Journal of Mathematics and System Science 6 (2016) 159-165
doi: 10.17265/2159-5291/2016.04.004

The Material Provisioning Dynamics Analysis and Simulation in the Smart Manufacturing Theme

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Received: February 01, 2016 / Accepted: February 28, 2016 / Published: April 25, 2016.

Abstract: The nature of production is time dominated based, it requires to manage the material supply, the product delivery, and the time of the process in an effective and efficient way. This paper posits the production behaves as a dynamic system that requires a model to optimize the production scheduling with the flexibility of predictive settings and to give a holistic overview about the dynamic properties of the material and the product across the cycle time to the factory planner.

Key words: Material Provision, Production Scheduling, Smart Manufacturing, Differential Equations, System Dynamics

1. Introduction

The challenge of manufacturing is always about how to manage the resources well in a proactive way. The dilemma for this resources management is linked to the costs. For instance, if the product inventory is too high, then it will incur the inertial cash flow, but will benefit the in-time delivery; another case is when the material is under supplied, this will benefit the payables, but may jeopardize the smooth production.

The common approach to deal with the dilemma is to maximize the benefits and/or minimize the costs through *Linear Programming* equations [1]. How to rule out the certain criterion to make these equations have solutions is not an easy task for the factory planner, especially when the benefit and the cost functions are time dominated based. Another approach is applying the *Dynamic Programming* [2] to model and solve the dilemma; but in the real business scenario, it is not easy to identify the optimum-value function to find the optimized paths when timing is an issue to the production.

Undoubtedly, the nature of production is time dominated based, it requires to manage the material supply, the product delivery, and the time of the process in an effective and efficient way. Both the supply and the delivery are usually uncertain and volatile in the real business scenarios. For instance, the critical parts may be precious in value or a competing resource against the buyers, which means that the production has the risk of disruption owing to lacking of the materials to build. On the hand, the yet-delivering orders may be cancelled, the delivery date or the quantity changed due to the market demand fluctuation. The business objectives are greedy, always looking for the solution of using the minimal material to produce the maximal products within the shortest time, and most importantly, at the least cost.

This paper posits the production behaves as a dynamic system that requires a model to optimize the production scheduling with the flexibility of predictive settings [3]. The purpose of this paper is to give a holistic overview about the dynamic properties of the material and the product across the cycle time to the factory planner by using the *Differential Equations* approach. It models the production life cycle into a series of equations and can be further automated

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through software programs. The proposed model aims to answer the material provisioning dilemma with the production and the order fulfillment considerations together. The Figure 1 illustrates the dynamic model of material provisioning. There are seven settings can be flexibly configured according to the real business scenarios, and three differential equations in the model. The example scenario is order-driven production with the following properties:

- the orders (*Sales*) are already placed or behaved as a predictive curve—in this case, the model assumes the order quantities were randomly from a *POISSON* distribution [4];
- the procurement (*Purchase*) quantity of a parts is fluctuated as a sinusoidal curve [5]—in this case, the model assumes the quantity of material supply was a symmetric *Cosine* function (in the real business scenario, the critical parts supply behaves as a attenuated sinusoidal curve) over the cycle time because the vendor must provide the material before the build, otherwise it would never be placed into the production schedule;
- maintaining the safety stock at all time is an essential measure to efficient delivery; it governs the criterion to control the behavior of production;

BOM (Bill of Material) is the quantity used to build a product.

2. Experimental Section

Experimental details (sections titled Experimental Methods, Experimental Section, or Materials and Methods)

The Table 2 illustrates the equations of the proposed provisioning model; the notations, *if* (criteria, TRUE, FALSE) means that if the criteria is met, the function returns the result of the TRUE equations, otherwise returns the FALSE ones; *max* (E_1, E_2) returns the biggest value from the results of the computations of E_1, E_2. The Formula (2), (3), and (5), shown in grey color, are the intermediate equations that facilitate the concept articulation; the others are the constructs shown on Figure 1, the proposed model.

The Formula (1) assumes that the material provided by the supplier behaves as a sinusoidal curve because of the lead time and the fluctuation of the material market within the forecast time frame. This assumption can be replaced with the real data in the form of scalar vector, the size is the time frame.

