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Production Decision Support System for Multi-product with Multiple Different Size Processors

Lee Pheng Chee[a,b], Sharifah Rafidah Wan Alwi[a,b,*], Jeng Shiun Lim[a,b]

[a]Process Systems Engineering Centre (PROSPECT), Research Institute of Sustainable Environment, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[b]Faculty of Chemical & Energy Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
syarifah@utm.my

Aggregate planning is an operational activity with the objective of providing upfront information on quantity of material to be procured and resources to be secured. At a point of time, it might also influence both demand and supply. This is where the sales division will work closely with operation on aggregate planning to deliver maximum profit. Aggregate planning does not only serve as a master plan for the production planner, it is also closely linked to organisational decision-making. Realising its importance, researchers have worked on this subject consistently since 1950s but due to complexity and practicality issue, industry did not manage somehow to adopt the research work. In 2016, the concept of Production Decision Support System (PDSS) was introduced following the Pinch Analysis extended into supply chain area. In this work, the PDSS is applied to a batch industry case which involve multi-products with multiple different size processors. From the assessment, the PDSS has not only demonstrated its practicality but also helped the plant to realise their potential capacity. This has assisted the plant management to realign the strategy and avoided the original intention of expensive expansion.

1. Introduction

Aggregate planning is an operational activity. It is normally performed as part of a production process for an advanced period of two to 18 months with the objective of providing upfront information on quantity of material to be procured and resources to be secured (Chakrabortty et al., 2015). According to Chinguwa et al. (2013), production planning starts with a business plan where capacity investment is matched against projected market requirement. This is where the sales division will come into play and work closely with operation on aggregate planning to deliver maximum profit. This will then result aggregate planning to influence both demand and supply.

Aggregate planning does not only serve as a master plan for the production planner, it is also closely linked to organisational decision-making, especially during budgeting development and very often the budget revision can only be warranted with the agreement gained from aggregate planning. The importance of aggregate planning has attracted the interest of many researches ever since the 1950s, starting with Linear Decision Rule (Holt et al., 1955). All those research works including some other mathematical and heuristic based techniques have been summarised in the review paper by Martinez in year 2014 (Martinez-Costa et al., 2014). Despite all this, industry still somehow could not manage to appreciate completely on those good research works (Ramezanian et al., 2015).

Pinch Analysis from Process Integration Approach was applied into aggregate planning by Singhvi and Shenoy (2002). In the year 2016, Production Decision Support System (PDSS) was introduced by Chee et al. (2016) for dealing with multiple production contributory factors such as cycle time, batch size, plant availability, and number of stream and product mixes. In Chee et al. (2017), the method was extended for multiple product types and product grades with multiple reactors. The objective of this paper is to implement the Production Decision Support System concept to a batch industry case which involves multi-products with multiple different size processors.

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2. Case Study

This plant has twelve reactor streams. Not all the streams share the same size. Four of the twelve reactors have half the reactor size of the rest of the streams. Out of these four smaller-sized reactors, two of the reactors have been taken out and are now being revamped to prepare for different product production. In short, there are ten available reactors: two small and eight big reactors.

This emulsion plant operates 24 h / 7 d a week, which is the same as the other plant. This plant has six grades but only produces one type of product, which is Type I. The sales forecast is tabulated as per Table 1 and the respective processing time as well as the batch sizes have been compiled and consolidated in Table 2.

Table 1: Annual sales forecast in t for the emulsion plant

Product, j	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
61A	1,760	1,545	1,521	1,039	1,031	1,420	1,116	1,122	1,173	1,134	1,134	1,134
62B	2,492	2,344	3,075	2,549	2,922	3,330	3,741	3,301	3,301	3,278	3,255	3,255
67C	1,395	1,390	1,250	888	1,328	1,503	1,392	1,505	1,505	1,447	1,493	1,447
60D	69	92	-	69	-	-	-	-	-	-	-	-
69E	1,816	1,778	1,761	1,855	2,115	2,152	2,000	2,156	2,098	2,098	2,098	2,098
68D	93	59	177	106	23	118	61	106	83	83	106	83
Total	7,624	7,208	7,783	6,507	7,419	8,524	8,310	8,190	8,160	8,040	8,086	8,017

