Reliability Evaluation and Design Optimization of Inventory Management System

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Abstract

Time variances and operating conditions are variables that can complicate dynamic reliability measures and controls within inventory management systems. Proficiency over time when dealing with contingent inventory flow is essential. Sudden delays can hinder inventory movement and weaken the overall reliability and steadfastness of the inventory management system of a company. This paper introduces a reliability measure that is able to quantify the reliability of an inventory management system. Also a novel, reliability-based, robust optimizations model is being developed to most effectively allocate resources and schedule time, giving consideration to the uncertainty associated with inventory movement. This model is comprised of various processes including: purchasing, shipping, receiving, tracking, warehousing, storing, and turnover.

Keywords
Reliability Evaluation, Optimization, Inventory Management System, Uncertainty

1. Introduction

The globalization of today's marketplace has brought new opportunities and challenges to the industry. This new frontier allows businesses to reach more consumers than ever. However, this also increases the need for reliable and robust global inventory management systems (IMSs). Technology has become an amazing tool that managers can use to keep accurate records. There are so many variables when managing stock that can ultimately determine the success or failure of a business. This makes the need for an effective IMS essential. Any IMS should help in organizing inventory by specifying inflow and outflow (Sani, 2014). This defines how much stock is received and sold from an inventory system. An IMS needs to be able to recognize valuable information. Inventory consists of stock-keeping. This includes raw material, work-in-progress, and finished or value-added products or services. According to Ernst, Guerrero, and Roshwalb (1993), having a good IMS will help in keeping an updated record of the stock-keeping units (SKUs). Hence, having a precise stock level where the system-recorded stock reflects the actual stock is essential.

An inventory manager might face two major problems. These problems include having excess inventory or the opposite, having a stock shortage. An excess of the inventory stock level will automatically become overstock. This is problematic for businesses and has many negative consequences. One of the major effects is an increase in cost. Storage and security fees would be increased as well as money being tied-up in nonessential goods inventory. There is also more risk involved in having too much inventory on hand. There are two costs of holding an inventory. First, carrying cost, also known as holding cost, is the cost of storage, insurance, material handling, etc. The second type of cost is ordering cost. This is the cost associated with placing orders and receiving goods such as transportation and shipping, receiving and inspecting materials, etc. These two costs are the core of inventory problems. If an increase occurs in order size, it will lead to an increase in the average number of processed goods in inventory; therefore, it will lead to an increase in the carrying cost.

On the other hand, the stock shortage can also have dire consequences. Business' reputations rely on the consumers' trust. Providing high quality and affordable goods in a timely and predictable fashion is the key to success. As a result, having a shortage of stock can lead to massive losses to the company. These losses can come from increased production times, increased purchasing costs, loss of sales, and ultimately the loss of goodwill from consumers (Kontus, 2014). Inventory decision-making is hazardous as well, as it may affect the supply chain (Bowersox, 1999; Closs, & Cooper, 2005; Quesada-Pineda, 2010). Having an IMS is necessary to accomplish customer demand at the right time and in a cost-effective manner (Zaidi, Khan, & Dweiri, 2012). Hence keeping too little stock may result in production problems; while keeping too much means investing a lot of money unnecessarily. Creating a balance is, therefore, imperative. Inventory is one of the most expensive assets many companies invest in. Thus, this paper will first introduce a method that helps to evaluate the reliability of an inventory system based on satisfying customer demand. Then, this measure can be used in the organizing and scheduling process using reliability design optimization. This will assist in keeping accurate records that will save the effort of recounting as a result. Having a good IMS will save an enormous amount of money and time.

