although this approach cannot compete with other previously mentioned formal aggregate planning approaches in terms of optimal results, it could still help industry users to acquire a holistic view on overall planning including evaluation scenarios in the presence of uncertainties, and thus can act as a managerial rule of thumb.

2.3 Supply Chain Cascade Analysis

Figure 1, adopted from Singhvi et. al. [19] & Foo [21], illustrates how material is accumulated at the end of a certain period. As shown, material accumulated for the period t originates from the previous time interval, indicated as inventory ΔI_{t-1}, and is then topped up with the fresh production quantity that is being produced, P_t, and from this amount, the sales quantity of that period is taken away as demand, D_t.

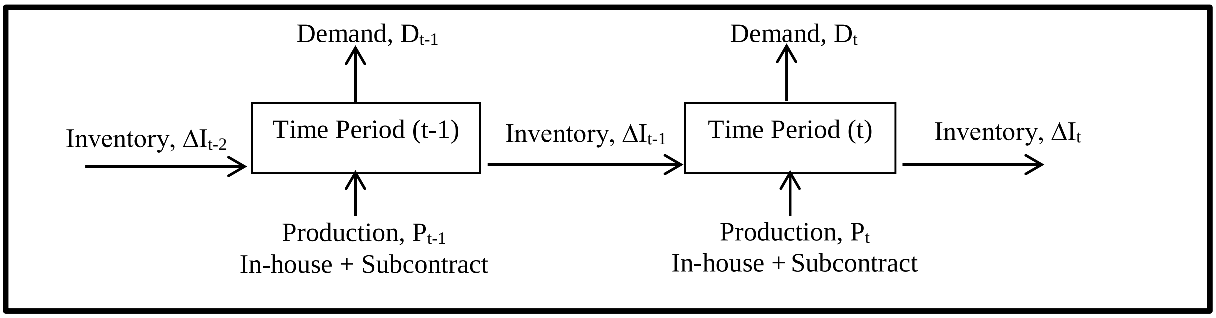


Fig. 1. The concept of supply chain cascade analysis which derived from material quantity balance over a time period

At the end of this period, there will either be excess in inventory or deficit (often called stock-out). From a calculation point of view, surplus will carry a positive sign whilst deficit will be denoted with a negative sign. This can be further demonstrated by using Supply and Demand Composite Curve as well as Grand Composite Curve. These two charts relay the same message, but the Grand Composite Curve magnifies the consequences.

In their later work, Singhvi et al. [22] briefly extended their targeting approach into multi products on single processors whilst Foo [23] extended his targeting approach into scheduling and allocation of the batch reactor. To overcome the limitation in graphical tools, especially in accuracy and cumbersomeness, Foo et al. suggested a cascade analysis technique that was originally developed in resource conservation networks [24] and also introduced minimum and maximum inventory as well as its application in scheduling process shut down. This kind of production planning problem with inventory constraints is reported equivalent to the Euclidean shortest path problem in computational geometry [25] and the optimised framework that built on to the cascade analysis techniques namely, automated targeting model which originally for resource conservation network development was further extended into aggregate planning for production [26].

Later on, Lim et al. [27] also proposed a new set of Composite Curve and Grand Composite Curve for matching production sinks and sources. The author concluded that the accurate demand forecast is important for timing before the pinch by exploring the sensitivity using Composite Curve [28].

In all these studies, however, none of the Pinch Analysis in supply chain applications has considered multiple products with multiple batch processors as well as its implications on company strategy. Thus, this study is conducted to develop a Production Decision Support System based on a simulation approach leveraging on the Pinch Analysis Graphical approach to support planning strategy for batch manufacturing and in so doing, prove the effectiveness of this system. At the same time, this research is the first of its kind to venture into, and expand upon previously undiscovered area of batch multiple products on multiple processors.

This research will leverage on the widely available Microsoft Excel software, allowing plant managers access to a simple and quick assessment tool for re-planning or scenario changes.

3. Methodology

This section presents an overall framework for batch production capacity planning and hence supports the establishment of manufacturing strategies. The detailed procedures for designing and developing the Production Decision Support System in this study are outlined in the following flow chart of Fig. 2.