Table 2: Processing data of the product grade for the emulsion plant

Grade, i	Reactor conditioning, RC (h)	Recipe Time, RT (h)	Reactor Transfer time, TT (h)	Adjustment, AT (h)	Stripping time, ST (h)	Sieving time, FT (h)
61A (S)	1.0	10.0	0.4	0.9	6.0	1.3
62B (S)	0.5	12.0	0.4	1.3	9.5	1.5
67C (S)	0.5	10.0	0.4	1.5	7.0	1.4
60D (S)	0.6	10.0	0.4	0.8	8.0	1.4
68D (S)	0.9	10.5	0.4	1.0	8.0	1.3
61A (L)	1.3	11.0	0.5	1.0	8.0	1.3
69E (L)	0.8	12.5	1.0	3.0	9.0	1.3
62B (L)	0.8	12.5	1.0	3.0	9.0	1.3
67C (L)	0.5	10.0	0.4	1.5	7.0	1.4

There are several product grades that can be produced with either the small or big reactors. The same grade produced from the different-sized reactors will be treated as two different grades during plant data collection. In the sales forecast, this parameter is treated the same. An overview of case study is illustrated in Figure 1.

3. Data translation and problem formulation

The step by step procedure to calculate the effective plant capacity based on sales forecast are described next.

3.1 Determine of minimum Cycle Time, Ct_{min}

Following the definition from Biegler et al. (1997), both reactor and stripper cycle time for this case study can be rewritten as Eq(1) and Eq(2).

$$CT_j^R = RC_j + RT_j + TT_j \quad (1)$$

$$CT_j^S = TT_j + AT_j + ST_j + FT_j \quad (2)$$

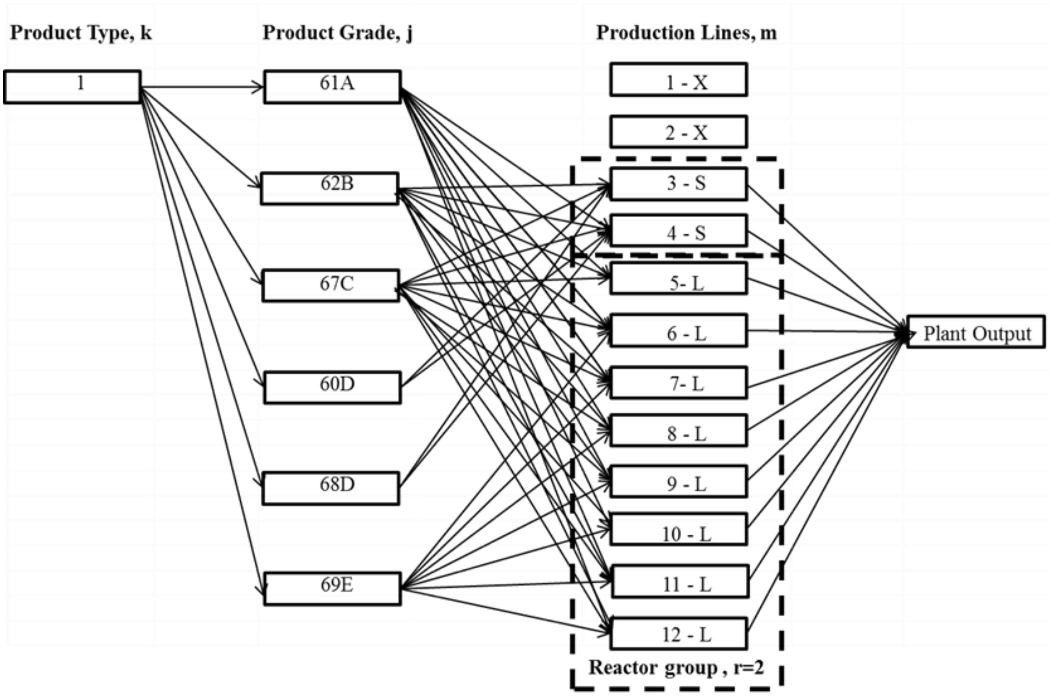

Figure 1: Product arrangement overview of the case study

The minimum cycle time, Ct_{min} can be determined by using Eq(3), and the values are presented in Table 3. The processing time of the same grade products produced by the different reactor sizes are different since the reaction time is not the same.