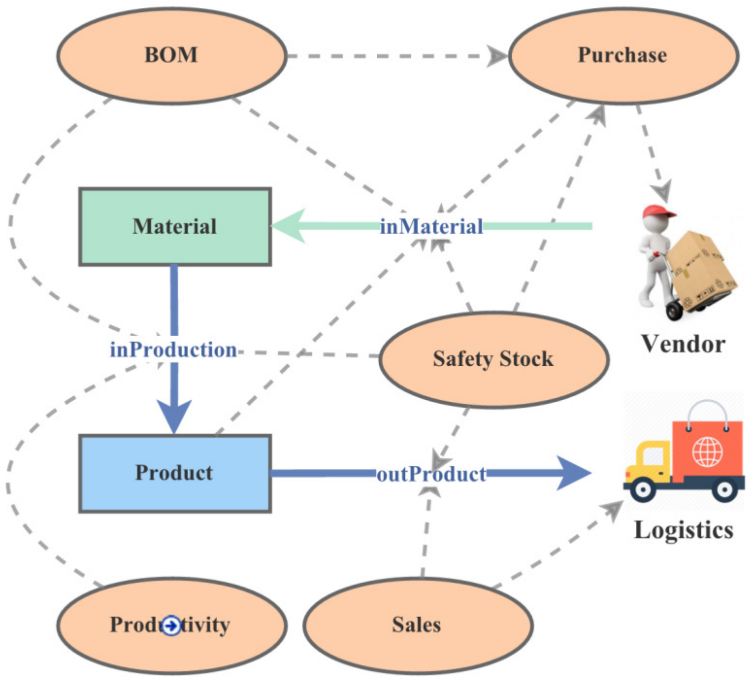

Fig. 1 The Material Provisioning Dynamic Model.

Table 1 The Example Model Settings.

Variable	Explanation/Value Setting	
The Time Frame of Forecasting.		
Cycle Length	60	days
The Material Usage in Each Product.		
BOM	2	piece/unit
The Initial Material Quantity in Stock.		
Material	20	pieces
The Minimal Product Units in Stock.		
Safety Stock	10	units
The Capacity of Production.		
Productivity	8	units/day
The Initial Product Quantity in Stock.		
Product	10	units
The Quantity Vector of Goods Sold.		
Sales	Poisson(mu=20)	units/cycle

Table 2 The Equations of the Material Provisioning Dynamic Model

$\frac{d}{dt}Purchase(t) = \cos\left(\frac{2\pi}{CycleLength}t\right)$	(1)
$deltaQuantity(t) = Product(t) - SafetyStock$	(2)
$materialNeed = BOM * SafetyStock$	(3)
$inMaterial(t) = \boldsymbol{if}(deltaQuantity(t) > 0, Purchase(t) - materialNeed, Purchase(t) + materialNeed)$	(4)
$Usage(t) = \boldsymbol{if}(Product(t) < SafetyStock, \boldsymbol{max}(SafetyStock - Product(t), Productivity) * BOM, Productivity * BOM)$	(5)
$inProduction(t) = \boldsymbol{if}(Material(t) > Usage(t), Material(t) - Usage(t), 0)$	(6)
$\frac{d}{dt}Material(t) = inProduction(t) - inMaterial(t)$	(7)
$outProduction(t) = \boldsymbol{if}(Product(t) > Sales(t), Sales(t), 0)$	(8)
$\frac{d}{dt}Product(t) = outProduction(t) - inProduction(t)$	(9)

The Formula (4) checks the product's *Safety Stock*, the minimal quantity for assurance of the production; if the product is stacked in the stock, the procurement quantity will be reduced by the *Material Need*, otherwise increased it; either case is to maintain the level of the *Safety Stock*.

The Formula (5) checks the product *Safety Stock*, if the quantity is less than the *Safety Stock*, the production priority is to maintain the level of stock first by recruiting additional production lines and/or increasing the work time.

The Formula (6) checks the material stock, if the stock is not adequate for the efficient build, the production will be in the dormant mode that definitely poisons the efficiency.

The Formula (7) simply shows the net outcome of both materials in and out (consumed by the production). The integral of this net outcome, the *Material*, is the quantity waiting for production.

The Formula (8) checks the safety stock, if the quantity is adequate for the sales (the order), then the factory ships the goods out; otherwise it returns zero, no sell at all, which is another inefficient case of production.

