Optimization of Review Periods and (*s*, *S*) Levels of Floor Stock Items in a Paint Production Environment

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Abstract

In this paper, a mixed integer linear programming model is proposed in order to optimize review periods and (*s*, *S*) inventory levels of floor stock items (FSIs) in a paint production facility to decrease the number pauses in the production process. In the model, power-of-two policy for periodic review scenario is considered. The optimum review periods are determined for multi-item types satisfying pre-defined cycle service level (CSL) under a capacity constraint. It is significant to determine the optimum review periods and safety stock levels of FSIs to be hold in the floor stock storage areas (FSSAs) so that the number of stops will be minimized in the production process. We model the problem as multi-item, single-echelon inventory system using periodic review *(s, S)* policy. In the facility, raw materials are hold in nine inside inventory locations which are supplied from the main warehouse whose capacity is infinite. The objective function is considered as minimization of total number of reviews completed in a year, i.e., the total number of transportations completed from the main warehouse. The results indicate that there is a positive correlation between the review periods and the difference between the *S* and *s* values.

Keywords
(*s*, *S*) policy, cycle service level, optimization, power-of-two policy

1. Introduction

There are different reasons which may lead a production system to face interruptions such as machine failure, worker errors or disasters or even pandemics. In our study which is a paint industry, the main reason of the interruptions is the inadequate level of raw material(s) for the production. Generally, the raw materials are replenished according to the demand forecasts, yet since there are several types of chemicals such as adjust materials, fillers, etc. whose usage amount may not be known and forecasted ahead of time may cause stock outs. Consequently, the shortage of some raw materials stops the production and may require long lead times to replenish these materials from the warehouse. Since these delays are costly, managers tend to hold these materials more than necessary at the periphery of the production area so that the stock out does not occur. However, the capacity of the production plant does not allow holding much inventory for each stock item. Therefore, it is significant to determine which materials and amounts to carry in the FSSAs as well as when to review these materials to decrease that number of stock outs.

To the best of our knowledge, this is the first study which considers a floor stock optimization problem using an (*s*, *S*) policy in an inventory control management of a chemical production facility. In the following section, articles including inventory models focusing on multi-item, power-of-two, and (*s, S*) policy from the literature are discussed. In Section 3, the problem is defined. A solution procedure is suggested and its results and the interpretation of these results are presented in Section 4. Finally, in Section 5, the conclusions and possible research directions are discussed.

2. Literature Review

In this paper, we model the problem using (*s*, *S*) inventory model with multi-items based on power-of-two policy. In this section, we review the literature on the related subjects.

There are three crucial decisions in an inventory management system that needs to be made: (1) the review period, (2) the reorder level and (3) the replenishment quantity of the each product.

The joint replenishment of the several items may reduce the ordering cost as might be expected. Therefore, there are quite a few studies in the literature focusing on the multi-item inventory problem with joint replenishment: (Balintfy 1964; Aksoy and Ergenguc, 1988; Konur and Schaefer, 2016; Kalpakam and Arivarignan, 1993; Chen and Chen, 2005). For example, Balintfy (1964) investigates the classes of multi-item inventory problems, where the setup cost partially can be covered by joint order of several items. Under some conditions, he gives the results which are applicable for optimum reorder ranges. Then, Aksoy and Erenguc (1988) present a review article in which they focus on inventory control articles with multi-item system with a joint setup cost and coordinating the replenishments and most of the articles included use heuristic approaches. In a recent study, Konur and Schaefer (2016) consider a multi-item inventory control system with coordinated shipments. They study the deterministic joint replenishment problem from the perspectives of economic and environmental objectives under different strategies. They present formulations and suggest solution methods for each joint replenishment problem and compare different strategies with respect to their objectives' performances. They present computational results for the different settings where a specific strategy can be better than the other based on their objectives.

Power-of-two inventory policies are also used to determine coordinating the inventory system with multi-items. For instance, Chu and Shen (2008) focus on the coordination between a single-warehouse and multi-retailers inventory system. Their aim is to find a replenishment policy for each facility in the system which minimizes the total inventory-related cost of the entire system. Their solution methodology is based on heuristic which uses power-of-two policy for coordination of the inventory system. Their proposed heuristic gives 94% effective solution if all the facilities adopt the classical EOQ assumptions. Another study which is done by Rieksts (2009) presents power-of-two policies for a single-warehouse multi-retailer system. In this system, discounts are available on the purchasing cost to the warehouse. The computational study shows that every test problem considered has a power-of-two policy is very effective.