$$Ct_{min} = \max(CT_j^R, CT_j^S) \quad (3)$$

Table 3: Simplified cycle time using Eq(1) to Eq(3)

Grade, j	Change-over time, CO (d)	Reactor Cycle time, CT^R_j (h)	Stripper cycle time, CT^S_j (h)	Minimum Cycle time, Ct_{min}
61A (S)	0	11.417	8.583	11.417
62B (S)	0	12.917	12.750	12.917
67C (S)	0	10.917	10.333	10.917
60D (S)	0	11.000	10.667	11.000
68D (S)	0	11.833	10.667	11.833
61A (L)	0	12.833	10.750	12.833
69E (L)	0	14.250	14.333	14.333
62B (L)	0	14.250	14.333	14.333
67C (L)	0	10.917	10.333	10.917

Note: “S” indicate a small size reactor, “L” indicates big size reactor

3.2 Determine of plant availability, AD

In this plant, the number of days the plant is available is calculated according to the reactor size group, as per Eq(4). Two of the small reactors have been taken out for revamping (out of service for 2 y). The availability of the first two small reactors are indicated as zero available days. Based on the historical data, this plant requires five unplanned shut down days per month and 14 d of planned shut down for maintenance. The calculated plant availability for the respective reactor group is summarised in Table 4.

$$AD_{t,r} = \frac{\sum_m (FD_{t,m} - SD_{t,m})}{N_m}, \forall r, \forall t \quad (4)$$

where $SD_{t,m}$ is the total number of planned shutdown days of identical production line m for the month t, N_m is the total number of identical production lines, m, $FD_{t,m}$ is the total number of calendar days in the month t.

Table 4: The available days of all production streams

Month, t	Total days for the month, FD_t (d)	Shut down, SD		Available Day for the respective stream, AD (d)												Total Available Day, $AD_{t,r}$ (d)	
		Unplanned shutdown /reactor (d)	Planned shutdown/ reactor (d)	R1S	R2S	R3S	R4S	R5L	R6L	R7L	R8L	R9L	R10L	R11L	R12L	S	L
Jan-15	31	5	0	0	0	26	26	26	26	26	26	26	26	26	26	26	26.0
Feb-15	28	5	0	0	0	23	23	23	23	23	23	23	23	23	23	23	23.0
Mar-15	31	5	14	0	0	12	26	26	26	26	26	26	26	26	26	19	26.0
Apr-15	30	5	14	0	0	25	11	25	25	25	25	25	25	25	25	18	25.0
May-15	31	5	14	0	0	26	26	12	26	26	26	26	26	26	26	26	24.3
Jun-15	30	5	14	0	0	25	25	25	11	25	25	25	25	25	25	25	23.3
Jul-15	31	5	14	0	0	26	26	26	26	12	26	26	26	26	26	26	24.3
Aug-15	31	5	14	0	0	26	26	26	26	26	12	26	26	26	26	26	24.3
Sep-15	30	5	14	0	0	25	25	25	25	25	25	11	25	25	25	25	23.3
Oct-15	31	5	14	0	0	26	26	26	26	26	26	26	12	26	26	26	24.3
Nov-15	30	5	14	0	0	25	25	25	25	25	25	25	25	11	25	25	23.3
Dec-15	31	5	14	0	0	26	26	26	26	26	26	26	26	26	12	26	24.3
Total	365	60	140	0	0	291	291	291	291	291	291	291	291	291	291	291	291

3.3 Determine the reactor stream number, SR

The reactor stream is only meant for one type of product. As such, each reactor shares one full production reactor stream, which is the same reactor stream.