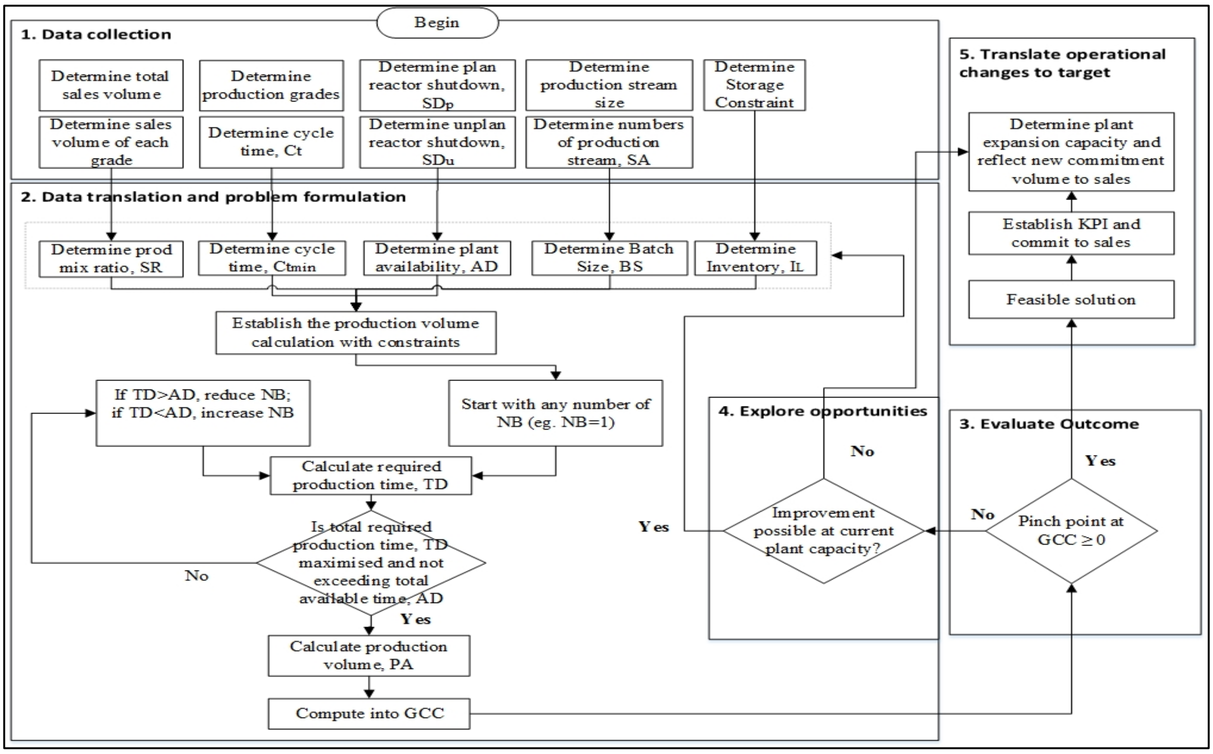


Fig. 2. Production Decision Support System (PDSS) flow chart

Firstly, data collection is to be started with. This includes the annual sales forecast to be tabulated according to respective grades, plant performance i.e. cycle time of each grades, plant reliability (historical unplanned shut down), shut down requirement of the year (planned maintenance), plant set up i.e. stream size and storage constraint, as well as available manpower. Using these available data, relationship among these parameters and constraints are to be established and determined by computing into spread sheet. This is to be followed by trial and error approach where the number of batches (NB) is manipulated until all constraints have been satisfied. If the ultimate simulated production volume is less than sale forecast, improvement opportunities are to be explored and the opportunities will act as the operation target for next year.

This concept of problem formulation can be further summarized into Fig. 3. A total of two case studies, which are for a single product with single reactor as well as for multiple products with multiple reactors have been included for better illustration of the methodology.

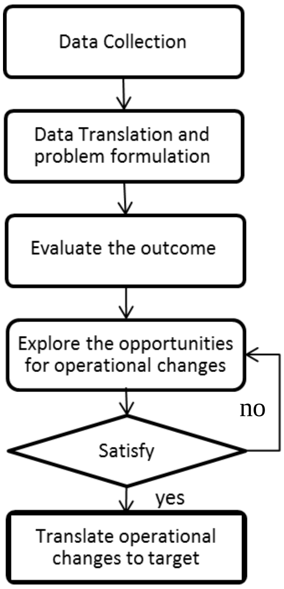


Fig. 3. Concept formulation of production decision support system

3.1 Case Study for Multiple Products with Multiple Reactors

There are two production lines in plant DQ that produce two products, namely A and B. Due to the reactor stream size difference, there are two batch sizes for each product i.e. A – 5 t and 10 t with a cycle time of 4 and 5 days, respectively; B – 7 t and 14 t with a cycle time 5 and 6 days, respectively. The production line A is scheduled to undergo 12 days of shutdown in June whilst the production Line B is scheduled to undergo the shutdown in December. Other than the planned shutdown, each production line is anticipating a day of unplanned shutdown based on plant historical data. The sales forecast is given in Table 15, Column 10. The respective inventory ratio will have to be maintained within 20% tolerance of the sales ratio.

