System Dynamic Analysis of the Fleet Availability and Reliability Influence on the Lead Time of the Delivery Order Process

by Chatarina Dian Indrawati

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Abstract. The inventory replenishment process in the warehouse becomes difficult if there is uncertainty. It can cause warehouse performance not to be as expected. The warehouse is an important part of the supply chain subsystem, which smooths the flow of goods from upstream to downstream throughout the system. This paper uses system dynamics modeling to analyze the replenishment of raw materials where there is randomness in availability and reliability and their effects on the delivery lead time of the fleet. The model obtained is much simpler but more robust when compared to the analytical-mathematical model or the discrete-events simulation. Tests on the model show that the model can behave as it should logically. Several experiments were conducted to see how fleet availability's reliability can affect the delay in receiving or delivery lead time. One interesting thing revealed is that reliability does not have to be 100%, but there is a certain minimum threshold for the system to perform well. This is different from availability, which must be 100%.

Keywords: delivery lead time, fleet availability and reliability, warehouse system.

1. Introduction

The industry is complex, but if we understand it systematically, then this complexity can be seen more easily. This perspective is called a systemic perspective or systems approach [1] wrote in his book: " various sets of problem realities, both physical and non-physical, are always woven as a complex systemic event". Systems experts have initiated the concept of a systems approach for a long time, from Jay Forrester, Peter Senge, Donella Meadows, to John Sterman, and other recent experts. Discussion of this systemic approach continues to expand and is very beneficial in various fields, so it is very important to teach it in scientific and practical education [2, 3].

Industry comprises supply chains, producing products in the form of goods (tangible) or services (intangible). Several supply chain systems interact with each other to form an industrial system. Furthermore, interaction is not only between supply chains that produce goods that are allied, but also those that are not allied, even with those that produce services. Knowledge of supply chain systems has been well established and discussed in various books, one of which can be seen in the book written by [4]. In actual conditions, the supply chain system is a branched system, both upstream and downstream. Some suppliers make branches on the upstream side of the supply chain. Some distribution center locations make branches downstream [5].

Warehouses are an important constituent of supply chain systems, which can be raw material warehouses and finished product warehouses in factories, warehouses in distribution centers, or retailers. Its important use is to stabilize the flow of goods from upstream to downstream. The availability of goods in the warehouse must be guaranteed so that the level of service to customers is always maintained high and the total cost of inventory can be as low as possible.

The total cost will be affected by inventory levels, the frequency of restocking, and the frequency of stockouts. The associated costs will also be high if these three factors are high. However, the first factor will conflict with the second and third. If the inventory level is increased, the replenishment frequency will decrease and the stockout probability will also decrease. If the inventory level is lowered, the replenishment frequency and stockout frequency increase. At low inventory levels, stockout becomes challenging to avoid when the uncertainty of the replenishment duration is so high.

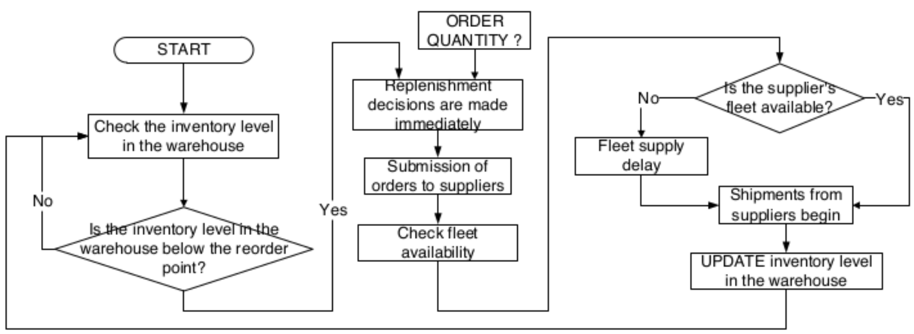

Figure 1. Conceptual model of inventory control issues in the warehouse

The uncertainty of delivery lead time from suppliers is an important thing that cannot be ignored because it can trigger stockouts in the warehouse. Of course, this will affect the service performance of the warehouse. In addition, on the supplier side, the probability of fleet availability and reliability, which is often assumed to be 100%, is not the case in reality ([6], [7]). When the fleet is unavailable at that time and/or exists but is unreliable, a delay in the provisioning of the fleet occurs. So, the overall lead time will be determined by the transportation lead time and possibly also by the fleet preparation lead time, all of which are random. If the case is described with a conceptual diagram, then Figure 1 below can explain it better. It is necessary to make the right order quantity decisions so that inventory performance can be maximized, that is, stockouts do not occur at a fairly low average inventory.