3.4 Determine product mix

From the annual sales forecast, the product mix ratio is calculated as per Eq(5) and then tabulated in Table 5.

$$SR_{j,t} = \frac{S_{j,t}}{SF_t}, \forall t \tag{5}$$

where $S_{j,t}$ is the total sales of the product j for the month t, and SF_t is the total sales forecast for the month t.

Table 5: Product mix ratio on respective grades as calculated based on sales forecast

Product, *j*	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
61A	0.231	0.214	0.195	0.160	0.139	0.167	0.134	0.137	0.144	0.141	0.140	0.141
62B	0.327	0.325	0.395	0.392	0.394	0.391	0.450	0.403	0.405	0.408	0.403	0.406
67C	0.183	0.193	0.161	0.136	0.179	0.176	0.168	0.184	0.184	0.180	0.185	0.181
60D	0.009	0.013	0.000	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
69E	0.238	0.247	0.226	0.285	0.285	0.252	0.241	0.263	0.257	0.261	0.259	0.262
68D	0.012	0.008	0.023	0.016	0.003	0.014	0.007	0.013	0.010	0.010	0.013	0.010
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

3.5 Calculate the Effective Plant Capacity (EPC)

Given the plant availability (AD_t) is equal to Total Required Production day (TD_t) for this case study; the Effective Plant Capacity EPC_t adopted the calculation for Production Volume PA_t where product mix, minimum cycle time, and the batch size are taken into consideration (Chee et al., 2016), as shown in Eq(6).
The Production Volume PA_t is calculated by using Eq(7). The calculated EPC is summarised in Table 6.

$$EPC_{t,r} = \frac{\sum_m PA_{t,m} \text{ x } AD_{t,m}}{TD_{t,m}}, \forall r, \forall t \tag{6}$$

$$PA_t = \sum_m (NB_{j,t,m} \times BS_{j,t,m}), \forall j, \forall t \tag{7}$$

Table 6: Summary of calculated Effective Plant Capacity based on sales forecast

Month, t	Total days for the month, FD_t	Total Available Day, AD_t (d)		Time required, TD_t (d)		Number of batches, NB_t	Sales Forecast, SF_t	Production Vol, PA_t			Accumulated Inventory of the month, AI_t
		S	L	S	L			S	L	Total	
Jan-16	31	26.0	26.0	26.0	26.0	425	7,624	1,338	9,617	10,955	3,331
Feb-16	28	23.0	23.0	23.0	23.0	378	7,208	1,188	8,492	9,680	5,803
Mar-16	31	19.0	26.0	19.0	26.0	408	7,783	966	9,543	10,509	8,529
Apr-16	30	18.0	25.0	18.0	25.0	387	6,507	925	9,083	10,007	12,029
May-16	31	26.0	24.3	26.0	24.3	395	7,419	1,339	8,758	10,097	14,707
Jun-16	30	25.0	23.3	25.0	23.3	381	8,524	1,281	8,457	9,739	15,922
Jul-16	31	26.0	24.3	26.0	24.3	391	8,310	1,336	8,739	10,075	17,687
Aug-16	31	26.0	24.3	26.0	24.3	395	8,190	1,333	8,777	10,110	19,606
Sep-16	30	25.0	23.3	25.0	23.3	379	8,160	1,283	8,423	9,706	21,152
Oct-16	31	26.0	24.3	26.0	24.3	395	8,040	1,328	8,780	10,108	23,220
Nov-16	30	25.0	23.3	25.0	23.3	378	8,086	1,282	8,422	9,703	24,837
Dec-16	31	26.0	24.3	26.0	24.3	393	8,017	1,334	8,776	10,110	26,930
Total	365	291	291	291	291.0	4,623	93,869	14,365	104,505	120,799	

4. Results and Discussion

Both demand and supply are translated into a Composite Curves and Grand Composite Curve, as shown in Figure 2 and 3.