The Formula (9) is the net outcome of the goods in and out production (goods sold). The integral of this net outcome, the *Product*, is the quantity remaining in the stock.

The sales, the goods sold, contains a scalar vector, the size is the time frame, generated and randomly sampled by the *Poisson* distribution with $\mu = 20$, implying the velocity of the market consuming the product illustrated in Figure 2 which is very close to the real situation. This implies the order taking list or the forecast of the demand in the near future.

3. Results and Discussion

The proposed model using the the aforementioned settings discloses the insights about the resources (the material and the product) dynamics to the production planner.

The Figure 2 illustrates the curve of product fulfillment, in which there are several occasions (13 out of 60) that the stock level was under the *Safety Stock* because the demand is stronger (or move faster) than the supply at these occasions. If the fluctuation of the material supply is improved, then these under

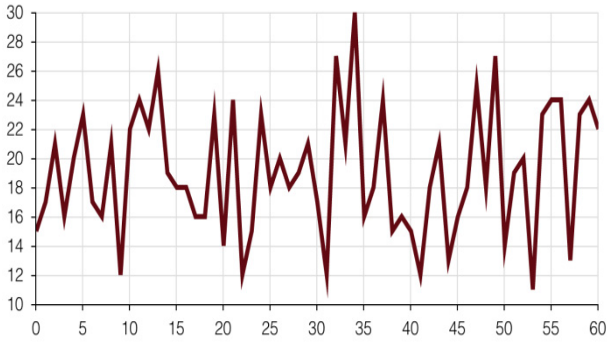

Fig. 2 The Market Demand.

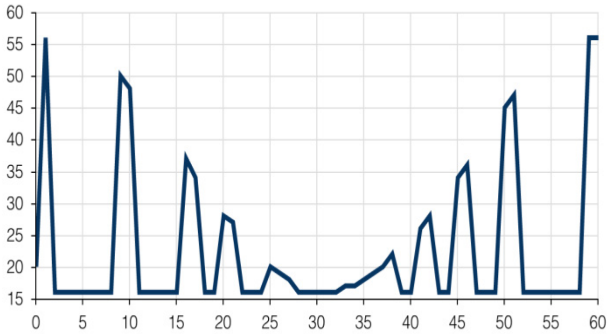

Fig. 3 The Material Provisioning.

stocking occasions will also be improved. On the other hand, even though the example procurement curve is set up and down drastically in the sinusoidal way, the proposed model is still robust to support the order fulfillment.

The Figure 3 illustrates the curve of material provisioning, the quantity seems rather higher, but each product needs the *BOM* (=2 for this example case) of this material. The curve coincides the critical parts in the real supply chain scenario: (1) it takes time to deliver the material; (2) the critical parts must be maintained in a safety level to ensure the production; (3) the supply will be dropped if the market is already saturated; (4) the procurement is made according to the magnitude of the sales; and (5) the model balances the price gain of buying more quantity and the risk of over provisioning.

The Figure 4 gives the holistic view about the material, the product, and the sales, of the example case which applies the proposed model. In the real application, the production planner or an automated computer program simulates this model by the steps of:

(1) aggregates the quantities of the orders by the deliver dates to form the *Sales* data;

(2) checks the histogram illustrated in Figure 5 against these quantities;

(3) sets the values shown in Table 1 such as the *Safety Stock* and the *Cycle Time* etc.;

(4) calculates the equations in Table 2 and records the values for each day within the forecast cycle time;

(5) draws diagrams based on the calculated values;

(6) checks the diagrams to see if there is no inefficiency of production;

(7) rearranges *Purchase* schedule and recalculates the equations until all *Sales* can be fulfilled;

(8) if the material procurement cannot fulfill the orders need, rearrange the orders by breaking the big orders into partial ones, and recalculates the equations until the results meet the deliveries.