In general, reliability is defined as an item's ability to start and continue to operate (Modarres, Kaminskiy, & Krivtsov, 2009). The RDO approach characterizes uncertainty variables and failure modes to optimize the designs for higher reliability. RDO accepts variability and uses the limit state function to separate out the stress and strength probability density functions (pdf) to achieve the desired reliability level. The Robustness concept was first introduced by Taguchi in 1987. During the early days, many models of productions and inventory system were developed in the operation management field (Auoam, & Brahimi, 2013). A common method used in solving optimization problems specifically under uncertainties was established by using Monte Carlo Simulation method. There are many research aimed to systematically treat uncertainties in engineering analysis and more recently, to develop RDO (Chen, Hasselman, and Neill, 1997; Choi, and Du, 2005; Du, and Chen, 2004; Youn, and Wang, 2009; Youn, Wang, Hu, and Youn, 2011; Wang, Wang, & Almaktoom, 2014).

This research focuses on developing a reliability design optimization approach that helps to satisfy reliability requirements in every stage of the inventory system, while coping with uncertainty and minimizing over all handling and managements cost. The proposed model will help to balance cost and reliability requirements, while also minimizing the impact of uncertainty associated with the movement of products. The remainder of this paper is organized as follows: section two introduces method for evaluating the reliability of inventory systems, section three presents the developed methodology for design reliable inventory system, section four presents findings of this dissertation by applying developed model using a case study of a complex supply chain systems SCS that consists of factories connected in parallel and series in Kansas City, and finally the conclusion is presented in section five.

2. Reliability Evaluation of Inventory Management System

Progression and development of an Inventory Management System Reliability (IMSR) measure is affected by not only internal factors, but also numerous external factors such as: growing globalization, information availability, global trade, ecological concerns, etc. The reliability of an inventory system can be defined as the ability of the inventory system to complete all required processes before the due date. Therefore, an IMSR output should be measured and compared with a qualified set of performance measures. In order to control the performance of an IMS, the process parameters of the SCS must be kept within a constant range limit. By doing so, comparisons of target performances and actual performances are possible. Once comparisons are completed, specific identified processes in the companies can be targeted in order to improve the inventory management performance. By using an appropriate set of measures, the overall IMSR can be monitored closely for its performance. Successive improvements can be applied to each entity in the inventory management in order to determine the impact of improvements on the overall

IMSR. The IMSR of suppliers, routs, factories and the overall inventory management can be used to identify satisfaction of the customer. In general, IMSR can be defined as the probability of completing all required process at time (X) before the due time (Y) and can be statistically expressed as shown in Equation (1).

$$\text{IMSR} = \Pr(X_1+X_2+\cdots\cdots..+X_n \leq Y) \quad (1)$$

3. Reliability Design Optimization of Inventory Management System

This section presents the RDO of an IMS. In general, Reliability design optimization (RDO) aims to find the best compromise between cost and reliability by taking uncertainties into account. RDO is used to control reliability and reduce cost variances. It was stated that the RDO model is designed by using a multi-objective function that minimizes cost and cost-uncertainty factors (variance) while it's constraint is the required reliability target as shown in Figure 1 (Wang, Wang, & Almaktoom, 2014; Wang, Wang, & Lee, 2013).