As far as the authors know, modeling such systems is often attempted mathematically, requiring a very strong understanding of probabilistic mathematics. The basic model is the economic order quantity (EOQ) which is then expanded to accommodate the overall lead time of the replenishment process. The randomness of the lead time is often assumed to be normally distributed. When the total lead time is composed by the transportation lead time and the fleet supply lead time, where the availability and reliability of the fleet is important to note, then the total lead time can no longer be normally distributed. The probabilistic mathematical analysis will be complicated and complex. It requires sufficient understanding of mathematics to be able to understand and apply it. So a heuristic method is often used [8, 9]. There will also be a limitation that the model tends to be inflexible so that its use becomes limited. A model to assign reliability, redundancy, and spare parts for a variable fleet is proposed by [10], among others, to assure system availability and reduce fleet expenses. The model determines the best option, which addresses the nonstationary need for replacement parts during fleet development.

Furthermore, reliability will be related to maintenance. For fleet systems, [11] suggests a decision framework for simultaneously choosing the dependability design and amount of maintenance. While [12] used various methods to improve the operability and reliability of tractors and agricultural machinery.

This current paper examines a warehouse system that manages the inventory of a particular single item, using system dynamics modeling. The inventory level of the item will increase and decrease cyclically. Decreasing by, when there is continuous use by customers and, rising again when the order for the item has arrived and is received at the warehouse. The nature variables that are considered come from two sources, i.e., from the supplier side there is a procurement lead time variable, and from the user's point of view, there is a usage rate variable.

Lead time (of the replenishment process) is random because it comprises the transportation lead time and the fleet supply lead time to carry out the transportation. The two constituent lead times can have very different duration distributions. In real terms, the lead time cannot always be modeled with a normal distribution. The usage rate is expressed in terms of the variable time between arrivals and the quantity demanded. In this regard, the random variables that are considered are: time to respond to an order which is assumed to be uniformly distributed, availability and reliability, which are each assumed to be Bernoulli distributed, time to make the fleet available, which is assumed to be normally distributed, and time to make the fleet reliable, which is assumed to be Weibull distributed, with certain parameters. The length of the lead time is then observed as a response.

This paper focuses on a specific question: what happens to the length of the procurement lead time if the availability and reliability of the fleet is not 100%?

2. Modeling

When the inventory level drops to the reorder point, management immediately reorders. The supplier responds by setting up fulfillment. It starts with processing the order administratively and continues with the process of supplying the fleet. There are two steps in the fleet supply process, namely checking the fleet's availability and the reliability of the available fleet. Both fleet availability and reliability will be probabilistic. Here, it simply be modeled by a Bernoulli process. If empirical data can be obtained, reliability can be formulated based on this data [13, 14]. Almost any type of probability can be easily accommodated when modeling system dynamics.

The Bernoulli process in principle compares the average value with the generated random events. For example, for availability, the process is stated in equation-1 and equation-2.

$$\textit{Bernoulli Availabilitys} = \textit{RANDOM UNIFORM}(0, 1, \textit{seed}4) \quad (1)$$

$$\begin{aligned}&\textit{Check Fleet Availability} = \\ &\quad \textit{Order Service Administration IS MADE} * \textit{IF THEN ELSE} \\ &\quad (\textit{Bernoulli Availability} \leq \textit{Average Fleet Availability}, 1, 0)\end{aligned} \quad (2)$$

$$\begin{aligned}&\textit{TIME average for Fleet Provision} = \textit{IF THEN ELSE}(\textit{Fleet not Available} = 0, \\ &\quad 0, \textit{RANDOM NORMAL Distribution})\end{aligned} \quad (3)$$