Differently, Chu and Shen (2010) consider a two-echelon supply chain network with one warehouse and a number of retailers whose demand structure is stochastic. They propose power-of-two policy to manage inventory. They also keep safety stocks at the warehouse and each retailer to maintain a pre-specified service level. Their analysis shows that the warehouse safety stock level is crucial for the length of the warehouse order interval and affects the time between the retailers' orders.

Base stock policies are also very common in inventory management systems (Graves, 1999; Roundy and Muckstadt, 2000). Graves (1999) employs the adaptive base stock policy where the demand is nonstationary. He concludes that the behavior of the required inventory changes much for the nonstationary and stationary demand. Roundy and Muckstadt (2000) also study base stock policy and they aim to give orders so that the inventory position at the end of the period is close to the base stock level. They find a near-optimal solution for the base stock policy parameters using a heuristic approach.

Furthermore, fill rate is another significant criterion considered in inventory systems. For example, Vaez-Alaei et al. (2018) study the methods to find out the spare parts inventory system, which allows defining the Target Stock Levels by considering the demand forecasts for a given planning horizon. They study the historical data of a well-known business aircraft and propose a methodology to find optimal Target Stock Levels, Re-Order Point, Safety Stock and on Expected Backorder (EBO), while achieving the global fill rate. Ekren and Ornek (2015a, 2015b) adapted (s, S) policy to compare different lateral-transshipment strategies for inventory control problem in a single-echelon supply chain network. Ekren and Arslan (2019) also studied simulation-based optimization for lateral trans-shipment policy under *s*, *S* inventory control policy. . Since the optimization procedure depends on simulation, it is time consuming to reach optimal solution. Hence, utilization of advantage of analytical models is worth to investigate in the optimization procedure.

Similar to our problem setting, Chan (2019) focuses on deterministic multi-item inventory problem with capacity constraint, and independent demand occurs for each item. He proposes an iterative heuristic algorithm to find the time between orders for each item. He argues that his proposed heuristic approach is robust by computational results.

In this study, an analytical solution approach for an inventory management problem of a paint manufacturing company located in Izmir, Turkey is provided. An inventory control policy which determines the time intervals for periodic review, the optimum levels of reorder and order-up-to levels under the power-of-two policy assumption is proposed.

3. Problem Definition

A paint company having nine production lines (PLs) is considered. Common raw materials can be used for the production of different product types in these lines. This problem is motivated due to unexpected long production stops happening in these PLs due to inadequate raw materials during the manufacturing process.

At the beginning of each shift, raw materials that will be used in the manufacturing process are supplied in required amount at each PL. Before the start of production, the raw materials in the requested amount are sent from the main warehouse to the each PL according to requirement list. Generally, the requested amounts of the raw materials are the forecasted values therefore, some of the chemicals such as adjust materials, fillers, etc. is likely to stock out during the production process. If the level of one raw material is inadequate, then the production stops in the relevant PL and that raw material is requested from the main warehouse in the sufficient amount. Since lead time would be long for the requested materials, it is important to manage inventory levels for the items successfully. The raw materials which stops production in the chemical industries are usually commonly and frequently used materials such as adjust materials, fillers, etc. These materials are named as FSIs throughout this article. As a result, it is crucial to find out critical items, their safety stock levels that carried out at the FSSAs and their review period. Thus, the company may decrease the number of stops in the PLs which will inevitably decrease the total costs of the company.

We model the problem as multi-item, single-echelon inventory system using periodic review (s, S) policy. In the facility, raw materials are hold in nine inside inventory locations which are supplied from the main warehouse whose capacity is infinite. In the system, PLs place the orders. For the review policy of inventory levels of FSIs, a periodic review policy specifically, power-of-two policy is considered. For the optimization purpose, analytical formulations are detailed from Chopra and Meindl (2013) in the below section.

4. Solution Procedure

In a periodic review, multi-item (s_i, S_i) inventory model, when current inventory level (I_i) is less than or equal to the reorder level s_i at the review, then the item i is ordered. The order quantity Q_i is the difference with the current inventory level I_i and the order-up-to level S_i:

$$Q_i = \begin{cases} S_i - I_i & \text{if } I_i \le s_i \\ 0 & \text{if } I_i > s_i \end{cases} \tag{1}$$

Each PL has a capacity constraint in FSSA. These areas based on PLs are provided in Table 1. The area constraints are defined as kilogram unit. To be able to model and solve the problem, the below steps are followed:

1. First, the product types (FSIs) which delays the production in each PL is determined using real data. In this step, 80% of most frequently requested items based on each PL is calculated.
2. Hourly mean values and variance of demand amounts (in kilogram) of the pre-defined raw materials (from step 1) are calculated.
3. The model is optimized by minimizing the total number of reviews (transportations) completed in a year by considering (s_i, S_i) and review period of a material as decision variables satisfying 100% CSL (no backorder) and capacity constraint at each PL.

