ORDER ASSIGNMENTS FOR A GLOBAL APPAREL PRODUCTION NETWORK

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ABSTRACT
In this case study, an apparel company that has its orders manufactured by a few dozen of factories located in various countries in Asia. An order is a specific style of clothes. The apparel production is highly labor-intensive and it involves learning curve improvement, especially for the sewing operations. The longer a sewing operator works on the same operation, the higher efficiency the operator can achieve. Similarly, the larger quantity a factory produces a product type, the higher efficiency the factory can achieve. Normally, only one factory is selected for production of an order due to logistic consideration and production efficiency. In this case study, we formulate a mixed integer program to assign the orders to factories with the objective of maximizing the corporate profit. By solving the mixed integer program optimally or heuristically and using the actual planning data, we are able to increase the overall planned production quantity significantly.

KEY WORDS
Order Management, Apparel Production, Mixed Integer Programming

1. Introduction
Apparel manufacturing is a highly labor-intensive industry. However, the skills of the worker determine the efficiency of production. The case study company operates a global manufacturing network in Asia to take advantage of cheap labor costs. There are dozens of factories that produce clothes for the company. Some of the factories are owned by the company, and the others are subcontractors. Both of these two kinds of factories have capacity limitations. Within a country, there is a region office that manages those factories located in the country. Thousands of orders are sold by the company a year. The assignments of orders to the factories are used to be performed by manual operations. It not only takes a longer time, but also needs two separated decisions phases. The first phase is performed by the planners in headquarter to assign the order to the region office of a country. Then, the second phase is performed by the planners in the region office of the country to further assign the order to a particular factory. The proposed system utilize a mathematical programming approach to assign the orders from headquarter to a particular factory directly. Hopefully, it will achieve global optimization by considering the overall order assignments without separating the decision processes into two phases like the manual system. A few applications of mathematical programming to supply chain planning can be found in [1], [2], [3], and [4].

2. Practical Consideration
An order can only be assigned a particular set of factories. These factories have to be qualified by the customer of the order and the company policy. These assignable factories are different for different orders. A particular order consists of a style of clothes. The company classifies the clothes into several production types. When a product type is assigned to different factories, the efficiencies are different. The making of clothes involves learning curve improvements, the longer a worker works on an operation, the higher efficiency the worker produces. Similarly, the larger quantities a factory produce a product type, the higher efficiency the factory produce the produce type. We can collect the statistics of production efficiencies of various product types for each factory. For an unassigned order, we should try to select the factory that has higher efficiency to produce the product type of the order. However, the overall product mix may not match exactly with the capacities of the highest efficiency product type of the factories; that is, we cannot always assign an order to the factory that has the highest efficiency to produce it.

In addition, the producible period of an order is the duration between the month when materials arrive and the month when the shipment is due. For a small and urgent order, the producible period can be only one month. For most of the orders, the producible periods are two or three months. The flexibility provided by the mathematical programming is that we can dynamically allocate the quantity of an order to each month of producible period to achieve a better overall output. The demands in the
planning processes includes confirmed orders and forecast orders. Generally speaking, the sum of these two demand types exceeds the overall capacity of the company. In this study, we use the net profit as our objective of the mathematical program to drive the production plan to achieve a higher profit and a larger output quantity.

3. Mathematical Programming

The problem we can formulate as a mixed integer program.

**Index:**
- \( f \): factory.
- \( m \): month.
- \( o \): order.

**Parameters:**
- \( p_o \): profit of order \( o \).
- \( r_o \): the month when order \( o \) can start production (materials arrive).
- \( d_o \): the month when order \( o \) must be completed for shipping before due date. The months between \( r_o \) and \( d_o \) are producible period.
- \( a_{of} \): required man-hours per dozen of order \( o \) in factory \( f \).
- \( q_o \): demand quantity of order \( o \).
- \( n_o \): the number of factories can be simultaneously to produce order \( o \). Normally, this number is 1.
- \( c_{fm} \): capacity of factory \( f \) in month \( m \).
- \( H \): a huge number, far larger than the quantity of a single order.

