

# Multi-Stage, Multi-Product Optimization Problem in a Multinational Chemical Company

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**Summary:** This thesis provides an evaluation of a linear optimization model for the production process of a specialty chemical company in Indonesia. Base on linear programming, the optimization model provides optimal solutions for raw material procurement, production and final delivery to customers. The results obtained from the model proved that there is significant potential to minimize the total cost for production with implementation of the model.



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## KEY INSIGHT

- Significant potential cost reduction by implementing linear optimization model into production decision making process
- The proposed model can be used at any stage of supply chain to simulate and analyze different production decisions.
- Choosing right combinations of raw material to produce products is the most critical to the production process.

## Introduction

The company is one of the world's leading specialty chemicals companies which has 156 subsidiaries spread over 52 countries. The company has invested in operational excellence, commercial excellence and people excellence as key foundation pillars of growth. The highest proportion of the company's sales originates from Europe, but recent trend shows that the Middle East & Asia Pacific regions are increasingly contributing to sales volumes. The company operates in four key areas as 1. Care

Chemicals 2. Catalysis 3. Natural Resources and 4. Plastics and Coating. The company has several factories in Europe, Latin America and Asia & Pacific as part of its global supply chain. Each of these group of factories serves corresponding markets and the facilities serving Asia & Pacific market are located in Indonesia. For this thesis, the scope is defined as to optimize the production process for a "BT" (fictitious name) products produced & distributed in Indonesia.

## Research Objective

The complexity of this study is originated from the variability exists in selecting raw materials, Bill of Materials and production facilities to produce enough amount of products to fulfill the demand. The company's production process has unique features which distinguishes the problem to other optimization problem. First one is the "Grade" feature which means that the group of SKUs which have same "Grade" can be substituted when one SKU is not enough to fulfill the demand. Another feature is the "Bill of Material(BOM) selection). There are multiple BOMs can be used to produce a single SKU. These features add significant complexity to the problem and cause difficulty to make an optimized decision. The objective of this thesis is to develop a linear programming model which can optimize the company's production decision by provide the solutions for below questions :

- What is the optimal setup that minimizes supply, manufacturing and distribution cost?
- What factory should serve what markets?
- What is the optimal BOM to use in order to minimize cost and maximize capacity?

## Literature Review

Supply chain management is often defined as the art of bringing the right amount of the right product to the right place at the right time within the right budget (Tilanus, 1997). Production systems with multi-stage processes are often present in the chemical industry. One main benefit of using such a line is the ability to manufacture the right quantity and the right product required by the market every day (Miltenburg and Sinnamon, 1989). Kim and Lee (2000) discussed multi-stage production and distribution planning in relation to the supply chain management concept. A problem similar to that of Kim and Lee was solved by Sim, Jang, and Park (2000), by means of a heuristic method. Azevedo and Sousa (2000) researched an order plan model that could serve a multi-stage production system. Such a system is capable of processing products and materials through different production units that are part of the logistics chain organized in several phases. The authors attempted to determine, for each order received, an "optimal" cost path through the network.

## Methodology

The steps undertaken in the development of the model are visually represented in figure 1 below.

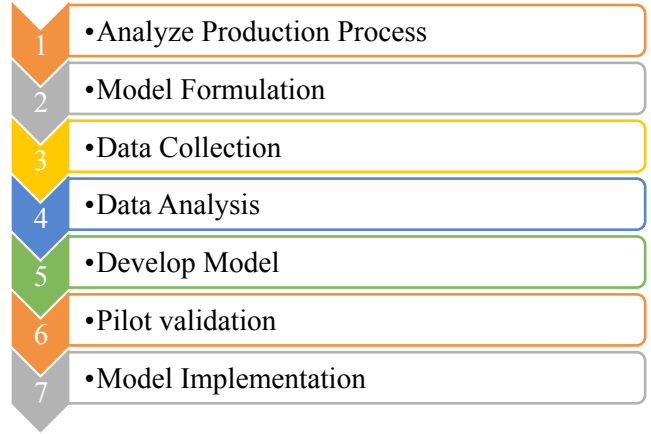


Figure 1 – Methodology

### Step 1: Analyzing Production Process

To clearly understand and develop a feasible model to implement, a thorough analysis on current production process is performed.