The Figure 6 illustrates three kinds of velocity, the velocity of the material devoted into the production, the velocity of the productivity, and the velocity of the goods shipping out of the factory. Several important properties of the proposed model—they all have idle

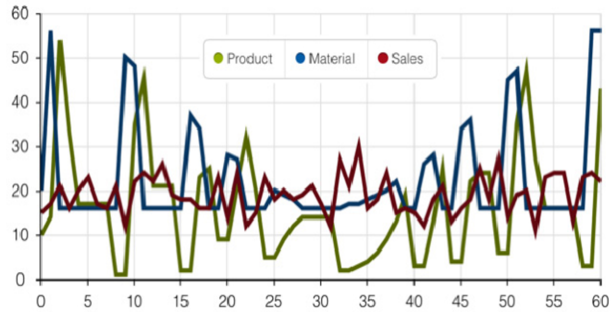

Fig. 4 The Holistic View

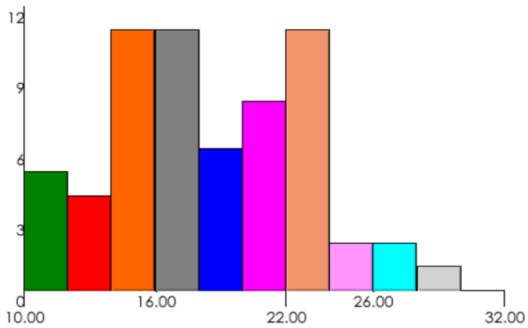

Fig. 5 The Market Demand Histogram.

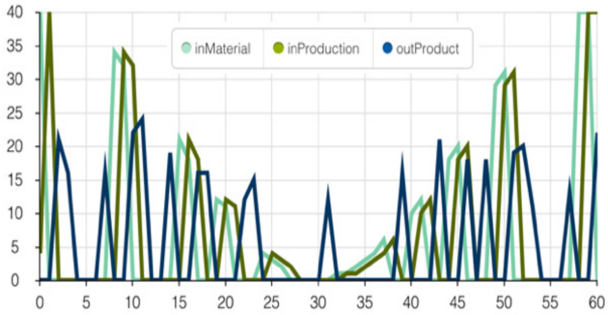

Fig. 6 Three Kinds of Velocity.

moments during the cycle time frame; this phenomenon implies:

- the material pulling in an optimized way—in the example case, there were 24 times of procurement made that will take the advantage of the buying power with as more quantity as possible;
- the production lines were occupied 27 times; this will give the available slots to switch to another production schedule;
- the product fulfillment will be also reduced because of the economic scale of 20 times shipping.

The example case was set to be a simplified version of the proposed model deliberately. In the real application, the key parts may have many; however, as long as the material replenishment behaviors are similar, the factory planner can aggregate these material into a virtual group parts number which is very easy to configure in the production systems; the *BOM* remains the actual usage of this virtual group material. On the other hand, the proposed model has the flexibility to coupe with the real business situation by reconfiguring the settings and/or slightly adjusting the conditional logic part among the Equation (4, 5, 6, 8).

4. Conclusions

The proposed model not only gives the rationale in a mathematics—applying the differential equations—but also disclose the business implications in a systematic way to the practitioners. Automating the calculation of the equations of the proposed model by using the software programs is essential to practice the actual business cases.

To implement this, either applying the programming approach designed by *Python*—a programming language [1] or by *GNU R*—a software environment for statistical computing and graphics [2] that can easily reconfigure, adjust, and simulate the proposed model quickly and effectively; or applying an integrated tool with rich graphic user interface for modeling, compilation and simulation the proposed model, such as *OpenModelica* [3] and *Vensim* [4].

The concept of *Smart Factory* is to foresee or predict the possibility of fluctuation of the material supply and the market demand. The proposed model is a subset of the holistic view of the *Smart Factory* dynamics illustrated in Figure 7 which consists of seven major categories:

- purchase orders—to find the patterns of the products purchased, to optimize the batch (combination of orders) based on the additional factors such as the revenue contribution and the impact of customers, and to suggest the order priorities and the quantity adjustment to the production scheduling;
- production scheduling—to find the variances between the planned and the actual schedules and why the variances occurred, to optimize the resources allocation by simulation given a various of conditions;
- inventory management—to find the aged and predicting the aging material and products in the stocks, and to estimate the safety stock optimally;
- quality assurance and control—to find the potential quality risk measures; and to optimize the inspection and the equipment maintenance plans;
- production management—to find the variances of each production step, and to suggest the optimal outsourcing plans;
- logistics management—to find the variances of shipments, and to suggest the optimal routes of shipping;