**Set:**
- \( F_o \): the set of assignable factories for order \( o \).
- \( O_f \): the set of orders that factory \( f \) can be assigned to produce.
- \( R_{fm} \): the set of orders that factory \( f \) can be assigned to produce in month \( m \). That is,
  \[ R_{fm} = \{ o \in O_f | r_o \leq m \text{ and } m \leq d_o \} \]

**Decision variables:**
- \( p_{ofm} \): the production quantity of order \( o \) by factory \( f \) in month \( m \).
- \( s_o \): the shortage of order \( o \).
- \( I_{of} \): a binary integer variable; the indicator variable of whether order \( o \) is assigned to factory \( f \). \( I_{of} = 1 \), if order \( o \) is assigned to factory \( f \). \( I_{of} = 0 \), otherwise.

**Objective function:**
Maximize \( \sum_o \sum_{f \in F_o, m=r_o} d_i \cdot p_o \cdot P_{ofm} \)

**Constraints:**
1. capacity limitations

   \[ \sum_{o \in R_{fm}} p_{ofm} \leq c_{fm} \quad \forall f, \forall m \]

   The sum of production quantities of a factory in a month has to be less than the available capacity.

2. demand satisfaction

   \[ \sum_{f \in F_o} \sum_{m=r_o}^d p_{ofm} + s_o = q_o \quad \forall o \]

   The capacity may not be enough for the production of the order; therefore, shortage variable is required.

3. the number of factory can simultaneously produce an order.

   \[ \sum_{f \in F_o} I_{of} \leq n_o \quad \forall o \]

   The sum of indicator variable has to be less than or equal to the number of factories share the production of an order.

4. the upper bound of production quantity for an order in a factory

   \[ P_{ofm} \leq H \cdot I_{of} \quad \text{for } r_o \leq m \text{ and } m \leq d_o \quad \forall o \in O_f, \forall f \]

   If the indicator variable is zero, the production quantity has to be zero.

4. A simple Greedy Algorithm

   It may take a lot of computation time to solve a mixed integer programming problem outlined in the previous section. However, various selection policies set by the management narrow the eligible factories to a small number. Many of the orders are limited to only one eligible factory. The reasons are: (i) when an order is confirmed with the customer, the production factory cannot be changed unless having an agreement with the
customer. For such a confirmed order, no integer indicator variable is needed. A significant portion of the orders are confirmed orders at a planning time. (ii) For a customer, only a limited number of factories are qualified for producing its orders. Therefore, the number of integer indicator variable is usually small. In addition, order assignment policy set by the management will further reduce the number of eligible factories. At any planning calculation time, the number orders that required to be assigned manufacturing factory is limited. For most problems, the mixed integer program can obtained optimal solution or near optimal solution provided by ILOG CPLEX 7.5 [5]. If CPLEX cannot provide the integer solution in time, the simple greedy heuristic algorithm is used to determine the manufacturing factory for each order (generate integer solution). Then, the problem is reduced to a linear program that can be easily solved by CPLEX.

Let $L_{fm}$ be the current loading of factory $f$ in month $m$ and $r_{fm} = \frac{L_{fm}}{c_{fm}}$ be the loading ratio for factory $f$ in month $m$.

Step 1: sort the orders by the net profits.
Step 2: select the highest net profit order $o'$ from step 1.
Step 3: compute average loading ratio $\frac{\sum_{o'} r_{f'o'}}{(d_{o'} - r_{o'})}$ for all eligible factories. Find the factory $f'$ with the minimum average ratio.
Step 4: add the loading of $o'$ evenly into each month of the producible period of factory $f'$.
Step 5: remove order $o'$ from the list and go to step 2.
Step 6: if there is no more order, stop.

5. Conclusion

The benefits offered by such a mathematical-programming-based system are: (i) it provides an automatic planning system that calculates order assignment more efficiently. It makes re-planning easy and provides answers to various what-if questions. (ii) Without adding more capacity, the total planned production quantity is increased significantly from manual planning system.

References