Table 1. Studied number of material types based on PLs and PL capacities

PL_j	Number of material types (m)	Capacity (C_j)
1	8	2700 kg.
2	7	3600 kg.
3	3	3600 kg.
4	3	3600 kg.
5	4	3600 kg.
6	5	1800 kg.
7	3	3600 kg.
8	22	10800 kg.
9	18	9000 kg.

4.1 Periodic review and power-of-two policy

In a periodic review policy, there is fixed time period *t* in which inventory levels are reviewed at the beginning and if the level of current inventory (*Ii*) is less than the reorder level (*si*) order is given. In this case, the replenishment lot size (*Qi*) is the difference between the order-up-to level (*Si*) and the current inventory level (*Ii*) (see Eq. 1). The review period *t* is the time between two orders. There are a number of advantages of periodic review policies for retailers to implement compared to continuous review policies: They do not require monitoring inventory continuously; the replenishment can be done in regular intervals which eases the process for suppliers; they are cheap to implement.

One of the inventory management policies in reviewing inventory level is power-of-two policy. In this policy, material's inventory level is reviewed after $t = 2^n$ period of time where *n* is a positive integer number – e.g., 0, 1, 2, …, etc. This policy is easy to implement. Also, in our case because a PL may have several types of materials to review, by this policy some materials' replenishment cycles may overlap because these cycles are multiples of two. For instance, let us say if one material is reviewed at every 2^1 (2 hours) and the other one is reviewed at every 2^2 (4 hours) then, in every two transportations, the second material will also be included in the transportation.

4.2 Determining the optimum level of (*s*, *S*) values

CSL which is also known as fill rate is the portion of customer demands that is fully satisfied from the inventory. Because any interruption in the manufacturing process is costly, the company does not want to experience an interruption. Namely, we do not consider backorder in the solution procedure. Therefore, in the modeling approach a 100% CSL is considered. All the assumptions considered in the problem are provided below:

- There are nine PLs in the company.
- PL_1, PL_2, PL_3, PL_4, PL_5, PL_6, PL_7, PL_8 and PL_9 have 8, 7, 3, 3, 4, 5, 3, 22, 18 types of materials, respectively (see Table 1).
- Each material has normally distributed hourly demand whose mean and variance values are obtained again by considering one year's actual data.
- PLs have capacity constraints in FSSA which are defined by kilogram: 2700, 3600, 3600, 3600, 3600, 1800, 3600, 10800, 9000 for PLs respectively (see Table 1).
- Lead time (transportation from the main warehouse) is assumed to be constant – 35 minutes.

Given the desired CSL, the optimum safety inventory levels as well as (*s*, *S)* level calculations are provided in Chopra and Meindl (2013). According to those formulations, the required inputs are as in below:

D_i : Average demand of material *i* per period (i.e., hour)
σ_{D_i} : Standard deviation of demand for material *i* per period
L_i : Average lead time for replenishment of material *i* (35 minutes for each material)
T_i : Review interval of material *i* (2^{n_i} hour)
CSL_i : Desired cycle service level for material *i* (100%)

To be able to understand the safety inventory (*ss*) requirement, it is better to track the sequence of events over time as the orders are placed. The first order is placed at time 0 such that the *Q*i ordered and the inventory on hand (*Ii*) sum to the *Si*. Once an order is placed, the replenishment lot (*Q*i) arrives after the lead time *Li*. The next review period is time *Ti* when the next order is placed, which then arrives at time *Ti* + *Li*. *Si* represents, the inventory available to meet all demand that arises between periods 0 and *Ti* + *Li*. The company experiences a stock out if demand during the time interval between 0 and *Ti* + *Li* exceeds the *Si* (see Figure 1). Thus, the plant manager would like to identify an *Si* such that (1) is true:

$$\text{Probability (demand during } L_i + T_i \leq S_i) = CSL_i \qquad (1)$$

Second, the distribution of demand during the time interval $L_i + T_i$ is calculated by (2). Demand during the time interval $L_i + T_i$ is assumed to be normally distributed, with:

$$\text{Mean demand during } L_i + T_i \text{ periods, } D_{L_i + T_i} = (L_i + T_i)\, D_i \qquad (2)$$

$$\text{Standard deviation of demand during } L_i + T_i \text{ periods, } \sigma_{L_i+T_i} = \sqrt{L_i + T_i}\,\sigma_{D_i} \tag{3}$$