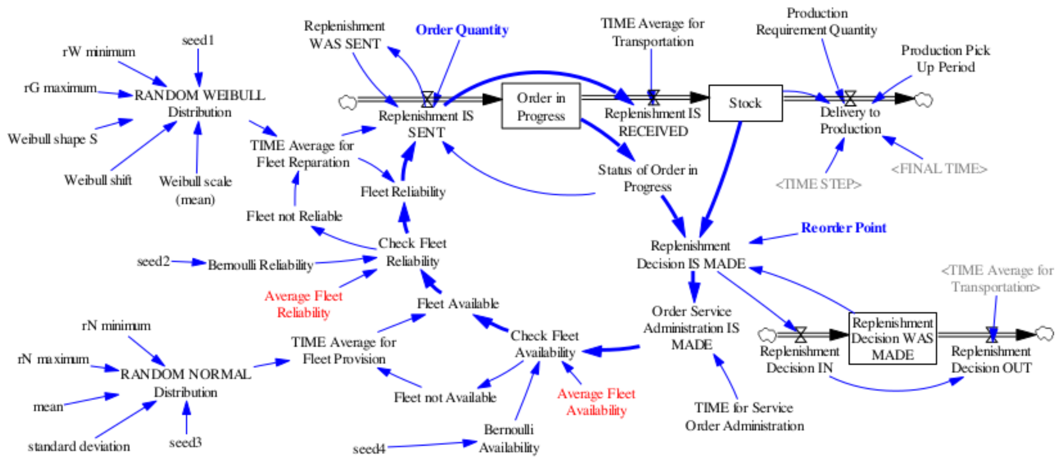

Figure 2. The overall Stock and Flow Diagram model

When the variable: Fleet not Available is active (its value is 1, which means the fleet is not available) then the system takes time for the fleet to become available. In equation-3, the time duration is called: TIME Average Duration of Fleet Supply, which is assumed to be normally distributed in this case. Other distributions can also be assumed, depending on the actual data available. Similarly, it can be explained for TIME Average Fleet Repair Duration, which in this case is Weibull distributed.

One thing learned from [15] is that the model must be able to accommodate the memory aspect so that there is no repetition of allocating values in important variables in the model. In this paper, the important variables are: *Replenishment Decisions IS MADE*, and *Replenishment is SENT*. If this memory aspect is neglected, then the two variables will repeat the value captured by the predecessor variable.

3. Analysis and discussion

The model that has been made can describe the process of ordering raw materials for production where suppliers have delivery vehicles that are not always available and reliable. The results of a simple test on a model that shows a tendency to behave as it should (logic) can provide confidence that the model successfully provides the appropriate behavior. By using this model, various useful experiments can be carried out.

The lead time length is calculated from when the order decision is made (i.e., when inventory drops to or below the reorder point) until the goods ordered are finally received at the warehouse, indicated by the additional bold line in both figures in the appropriate color. Logically, the lower the availability and reliability of the fleet, the longer the overall transportation lead time. According to this logic, the model shows a tendency in Figure 3 for the lead time for the first cycle replenishment, and Figure 4 for the lead time for the next one. In the same way it can be done on various reliability with certain availability. Figure 5 displays the results. In the first procurement cycle, there is no difference (the curves coincide), while in the second cycle, there is a difference in lead time as the fleet's reliability decreases.

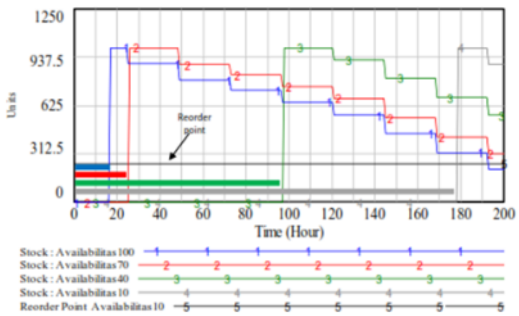

Figure 3. Stock profile and lead time for the first replenishment cycle at 100%, 70%, 40%, 10% availability (at 70% reliability).

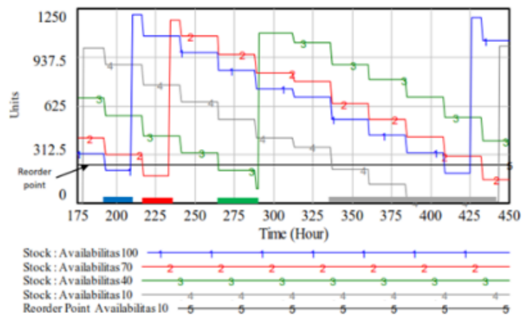

Figure 4. Stock and leadtime profiles of the second replenishment cycle at 100%, 70%, 40%, 10% availability (at 70% reliability).