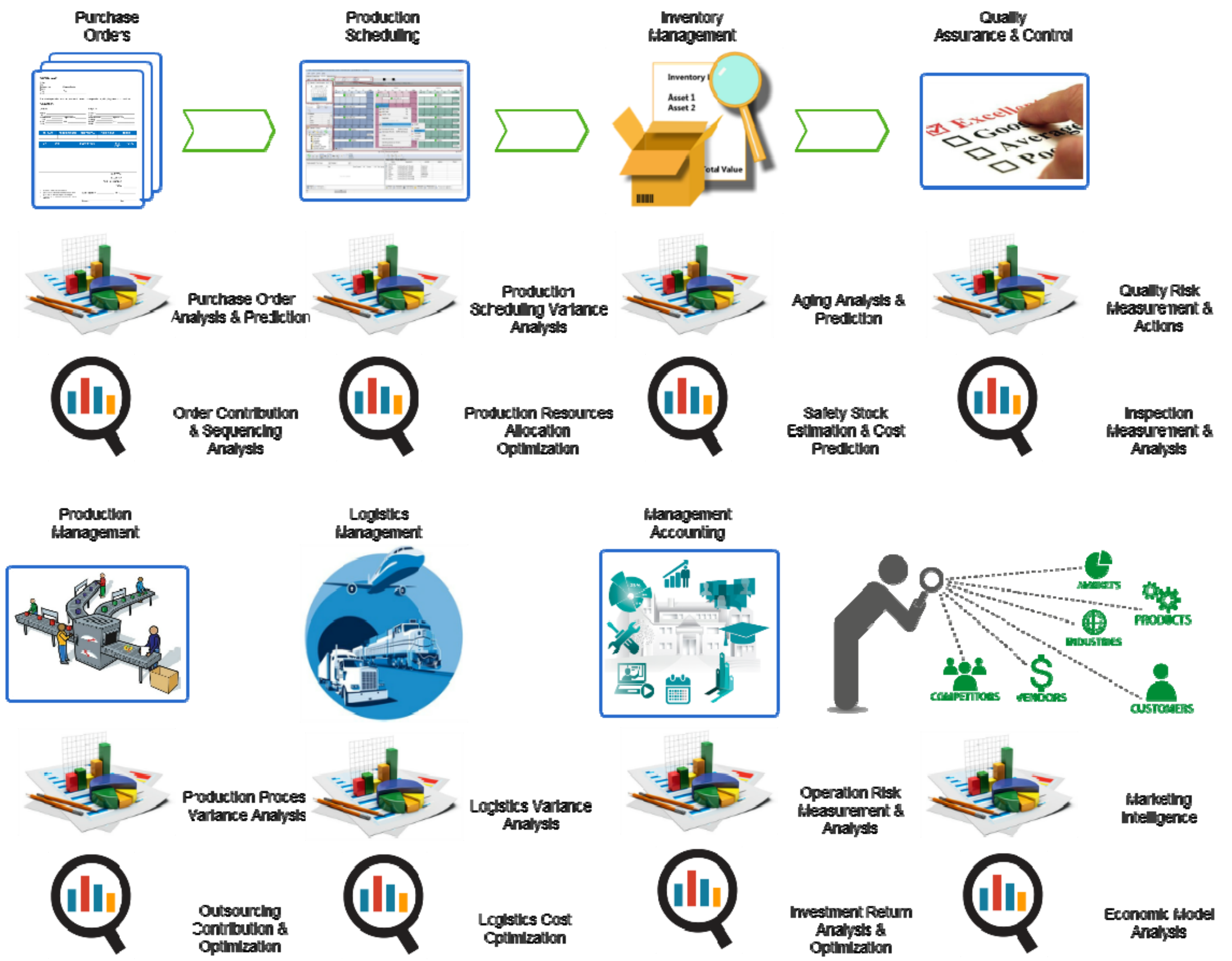

Fig. 7 The Holistic View of Smart Factory Dynamic Analyses.

- management accounting—to find the potential risks of the operation, to disclose the general market information and the concerns, and to optimize the investment programs and suggest the economic models.

It is essential to treat the productivity function as a time dominated based behavior. In order to manage this time dominated based *Lean Production*—relentlessly endeavoring on eliminating all wastes including resources and time during the manufacturing process—well, the future work is to continuously modeling the aforementioned holistic dynamics of *Smart Factory*, and to elaborate and disclose the business implications to the practitioners in the real manufacturing scenarios.

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