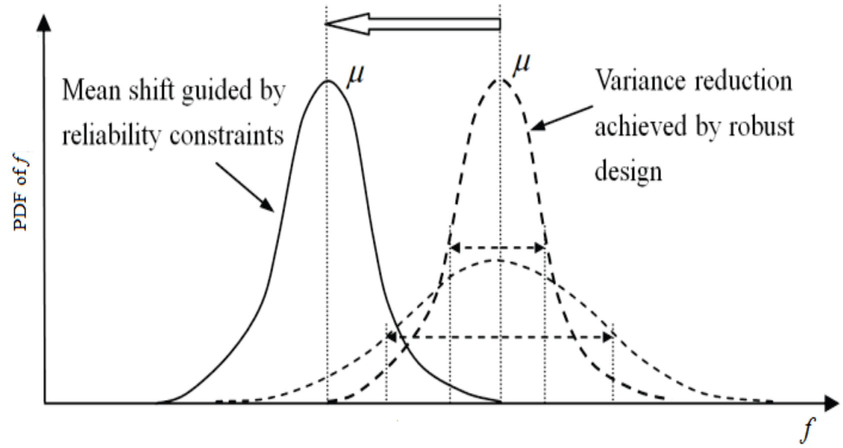

Figure 1: Typical RDO Phenomenon

The optimal design of an IMS can be obtained using RDO, which is a technique that seeks to find the optimal designs which are less sensitive to the uncontrollable variations that are often inherent to the design process. RDO aims to quantify the performance of IMS by regulating design characteristics and constraints for robustness by taking variability, and uncertainties involved in the process into consideration. RDO outperforms existing deterministic discrete optimization tools when dynamic or uncertainty is involved in optimization problems. When using RDO for (IMS), there are two objectives which are: minimizing mean of inventory cycle time, and minimizing the impact of uncertainties. The objective of this paper is to develop RDO model which will help to design a reliable IMS. Also, RDO considers various uncertainties introduced by the change of customer specification requirements, transportation delay, and unavailability of the raw material required by client, manufacturing processes, and operational condition. The general formula for the RDO of IMS is given by:

$$\min f_{(i,j)_{\sum_1^J \sum_1^I \mu_x(i,j)}} + f_{(i,j)_{\sum_1^J \sum_1^I \sigma_x(i,j)}} \quad (2)$$

s.t:

$$IMSR_{\ i,j}(x_s) \geq IMRS^T \qquad \forall\, i = 1,2,\ldots I \text{ and } j = 1,2,\ldots,J$$

$$x_s^L \leq x_s \leq x_s^U$$

$$x_s \geq 0$$

where $IMSR(x_s)$ is the reliability constraints, its prescribed reliability target $\text{IMSR}^T(x_s)$. $\sigma_x(i,j)$ represents the standard deviations (delay due to uncertainty) of the inventory cycle time function of node type X number i in level number j. $\mu_X(i,j)$ represents the mean of the inventory cycle time function of node type X number i in level number j, x^Ls and x^Us are the lower and upper limits of the design variable, respectively.

4. Case Study

The developed method is being applied to the IMS of a complex supply chain systems SCS that consists of connected parallel and series factories in Kansas City to test the effectiveness of the developed models. This system provides a wide range of products from South Dakota, Iowa, California and Mississippi to make their product within the budget rate. The IMS of the system consists of 8 stages for different types of operation. Table 1 below shows primary data which describes the minimum and maximum days required for each process to be accomplished by each entity.

Table 1: Design Parameter

#	**Title**	Minimum	Maximum
P1	Product choice	2	6
P2	Order Products from suppliers	6	12
P3	Putting orders for production	8	13
P4	Packages are ready for shipping	22	30
P5	Packages delivery from suppliers to Warehouse	10	15
P6	Receive in Warehouse	20	23
P7	Delivery to customer	2	6
P8	Installation	5	8

5. Results

The first step is to evaluate the current performance of IMS using Equation (1). From collected data and MCS, it has been found that the current total cycle time of an order will take around 92 Days and the reliability of the system (IMSR) is 65.22% Table 2. This means that if a customer places an order, it will take 92 to complete and the probability of completing this order on time is 65.22%. In order to change the design and find optimum total cycle time and/or satisfying reliability requirement developed model Equation (2) is applied.

Table 2: SCS Initial Design Variables

P1	P2	P3	P4	P5	P6	P7	P8	Total Cycle Time	Initial Reliability
4	8	10	26	13	22	3	6	92	65.22%

In order to make sure that the required order is being processed and delivered on time, the RDO Equation (2) has been applied to this IMS. To solve this case study, the IMS of SCS was modeled in MATLAB R2015b. Multiple scenarios have been implemented to this model. One of these scenarios is the case where SCS requests a design to be able to complete all processes in 60 days and with a reliability of 95% for a customer.

The current reliability of 65% is considered to be weak. In order to reach a high reliability, RDO is being applied and results are shown in the Table 3 below. Moreover, Table 3 shows the design variable of each task (time needed to accomplish each task) and to complete order on time with a reliability of 95%.