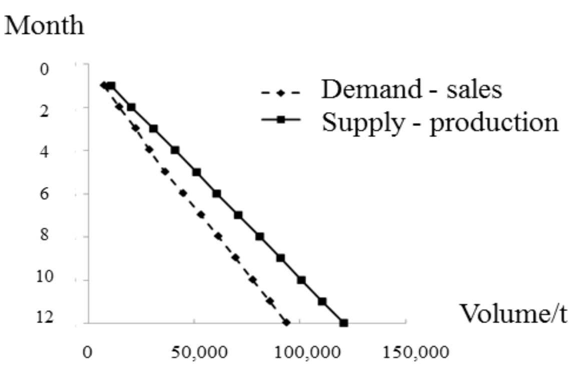

Figure 2: Composite Curve “as it is”

Based on the Effective Plant Capacity calculation as well as the Composite Curves, this batch plant should be able to cater for a sales volume of 120,800 t/y and stock-out scenarios should not exist. This is calculated based on the current product mix and at 80 % production stream availability. This result suggests that the local site management team look into their production stream availability in terms of reliability; the actual production stream availability is below 65 %. According to world-class production overall equipment effectiveness, the plant should achieve at least 85 % availability. From this, it can be concluded that much improvement can be done via an in-depth study of underlying causes to unlock any unutilised capacity before proceeding to future plant expansions.

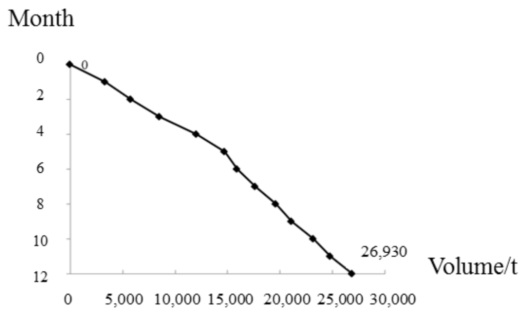

Figure 3: Grand Composite Curve "as it is"

5. Conclusions

Through this study, the Production Decision Support System has been applied for aggregate planning for multi-product with multiple different size processor. It demonstrated a much simpler way of tactical planning in batch processes. It provides a fast and true holistic overview of plant capability and 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 is also being used as a tool to set team site performance targets.

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Reference

Biegler L.T., Grossmann I.E., Westerberg A.W., 1997, Systematic Methods of Chemical Process Design, Prentice Hall, New Jersey, USA.

Chakrabortty R.K., Hasin M.A.A., Sarker R.A., Essam D.I., 2015, A possibilistic environment based particle swarm optimization for aggregate production planning, Computers & Industrial Engineering, 88, 366-377.

Chee L.P., Wan Alwi S. R., Lim J.S., 2016, Production decision support system for batch processes, Journal of Advanced Research in Applied Sciences and Engineering Technology, 5 (1), 7-21.

Chee L.P., Wan Alwi S.R., Lim J.S., Siwayanan P., 2017, Production decision support system: Real-life emulsion plant case study, Chemical Engineering Transactions, 56, 1267-1272.

Chinguwa S., Madanhire I., Musoma T., 2013, A decision framework based on aggregate production planning strategies in a multi-product factory: A furniture industry case study, International Journal of Science and Research, 2 (2), 370-383.

Holt C.C., Modigliani F., Simon H.A., 1955, A linear decision rule for production and employment scheduling, Management Science, 2 (1), 1-30.

Martínez-Costa C., Mas-Machuca M., Benedito E., Corominas A., 2014, A review of mathematical programming models for strategic capacity planning in manufacturing, International Journal of Production Economics, 153, 66-85.

Ramezanian R., Rahmani D., Barzinpour F., 2012, An aggregate production planning model for two phase production systems: Solving with genetic algorithm and tabu search, Expert Systems with Applications, 39 (1), 1256-1263.

Singhvi A., Shenoy U.V., 2002, Aggregate planning in supply chains by pinch analysis, Chemical Engineering Research and Design, 80 (6), 597-605.