3.1.1 Step 1 – Data collection

From the case study, set, parameters, and decision variables are defined as following Table 1and Table 2.

Table 1
Sets were used for case study DQ plant

Set	Description	Value
j	Product grades	2
k	Product types	1
m	Reactor stream	2
r	Reactor group	2
t	Calendar month	Jan to Dec

Table 2
List of decision variables for the case study of plant DQ

Notations	Unit	Description	Limit
AD_t	d	Number of available production days in the month for the period of t	See Table 15, column 8 and column 9.
IL	t	Inventory limit in kilogram	Nil
PR_j		product ratio of j	See Table 17 column 28.

Penerbit Akademia Baru

3.1.2 Step 2 – Data translation and problem formulation

a) Maximum production volume (PA_t) is stated as objective function. Refer equation (1).

Objective function = max $\sum PA_t$ (1)

b) Relationship is established by constructing Table 3 and Table 4.

i. Column 1 lists down the total days in the month (FD_t) whilst Columns 2 to 5 list down the unplanned ($SD^u{}_{t,r}$) and planned shutdown days of the respective reactor group ($SD^p{}_{t,r}$) with the sum of shutdown days in Columns 6 and 7 using equation (2).

$$SD_{t,r} = \sum_m (SD^p{}_{t,m} + SD^u{}_{t,m}), \forall r, \forall t \quad (2)$$

ii. Columns 8 and 9 are the available days of the respective reactor size group ($AD_{t,r}$) where total shut down days of respective reactor size group ($SD_{t,m}$) is deducted from the total days of the month of the respective reactor size group ($FD_{t,m}$) and divided by the total numbers of reactor in the group (N_m) using equation (3).

$$AD_{t,r} = \frac{\sum_m (FD_{t,m} - SD_{t,m})}{N_m}, \forall r, \forall t \quad (3)$$

iii. Sales forecast (SF_t) is listed in Column 10 whilst number of batches ($NB_{t,r}$) is listed in Columns 12 and 13 in Table 4. Number of batches is the total sum of batches made on these two reactor streams.

iv. Given the complexity of the different-sized streams that cause different batch sizes and cycle times, another table is established in addition to Table 3 and Table 4 as Table 5 and Table 6 where all grades are stated with their respective batch sizes ($BS_{j,t}$) and cycle time ($Ct^{min}{}_{j,t}$).

v. Column 18 lists down all grades (j), with respective batch sizes ($BS_{j,t}$) and cycle times ($Ct^{min}{}_{j,t}$) listed down in Columns 19, 20, 21, and 22. Number of batches in Columns 23 and 24 are estimated values. One may manipulate these values until the optimum production volume is achieved.

vi. Production volume (PA_t) can be calculated by summing up the multiplication from batch number ($NB_{j,t}$) and batch size ($BS_{j,t}$) of respective grade of the respective grade of the respective reactor stream using equation (4). The result is tabulated in Columns 25 and 26 with the sum of both in Column 27, as total production volume per month.

$$PA_t = \sum_m (NB_{j,t,m} \times BS_{j,t,m}), \forall j, \forall t \quad (4)$$

vii. Product ratio ($PR_{j,t}$), which is calculated using equation (5), is listed in Column 28.

$$PR_{j,t} = \frac{\sum_m PA_{j,t,m}}{PA_t}, \forall j, \forall t \quad (5)$$

viii. Total time required for production ($TD_{t,r}$) in Columns 29 and 30 can be calculated using data in Columns 21 to 24, as per equation (6).

$$\mathrm{TD_{t,r}} = \frac{\sum_m \mathrm{NB_{j,t,m}} \times \mathrm{Ct^{min}}_{\mathrm{j,t,m}}}{\mathrm{N_m}}, \forall \mathrm{r}, \forall \mathrm{t} \tag{6}$$

ix. Column 16 in Table 4 lists down the sum of Effective Plant Capacity *($EPC_{t,r}$)* using equations (7) and (8).

$$\mathrm{EPC_{t,r}} = \frac{\sum_m \mathrm{PA_{t,m}\ x\ AD_{t,m}}}{\mathrm{TD_{t,m}}}, \forall \mathrm{r}, \forall \mathrm{t} \tag{7}$$

$$\mathrm{EPC_t} = \sum \ \mathrm{EPC_{t,r}}, \forall \mathrm{t} \tag{8}$$

x. Accumulated inventory of the month (AI_t) is tabulated in Column 17 using equation (9). This will be used to plot the Grand Composite Curve later.