Table 3: Optimal Points Required to Reach the Target Delivery

P1	P2	P3	P4	P5	P6	P7	P8	Total Cycle Time	Initial Reliability
3	6	8	22	10	20	2	5	76	95.00%

The provided optimal points are considered the **best days required to fulfill the customer objective**. In order to determine the best result, the data was repeated several times to ensure the optimal points. The reliability increased, reaching 95%, which means that the company is 95% sure that the order will be delivered on time.

By applying the developed RDO model, the required reliability performance was achieved and uncertainty impact was minimized as shown in Figure 2. Also, all constraints were satisfied, as shown in Table 3.

6. Conclusion and Future Work

IMS is considered to be one of the most important factors of many business. Managing inventories requires a primary objective of determining and controlling stock level. This requires balancing the need of product availability versus the need for minimizing stock holding. In order to achieve this, multiples design tools have been used to develop RDO, a technique to help designing reliable IMS. These techniques include Monte Carlo Simulation, deterministic nonlinear programing, and stochastic nonlinear programing. In addition, Microsoft Excel solver and MATLAB software have been used for modeling and mathematical simulation. Mainly this research is focusing on two main dimensions, which are the evaluation of IMSs and developing a method that helps to design a reliable IMS.

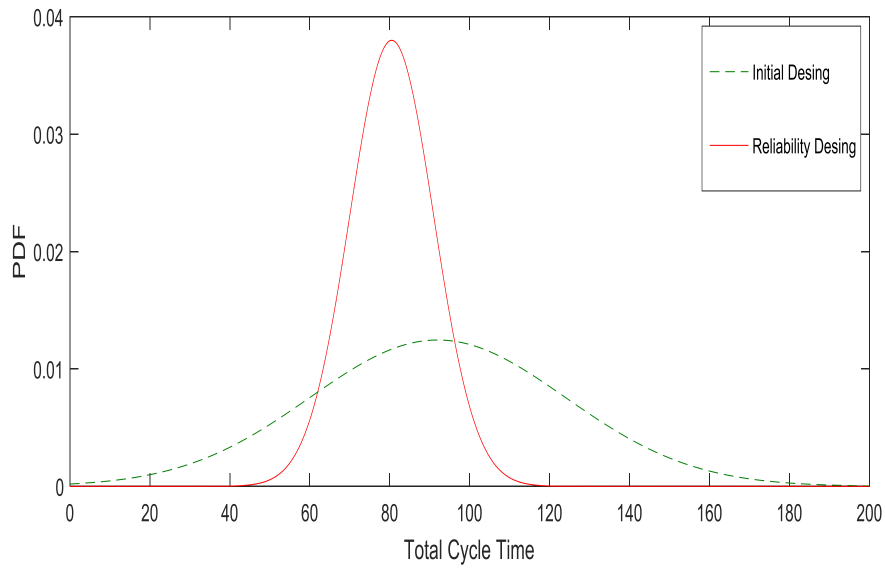

Figure 2: Results of RDO Model

The case study of IMS did verify and validate developed models. The case study shows that RDO has the capabilities to design a reliable IMS for system, while minimizing uncertainty impacts. This will positively impact customers' satisfaction of IMS. The model helps to determine the optimal time each task needs to accomplish the objective target time requested from a client. In this way, there will be a reduction in delay, which will increase the level of trust and satisfaction of a client. As future research, this work will continue to investigate how reliability performance influences the total cost of managing inventory systems. Also, different scenarios with multiples reliability rates well be performed. The research will investigate how the RDO model could help in reducing the total cost while satisfying the reliability requirement.

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Biography

Ahmed K. Alsaadi is a Ph.D. candidate in Industrial and Manufacturing Engineering at Wichita State University. He received his M.S. in Petroleum Engineering from King Saud University, Saudi Arabia, and B.E. in Petroleum Engineering from King Saud University, Saudi Arabia. His research interests include supply chain management and logistics, optimization under uncertainty, reliability based robust design optimization, resilience based design optimization, and lean supply chain management.

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