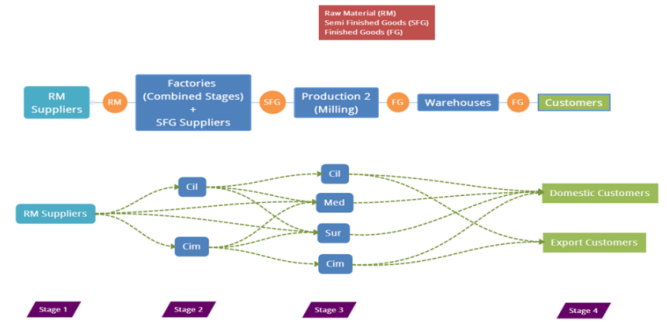


Figure 2 – Production Flow

### Step 2: Mathematical Formulation

A mathematical formulation to minimize the total cost associated within the production process is developed.

To minimize :

$$\sum_{fpl \in FPL} \sum_{bp \in BP} qso_{fpl, bp} * dc_{fpl, bp} \quad (1)$$

$$+ \sum_{g \in G} \sum_{p \in P} \sum_{b \in B} \sum_{fpl \in FPL} qpr_{g, p, b, fpl} * cc_{fpl, p} \quad (2)$$

$$+ \sum_{g \in G} \sum_{p \in P} \sum_{b \in B} \sum_{tpl \in TPL} qpr_{g, p, b, tpl} * cc_{tpl, p} \quad (3)$$

$$\begin{aligned}
& + \sum_{fpl \in FPL} \sum_{tpl \in TPL} \sum_{bp \in BP} qit_{fpl.tpl.bp} * tc_{fpl.tpl} \\
& + \sum_{tpl \in TPL} \sum_{c \in C} \sum_{l \in L} \sum_{g \in G} \sum_{p \in P} qdi_{tpl.c.l.g.p} * tc_{tpl.l}
\end{aligned} \quad (5)$$

Where :

**FPL:** Set of production plants in stage 2

**TPL:** Set of production plants in stage 3

**C:** Set of customers

**L:** Set of delivery locations

**B:** Set of BOM Ids

**BP:** Set of BOM PPCs

**G:** Set of PPC grades

**P:** Set of PPCs

Subject to :

$$\begin{aligned}
& \sum_{fpl \in FPL} qso_{fpl.bp} \leq cmax_{bp} \quad \forall bp \in BP \\
& \sum_{g \in G} \sum_{b \in B} qpr_{g.p.b.fpl} \leq cp_{st.fpl.p} \quad \forall fpl \in FPL, p \in P \\
& \sum_{g \in G} \sum_{b \in B} qpr_{g.p.b.tpl} \leq cp_{tpl.p} \quad \forall tpl \in TPL, p \in P \\
& qso_{fpl.bp} - \sum_{g \in G} \sum_{p \in P} \sum_{b \in B} qpr_{g.p.b.fpl} * uqbom_{p.b.bp} \\
& \quad = 0 \quad \forall bp \in BP, fpl \in FPL \\
& \sum_{g \in G} \sum_{b \in B} \sum_{fpl \in FPL} qpr_{g.p.b.fpl} - \sum_{fpl \in FPL} \sum_{tpl \in TPL} qit_{fpl.tpl.bp} \\
& \quad = 0 \quad \forall p = bp \text{ and } bp \in BP, p \in P \\
& \sum_{fpl \in FPL} qit_{fpl.tpl.bp} - \sum_{g \in G} \sum_{p \in P} \sum_{b \in B} qpr_{g.p.b.tpl} \\
& \quad * uqbom_{p.b.bp} = 0 \quad \forall bp \in BP, tpl \\
& \quad \in TPL
\end{aligned}$$

$$\begin{aligned}
& \sum_{p \in P} \sum_{b \in B} \sum_{tpl \in TPL} (qpr_{g.p.b.tpl} - \sum_{c \in C} \sum_{l \in L} qdi_{tpl.c.l.g.p}) \\
& \quad = 0 \quad \forall g \in G \\
& \sum_{tpl \in TPL} \sum_{c \in C} \sum_{l \in L} \sum_{p \in P} qdi_{tpl.c.l.g.p} - qde_{c.l.g.p} \geq 0 \quad \forall g \\
& \quad \in G
\end{aligned}$$

Equation (1) is the objective function which is to minimize the raw material cost.

Equation (2) is the objective function which is to minimize the production cost(stage 2).

Equation (3) is the objective function which is to minimize the production cost(stage 3).

Equation (4) is the objective function which is to minimize the inter-transportation cost.