$$\mathrm{AI_t} = \mathrm{AI_{t-1}} + \mathrm{PA_t} - \mathrm{SF_t}, \forall \mathrm{t} \tag{9}$$

c) All constraints are listed below:
   i. The time required for production (TD), has to be less or equal to total available days (AD), as per equation (10)

$$TD_{t,r} \leq AD_{t,r}, \forall t, \forall r \tag{10}$$

   ii. The product ratio of storage inventory has to be added with 20% sales product ratio, translated into the following constraint. This is tabulated in Columns 32 and 33.

$$SR_{j,t}\, x(1-0.2) \leq PR_{j,t} \leq SR_{j,t} x\ (1+0.2) \tag{11}$$

d) Trial-and-error method is done by entering the NB_t value in Columns 23 and 24 until the objective constraints are fulfilled. Alternately, the Microsoft Excel Solver function can be used to facilitate this process. Table 5 and 6 are referred.

Table 3
Tabulation of Production available days for plant DQ to meet the sales forecast in the original case

Remarks	1	2	3	4	5	6	7	8	9
Month, t	Total days in the month, FD_t	Unplanned Shut down days, $Sd^u_{,t,r}$		Planned Shutdown Days, $SD^p_{,t,r}$		S/D, $SD_{t,r}$		Available Day, $AD_{t,r}$	
Reactor stream, r		S	L	S	L	S	L	S	L
Jan-16	31.0	1.0	1.0	0.0	0.0	1.0	1.0	30.0	30.0
Feb-16	28.0	1.0	1.0	0.0	0.0	1.0	1.0	27.0	27.0
Mar-16	31.0	1.0	1.0	0.0	0.0	1.0	1.0	30.0	30.0
Apr-16	30.0	1.0	1.0	0.0	0.0	1.0	1.0	29.0	29.0
May-16	31.0	1.0	1.0	0.0	0.0	1.0	1.0	30.0	30.0
Jun-16	30.0	1.0	1.0	12.0	0.0	13.0	1.0	17.0	29.0
Jul-16	31.0	1.0	1.0	0.0	0.0	1.0	1.0	30.0	30.0
Aug-16	31.0	1.0	1.0	0.0	0.0	1.0	1.0	30.0	30.0
Sep-16	30.0	1.0	1.0	0.0	0.0	1.0	1.0	29.0	29.0
Oct-16	31.0	1.0	1.0	0.0	0.0	1.0	1.0	30.0	30.0
Nov-16	30.0	1.0	1.0	0.0	0.0	1.0	1.0	29.0	29.0
Dec-16	31.0	1.0	1.0	0.0	12.0	1.0	13.0	30.0	18.0

Note: S and L denote the two different reactor sizes in the plant DQ.

Table 4
Production and manpower simulation tabulation for plant DQ in meeting the sales forecast in original case

Remarks	10	11	12	13	14	15	16	17
Month, t	Sales Forecast, SF_t	Prod Volume, PA_t	Number of batches, $NB_{t,r}$		Time Required, $TD_{t,r}$		Effective Plant Capacity, EPC_t	Accumulated Inventory of the month, AI_t
Unit	t	t	-		d		t	t
Reactor stream, r			S	L	S	L		
Jan-16	100.0	108.9	7.0	5.0	30.0	30.0	108.9	8.9
Feb-16	110.0	97.4	6.5	4.5	27.0	27.0	97.4	-3.7
Mar-16	100.0	106.6	7.5	5.1	30.0	30.0	106.6	2.9
Apr-16	105.0	101.7	7.3	5.1	29.0	29.0	101.7	-0.4

May-16	100.0	104.7	7.5	5.3	30.0	30.0	104.7	4.3
Jun-16	90.0	85.8	4.3	5.1	17.0	29.0	85.8	0.1
Jul-16	100.0	104.7	7.5	5.3	30.0	30.0	104.7	4.8
Aug-16	110.0	102.3	7.5	5.5	30.0	30.0	102.3	-2.9
Sep-16	95.0	98.7	7.2	5.4	29.0	29.0	98.7	0.8
Oct-16	90.0	99.4	7.5	5.8	30.0	30.0	99.4	10.1
Nov-16	90.0	98.0	7.3	5.4	29.0	29.0	98.0	18.1
Dec-16	97.0	80.8	7.1	3.0	30.0	18.0	80.8	1.9
Total	1187.0	1188.9	84.1	60.5	341.0	341.0	1188.9	