The ss_i in this case is the quantity in excess of D_{Li+Ti} carried by the company over time interval $L_i + T_i$. The S_i is calculated by (4):

$$S_i = D_{Li+Ti} + ss_i \tag{4}$$

Given the desired CSL_i, the ss_i is calculated by (5):

$$ss_i = F_S^{-1}(CSL_i) \times \sigma_{L_i+T_i} = NORMSINV(CSL) \times \sigma_{L_i+T_i} \tag{5}$$

Then, average lot size Q_i equals the average demand during the review period T_i and is obtained by (6):

$$Q_i = D_{T_i} = D_i \times T_i \tag{6}$$

Last, re-order point (s_i) of each material i is calculated by (7):

$$s_i = D_{L_i} + ss_i, \tag{7}$$

where D_{L_i} is calculated by (8):

$$D_{L_i} = D_i \times L_i \tag{8}$$

In Figure 1, an inventory profile for a periodic review period T_i with lead time L_i is presented. Note that ss_i should be sufficient to buffer demand variability over $L_i + T_i$.

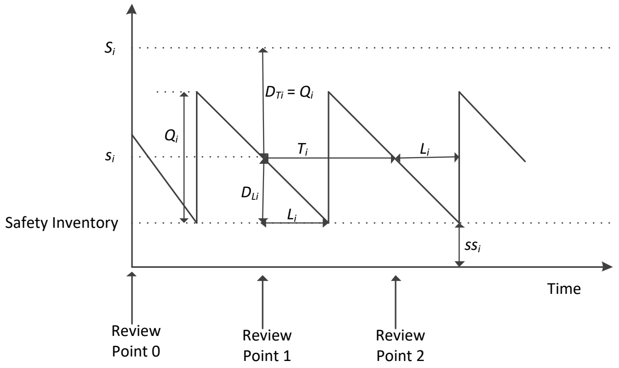

Figure 1. Inventory profile for periodic review policy

4.3 Solution, results and interpretations

Note that there is a positive correlation between review interval (T_i) and order up-to-level (S_i) and safety stock level (ss_i) as seen in Eqs (4)-(5). Therefore, minimization of T_i levels under desired CSL will also ensure minimum inventory amount carried at the shop floor. Namely, when review of inventory levels under desired CSL level (i.e., 100%) is minimized, the s, S levels will also be minimized (see, Eq. 4-5). Thus, the aim of this study is to find out the optimum review periods, for s and S levels of FSIs under pre-defined constraints. The constraints are considered as to satisfy the pre-defined CSL for each item and the capacity limit. For the optimization procedure, the below mathematical model is developed. The objective function is defined by (9) which minimizes the total number of annual reviews completed in a PL. The decision variables are defined as T_i, s_i and S_i which reflect the review period (RP) in hour, re-order point and order-up-to-level of material i, respectively. Here, m is the total number of material types in PLj (see Table 1).

$$\text{Min } 1/\textstyle\sum_{i=1}^{m} T_i \tag{9}$$

$$\sum_{i=1}^{m} S_i \leq C_j \tag{10}$$

$$T_i = 2^{n_i} \tag{11}$$

$$n_i \in \text{integer} \tag{12}$$

(10) provides the capacity constraint of each PL's FSSA in kg. and each is provided in Table 1. (11) is the review period (hour) calculation for each material type in a PL. Here, the decision variable T_i is calculated by n_i which is an integer value. (12) provides the integer constraint.

It should be noted that to be able to obtain S_i values in (10) the Eq. s (2), (3), (5) and (4) should be calculated in order. To be able to obtain the s_i values Eq.s (7) and (8) should be calculated in order. Based on the developed model, the optimization procedure is completed for each PL separately using the excel solver. The results are provided in Table 2 and 3.

Table 2. Optimization results of (s, S) levels and review periods of materials for PL 1-7

PL	FSI	CSL (100%)			Total S_i (kg.) (Capacity)
		s_i (kg.)	S_i (kg.)	RP (T_i)	
1	1	423.1	437	1	2667 (2700)
	2	107.3	114.1	2	
	3	76.3	83.1	4	
	4	96.4	102.5	4	
	5	108.1	124.3	2	
	6	250.2	274.3	2	
	7	74.3	82.7	4	
	8	1364.3	1449	1	
2	1	321.4	352.9	2	3587.2 (3600)
	2	408.8	443.3	2	
	3	249.2	289	2	
	4	543	618.2	2	
	5	691.3	750.2	2	
	6	189.7	219.2	2	
	7	848.5	914.4	1	
3	1	586.6	1095.2	128	3528.7 (3600)
	2	576.4	1220.4	128	
	3	633.3	1213.1	64	
4	1	1784.8	1928.4	1	3586.2 (3600)
	2	167.7	208.8	4	
	3	1364.3	1449	1	
5	1	786.2	1142.6	32	3548.7 (3600)
	2	680.5	1052.2	64	
	3	550.4	1019.2	64	
	4	213.5	334.7	32	
6	1	214.1	498.1	256	