The possibility that a product, system, or service will function as intended for a predetermined amount of time or will run faultlessly in a predetermined environment is known as reliability. The reliability of the fleet in thism paper is expressed in percentage terms. The experiment's findings show that it has a negative nonlinear effect on lead time. The higher the reliability, the shorter the lead time. However, from the experimental results, there is an interesting thing. The decrease in reliability from 100% to 70% does not seem to affect the length of the lead time. The reliability level is allowed for less than 100%, down to a certain lower value. If the reliability is less than this value, then the effect of reliability on the overall lead time starts to look significant. However, further research needs to be done to confirm this.

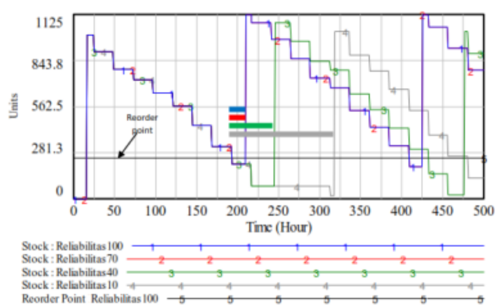

Figure 5. Stock and leadtime profiles at 100%, 70%, 40%, 10% reliability (at 100% availability).

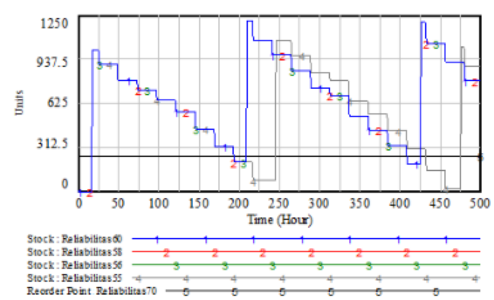

Figure 6. Reliability can decrease to a minimum limit (in this example, 56%) without affecting the total lead time.

There seems to be a minimum allowable reliability value at which system performance remains good. Figure 6 shows that for the discussed cases the reliability of the fleet can drop to a minimum of 56% to provide a leadtime performance that is not too different. If it drops below that, then there will be a significant change in lead time. Meanwhile, a decrease in availability will have a straight and instant impact on overall lead time as illustrated in Figure 8. Seeing that fleet availability expressed as a percentage of availability has a negative linear effect on lead time. This means when fleet availability drops, say 10%, from 100%, the lead time increases by 10%. This phenomenon can be described as Figure 7.

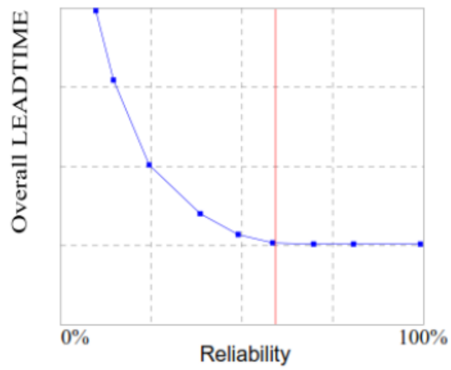

Figure 7. Overall leadtime profile as a function of reliability

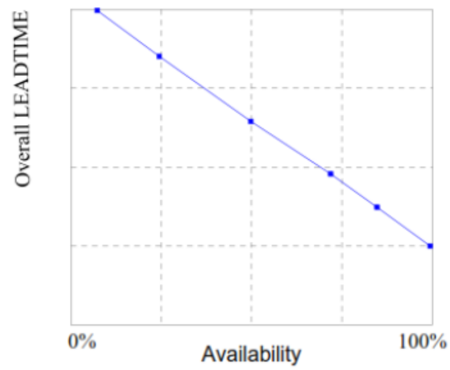

Figure 8. Overall leadtime profile as a function of availability.

4. Conclusion

The availability and reliability of the delivery fleet on the supplier's part can prolong the lead time for the delivery of ordered goods. An instant effect occurs when there is a decrease in availability, while a decrease in reliability gives a slower effect. Reducing reliability to a certain minimum value still gives no different lead time performance. Below that value, then the effect is very significant.

Analysis of ordering production raw materials can be facilitated by a model created in system dynamics language. The preparation is relatively easier and simpler while providing a model with more flexible/robust capabilities. The probability distribution of existing time durations can be adapted to the available data, called an empirical distribution. The model will be able to accommodate appropriately.

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