Table 5
Additional table required to tabulate the respective product information, such as grade and batch sizes from January to Jun

Remarks	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**
Month, t	Grades, j	Batch size, $BS_{j,t}$ (kg)		Min Cycle Time, $Ct^{min}{}_{j,t}$ (day)		Number of Batches		Prod volume, $PA_{j,t,r}$ (kg)		Prod Volume, $PA_{j,t}$ (kg)	Product Ratio, $PR_{j,t}$	Time required, $TD_{t,r}$ (day)		Sales Ratio, $SR_{j,t}$	Product Ratio Tolerance (20%)	
Unit	-	t		d		-		t		t	-	d		-	-	
Reactor stream, r		S	L	S	L	S	L	S	L			S	L		Upper	Lower
Jan	A	5	10	4	5	5.2	0.0	26.1	0.0	26.1	0.2	20.9	0.0	0.3	0.4	0.2
	B	7	14	5	6	1.8	5.0	12.7	70.0	82.7	0.8	9.1	30.0	0.7	0.8	0.6
Feb	A	5	10	4	5	5.7	0.0	28.3	0.0	28.3	0.3	22.7	0.0	0.4	0.4	0.3
	B	7	14	5	6	0.9	4.5	6.1	63.0	69.1	0.7	4.3	27.0	0.6	0.8	0.5
Mar	A	5	10	4	5	7.5	0.5	37.5	5.2	42.7	0.4	30.0	2.6	0.5	0.6	0.4
	B	7	14	5	6	0.0	4.6	0.0	64.0	64.0	0.6	0.0	27.4	0.5	0.6	0.4
Apr	A	5	10	4	5	7.3	1.3	36.3	13.2	49.4	0.5	29.0	6.6	0.6	0.7	0.5
	B	7	14	5	6	0.0	3.7	0.0	52.3	52.3	0.5	0.0	22.4	0.4	0.5	0.3
May	A	5	10	4	5	7.5	1.7	37.5	16.9	54.4	0.5	30.0	8.5	0.6	0.7	0.5
	B	7	14	5	6	0.0	3.6	0.0	50.2	50.2	0.5	0.0	21.5	0.4	0.5	0.3
Jun	A	5	10	4	5	4.3	1.9	21.3	18.8	40.0	0.5	17.0	9.4	0.56	0.7	0.4
	B	7	14	5	6	0.0	3.3	0.0	45.8	45.8	0.5	0.0	19.6	0.44	0.5	0.4

Table 6
Additional table required to tabulate the respective product information, such as grade and batch sizes from July to December

Remarks	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**
Month, t	Grades	Batch Size, $BS_{j,t}$ (kg)		Cycle Time, $Ct^{min}{}_{,j,t}$ (day)		Number of Batches		Prod volume, $PA_{j,t,m}$ (kg)		Prod Volume, $PA_{j,t}$ (kg)	Product Ratio, $PR_{j,t}$	Time required, $TD_{t,r}$ (day)		Sales Ratio, $SR_{j,t}$	Product Ratio Tolerance (20%)	
Unit	-	t		d		-		t		t	-	d		-	-	
Reactor stream, r		S	L	S	L	S	L	S	L			S	L		Upper	Lower
Jul	A	5	10	4	5	7.5	1.7	37.5	16.9	54.4	0.5	30.0	8.5	0.60	0.7	0.5
	B	7	14	5	6	0.0	3.6	0.0	50.2	50.2	0.5	0.0	21.5	0.40	0.5	0.3
Aug	A	5	10	4	5	7.5	3.1	37.5	31.3	68.8	0.7	30.0	15.7	0.73	0.9	0.6
	B	7	14	5	6	0.0	2.4	0.0	33.5	33.5	0.3	0.0	14.3	0.27	0.3	0.2
Sept	A	5	10	4	5	7.2	3.1	36.2	31.3	67.5	0.7	29.0	15.6	0.74	0.9	0.6
	B	7	14	5	6	0.0	2.2	0.0	31.2	31.2	0.3	0.0	13.4	0.26	0.3	0.2
Oct	A	5	10	4	5	7.5	4.9	37.5	48.6	86.1	0.9	30.0	24.3	0.89	1.1	0.7
	B	7	14	5	6	0.0	0.9	0.0	13.3	13.3	0.1	0.0	5.7	0.11	0.1	0.1
Nov	A	5	10	4	5	7.3	3.6	36.3	35.6	71.9	0.7	29.0	17.8	0.78	0.9	0.6
	B	7	14	5	6	0.0	1.9	0.0	26.1	26.1	0.3	0.0	11.2	0.22	0.3	0.2
Dec	A	5	10	6	10	5.3	0.0	26.7	0.0	26.7	0.3	21.3	0.0	0.41	0.5	0.3
	B	7	14	10	15	1.7	3.0	12.1	42.0	54.1	0.7	8.7	18.0	0.59	0.7	0.5