Equation (5) is the objective function which is to minimize the Final delivery transportation cost.

### Step 3: Data Collection

According to the cost equation developed above, a list of the data request is sent to the company. The objective of data collection is to gather as much as quantitative key factors and develop a set of the sound database which can be used in the model.

### Step 4: Data Analysis

The requested datasets were given in the company's format which does not fit into the model. It was clear that a thorough cleaning and categorizing would be necessary to build a sound database. The gathered data was cleaned and standardized to build a consistent & solid database.

### Step 5: Developing Optimization Model

A pilot model is developed to clearly understand the design and flow of the final model. Due to the compatibility and by the request from the company, we used Open Solver on an electronic spreadsheet, so all the outcomes and variables had to be in a single spreadsheet.

### Step 6: Pilot Validation

The pilot model is presented to the company. To identify if the model is generating a feasible output, a set of sample demand data is used. Both parties analyzed the results and re-adjusted the model.

### Step 7 : Model Implementation

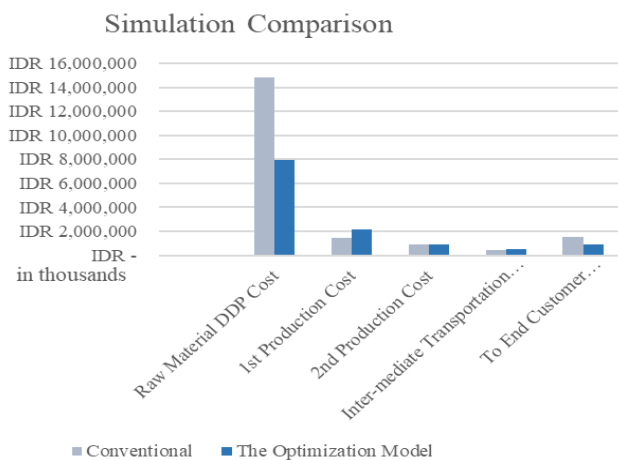
After validation of the model, forecasted(3 months) demand data is implemented to the model.

### Results

A simulation for the sample demand with current business practice is performed to compare the outcome with the result from the model.

The results show that with the sample demands of 12 SKUs in 6 destinations, the model produces only 8 SKUs to fulfill the demand. It was clear that the model is choosing the option with lowest cost to fulfill the demand in the same “Grade”.

The comparison with the simulation shows how much the model may contribute to the company’s production decision to reduce the cost. According to the comparison results, the total cost for raw material purchase significantly decreased from 14, 828 mil IDR to 7,946 mil IDR (46% reduction) and the transportation cost for final delivery decreased from 1,500 mil IDR to 879 mil IDR (40% reduction). On the other hand, the production cost for intermediate product increased from 1,432 mil IDR to 2,187 mil IDR (53% increase). Overall, the total cost for production went down from 19,248 mil IDR to 12,502 mil IDR (35%).



**Figure 4 – Simulation Comparison**

Another significant takeaway from the result is the sensitivity of each cost to the change of decision. The raw material cost takes almost over 65% of proportion in either case, which tells that the raw material selection is the single most contributing factor to the total cost. The 1<sup>st</sup> production cost varies a lot to the different decisions, but the 2<sup>nd</sup> production cost stays almost same in either case. The transportation cost for intermediate and final delivery varies a lot to the different decisions, but the effect of the change to the total cost is less significant than the raw material cost.

### Conclusion

The result from the model shows that the company’s production process has potential to be improved with the optimization model. It is suggested to focus more on optimizing the raw material selection process, because it is the most significant component of the total cost. The benefit of optimizing the production cost from stage 2 and stage 3 are somewhat minimal since the production cost for stage 3 will be almost same for any decision. Overall, the model proves that there are significant potential to reduce the total production cost by implementing and utilizing the model .

### Limitations and future work

The need for further studies is underpinned by the fact that the results of this thesis are limited by small sample sizes and the assumptions used to build the current business simulation. In addition, the design of current optimization model does not explicitly show the detailed movement of raw material or intermediate product. To capture each movement of each component, the design of the optimization model shall be expanded by 3 times bigger than current one. We suggest to consider another sophisticated software in further studies, because current model already has over 22,000 variables and it is taking significant time to solve each run of calculation. If the model is expanded in spreadsheet, the number of total variable will be at least over 40 thousands and it will be very inefficient to be used in practice.

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