	2	211	570.3	1024	1711.4 (1800)
	3	98.5	180.6	512	
	4	76	174.1	1024	
	5	154	288.3	1024	
7	1	995.11	1254.9	32	3379.4 (3600)
	2	446	631.9	16	
	3	1069.1	1492.6	16	

Table 2 and 3 shows the optimum review periods (T_i) as well as the optimum order-up-to (S) and re-order (s) levels of FSIs in the nine production lines. The first column represents the PL, while the second column shows the material type in that PL. The third, fourth and the last columns show the optimum values of (s, S) and review periods (hour), respectively. Some interpretations from Table 2 and 3 are provided below:

- It is observed that when the FSSA capacity is tight based on the demand in that PL, the optimum review periods are usually low to be able to satisfy the capacity constraint. PLs 1, 2 and 4 are examples for this case.
- It is also observed that when the FSSA capacity is tight, the difference between the optimum S and s levels is low. Namely, the value of the optimum (s, S) levels are close to each other. So, there is a positive correlation between the review periods and the difference between the S_i and s_i values. When one is high the other is also high.
- By the optimum review periods provided in Table 2, the company will also be able to identify how many times transportations will be completed in a year from the main warehouse to the PLs. By that, the optimum numbers of transporters as well as their capacities can also be determined.

Table 3. Optimization results of (s, S) levels and review periods of materials for PL 8-9

PL	FSI	CSL (100%)			Total S_i (Capacity)
		s_i	S_i	RP	
8	1	382.2	492.6	32	10775 (10800)
	2	963.9	1321.3	16	
	3	224.8	340.9	32	
	4	132.7	240.8	64	
	5	187.9	327.5	32	
	6	241.5	333.8	32	
	7	818.6	1134.1	16	
	8	164.6	290	64	
	9	421.3	610.1	16	
	10	387.9	658.6	32	
	11	414.6	599.8	16	
	12	159.8	230.6	32	
	13	172.2	231.1	32	
	14	433.7	603.4	32	
	15	137.4	202.7	32	
	16	306.5	508.2	32	
	17	175.4	303.4	64	
	18	162.5	268.7	64	
	19	493.6	660.6	32	
	20	185.6	262.9	32	

	21	378.8	569.9	16	
	22	449.2	584	32	
9	1	499.6	684.8	16	8904.8 (9000)
	2	177.2	307.7	64	
	3	339.1	474.5	16	
	4	224.8	391.8	32	
	5	280.9	373.2	32	
	6	257.5	367.9	32	
	7	132.4	203.2	32	
	8	217.4	357	32	
	9	648.2	963.6	16	
	10	164.6	292.5	64	
	11	265	434.8	32	
	12	328.2	463.1	32	
	13	458.4	649.6	16	
	14	165.3	242.6	32	
	15	306.5	508.2	32	
	16	343.3	459.4	32	
	17	708.1	1065.5	16	
	18	476.6	665.4	16	

5. Conclusion

In this paper, an analytical optimization procedure for determination of optimum review periods and (s, S) inventory levels of FSIs in a paint company is proposed. It is significant to determine the optimum review periods and safety inventory levels of the FSIs to be carried in FSSAs to minimize the stock outs in manufacturing process. The problem is modeled as a multi-item, single-echelon, (s, S) inventory system. The raw materials are hold in nine inside inventory locations which are supplied from the main warehouse whose capacity is infinite under a positive lead time. The objective function is considered as minimization of total number of reviews completed in a year so that the total number of transportations completed in a year from the main warehouse will be minimized. In the problem, periodic review specifically power-of-two policy is considered. Optimum review periods are determined for each FSI satisfying pre-defined CSL – 100% - under the capacity constraint of FSSA in each PL. To the best of our knowledge, it is the first time a floor stock optimization problem is studied by treating it as an (s, S) inventory model in the literature.

The procedure provided by this study can be used for optimization of any inventory control problem. There are many possible future work to extend this study. For example, the review periods can be optimized by allowing lateral transshipments between PLs having same FSIs. Another study can be conducted by considering different objective functions in the optimization procedure such as maximization of minimum review period in a PL. Also capacitated vehicles can be used for transportation of items, and then the optimization model can also be modified to a capacitated transportation problem.

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