3.1.3 Step 3 – Evaluate the outcome

Scenario 1 – original case: From the simulation outlined in Table 4, the Grand Composite Curve (Figure 4) was plotted. From this chart, it can clearly be observed that that plant capacity is unable to match the given sales forecast five out of twelve months of the year. This stock-out scenario happens before and after the plant shutdown. This would mean that rescheduling of shut down would not be able to help alleviate the entire situation. In addition, an immediate implementation will be required if any improvement is to be considered.

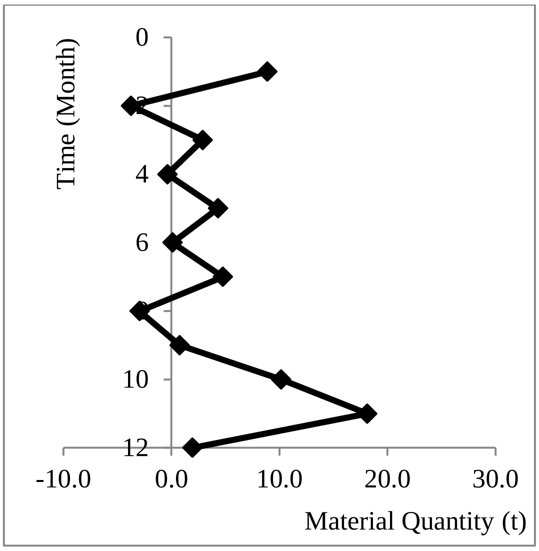


Fig. 4. Grand Composite Curve in original case for the example of multiple reactors

As such, Heuristic 1 (H1) is proposed: H1 Consider year-end inventory by using pinch to support the stock-out scenario at zero net inventory.

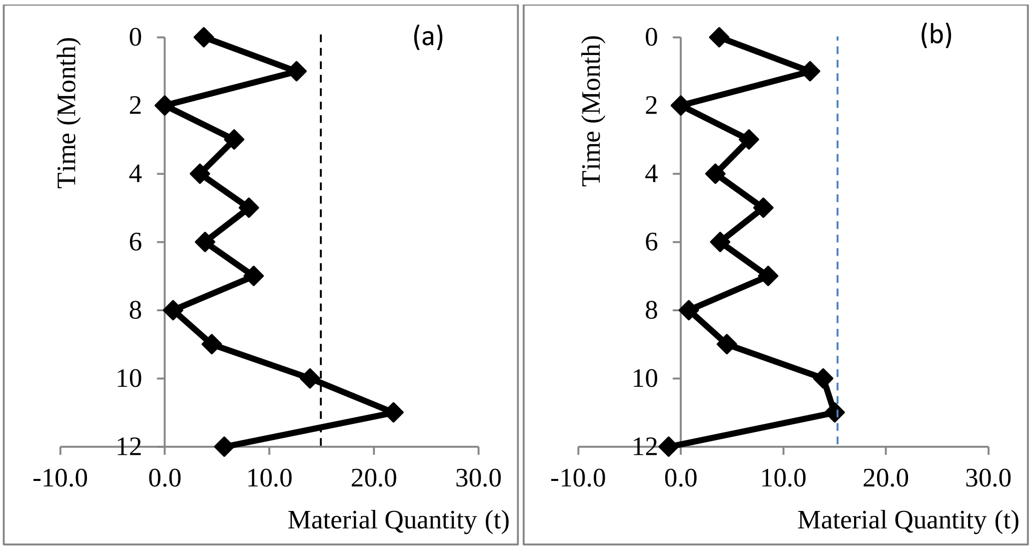


Fig. 5. Grand Composite Curve after H1 is considered (a: without inventory limit is being considered; b: with inventory limit considered)

3.1.4 Step 4 – Explore operational changes

Scenario 2 – Improved case with year-end inventory considered**:** After considering a minimum of 6.9 t of year-end inventory, the stock-out scenario could be resolved with the pinch point in Feb. Figure 5 is referred. A higher level of year-end inventory is to be considered if the plant were to fulfil the minimum stock inventory principle. However, the max inventory limit at site has to be kept not more than 15 t and thus the heuristic 1 alone will not be able to solve the stock-out scenario.

As such, Heuristic 2 (H2) is then proposed to consider optimising the batch size and cycle time. In this case, 0.1 t batch size increase and 0.02 d of cycle time reduction are being considered to address the stock-out scenario in December. See Fig. 6.

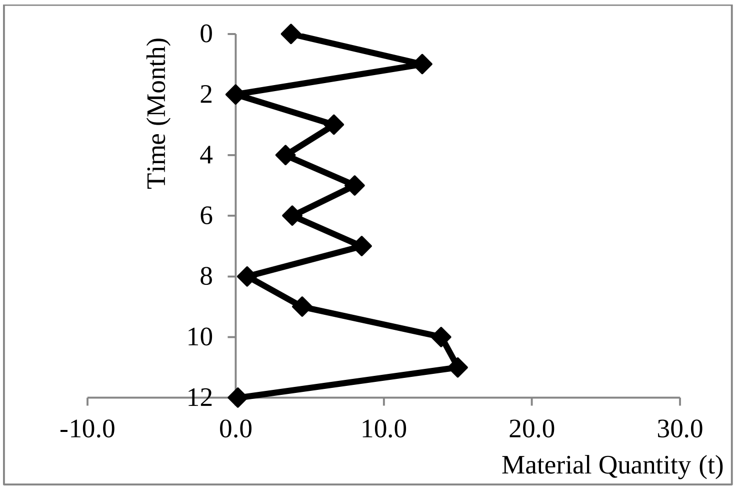


Fig. 6. Grand Composite Curve after H2 is being considered

3.1.5 Step 5 – Translation of changes to plant strategies

By simulating through the interactive Production Decision Support System, the plant now has a very clear strategy, which is to build the year-end inventory with a minimum of 3.7 t and also to implement the increase of 0.1 t batch size and the reduce of 0.1 d cycle time in order to meet the sales forecast next year.

From this example, a total of two heuristic rules are identified as the new strategies for the batch industry to match the plant capacity to the sales forecast:

i) Improve variables that can be influenced, such as cycle time, batch size, and plant availability to improve plant capacity.

ii) Consider sufficient year-end inventory taking into account the storage constraint in addressing the stock-out scenario.

4. Conclusion

This paper has successfully produced a general framework for batch production planning. The findings have successfully contributed towards the establishment of an algorithm tool to match production capacity against sales forecast by formulating possible batch manufacturing strategies via an aggregate planning methodology using the graphical pinch presentation and simulation approach. This study has also demonstrated the possibility of bridging the gap between the academic and industrial world when it comes to aggregate planning. The findings of this study have resulted in the development of a Production Decision Support System that integrates batch processes and tactical planning in a much simpler way. This system provides a fast and true holistic overview of plant capability, and thus helps plant managers to arrive at an effective decision in a timely manner. No specialised knowledge is needed and the Microsoft Excel tool, the only prerequisite for this system, is also widely available. Because of its flexibility, this system can also be used as a tool to set team site performance targets.

Acknowledgement
The authors would like to thank Universiti Teknologi Malaysia (UTM) for providing the financial support through the UTM Flagship Grant Scheme (UTMF), Vote number: R.J130000.7709.4J233.

References
[1] Zakwan, A.K.A., Zuhra, A.K.A. "Simulation of Scheduling Technique in a Food Processing Industry. " *Journal of Advanced Research Design* 19, no. 1 (2016): 14-18.
[2] Aghelie, A., Mustapha, N.M., Sorooshian, S., Azizan, N.A. "Mathematical Modelling of Interrelationship Analysis to Determine Multi-Criteria Decision Making Casual Relations." *Journal of Advanced Research Design* 20, no. 1 (2016): 18-33.
[3] Robert, A. "Planning and Control Systems. A Framework for Analysis." *Boston: Graduate School of Business Administration, Harvard University,* (1965).
[4] Verderame, P.M., Floudas, C.A. "Operational planning of large-scale industrial batch plants under demand due date and amount uncertainty. I. Robust optimization framework." *Industrial & engineering chemistry research* 48, no. 15 (2009): 7214-7231.
[5] Bitran, G.R., Tirupati D. "Hierarchical production planning." *Handbooks in operations research and management science* 4 (1993): 523-568.
[6] Pinedo, M. *Planning and scheduling in manufacturing and services*. Vol. 24. New York: Springer, 2005.
[7] Koulouris, A. "Estimating analytically the capacity of batch plants with shared equipment: a yoghurt plant case study." *Procedia Food Science*1 (2011): 1792-1798.
[8] Moreno, M.S., Montagna, J.M. "New alternatives in the design and planning of multiproduct batch plants in a multiperiod scenario." *Industrial & engineering chemistry research* 46, no. 17 (2007): 5645-5658.
[9] Biegler, L.T., Grossmann, I.E., Westerberg, A.W. "Systematic methods for chemical process design." (1997).
[10] Manganaro, J.L. "Estimate the capacity of simple batch processes." *Chemical engineering progress* 98, no. 8 (2002): 70-75.
[11] Chakrabortty, R.K., Akhtar Hasin, M.A., Sarker, R.A., Essam, D.L. "A possibilistic environment based particle swarm optimization for aggregate production planning." *Computers & Industrial Engineering* 88 (2015): 366-377.
[12] Holt, C.C., Modigliani, F., Simon, H.A. "A linear decision rule for production and employment scheduling." *Management Science* 2, no. 1 (1955): 1-30.
[13] Mula, J., Poler, R., Garcia-Sabater, J.P., Cruz Lario, F. "Models for production planning under uncertainty: A review." *International journal of production economics* 103, no. 1 (2006): 271-285.
[14] Martínez-Costa, C., Mas-Machuca, M., Benedito, E., Corominas, A. "A review of mathematical programming models for strategic capacity planning in manufacturing." *International Journal of Production Economics* 153 (2014): 66-85.
[15] Buxey, G. "Aggregate planning for seasonal demand: reconciling theory with practice." *International Journal of Operations & Production Management*25, no. 11 (2005): 1083-1100.
[16] Buxey, G. "Strategy not tactics drives aggregate planning." *International Journal of Production Economics* 85, no. 3 (2003): 331-346.
[17] Ramezanian, R., Rahmani, D., Barzinpour, F. "An aggregate production planning model for two phase production systems: Solving with genetic algorithm and tabu search." *Expert Systems with Applications* 39, no. 1 (2012): 1256-1263.
[18] Ludwig, J., Treitz, M., Rentz, O., Geldermann, J. "Production planning by pinch analysis for biomass use in dynamic and seasonal markets." *International Journal of Production Research* 47, no. 8 (2009): 2079-2090.
[19] Singhvi, A., Shenoy, U.V. "Aggregate planning in supply chains by pinch analysis." *Chemical Engineering Research and Design* 80, no. 6 (2002): 597-605.
[20] Tan, R.R., Bandyopadhyay, S., Foo, D.C.Y., Ng, D.K.S. "Prospects for novel pinch analysis application domains in the 21st century." *Chem. Eng. Trans.* 45 (2015): 1741-1746.

[21] Foo, D.C.Y., Ooi, M.B., Tan, R.R., Tan, J.S. "A heuristic-based algebraic targeting technique for aggregate planning in supply chains." *Computers & Chemical Engineering* 32, no. 10 (2008): 2217-2232.

[22] Singhvi, A., Madhavan, K.P., Shenoy, U.V. "Pinch analysis for aggregate production planning in supply chains." *Computers & chemical engineering* 28, no. 6 (2004): 993-999.

[23] Foo, D.C.Y., Hallale, N., Tan, R. "Pinch analysis approach to short-term scheduling of batch reactors in multi-purpose plants." *International Journal of Chemical Reactor Engineering* 5, no. 1 (2007).

[24] Foo, D.C.Y., Abdul Manan, Z. "Setting the minimum utility gas flowrate targets using cascade analysis technique." *Industrial & engineering chemistry research* 45, no. 17 (2006): 5986-5995.

[25] Chaturvedi, N.D., Bandyopadhyay, S. "Targeting aggregate production planning for an energy supply chain." *Industrial & Engineering Chemistry Research* 54, no. 27 (2015): 6941-6949.

[26] Foo, D.C.Y. "Automated targeting model for aggregate planning in production and energy supply chains." *Clean Technologies and Environmental Policy*: 1-10.

[27] Lim, J.S.H., Foo, D.C.Y., Ng, D.K.S., Tan, R.R., Aziz, R. "Pinch analysis for production planning in manufacturing industries." *Chemical Engineering* 120, no. 8 (2013): 40.

[28] Lim, J.S.H., Foo, D.C.Y., Ng, D.K.S., Aziz, R., Tan, R.R. "Graphical tools for production planning in small medium industries (SMIs) based on pinch analysis." *J Manuf Syst* 33 (2014): 639-646.