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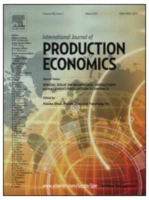

Robust material handling system design with standard deviation, variance and downside risk as risk measures

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ABSTRACT

The design and planning of major storage systems belong to the class of systems design problems under uncertainty. The overall structure of the system is determined during the design stage while the values of the future conditions and the future planning decisions are not known with certainty. Typically the future uncertainty is modeled through a number of scenarios and each scenario has an individual time-discounted total system cost. The overall performance of the material handling system (MHS) is characterized by the distribution of these scenario costs. The central tendency of the cost distribution is always computed as the expected value of the distribution. Several alternatives for the dispersion of the distribution can be used. In this study the standard deviation, variance, and the downside risk of the cost distribution are investigated as the risk measures of the system. We propose an algorithm to efficiently identify all configurations of the MHS that are Pareto-optimal with respect to the tradeoff between the expected value of the costs and the risk; such Pareto-optimal configurations are also called efficient. Although the MHS model has non-linear constraints, our proposed algorithm can solve such non-linear models taking into account both the expected costs and the risk. The final selection of the storage system for implementation can then be made based on the Pareto graph and other considerations such as the risk preferences of the system owner. The algorithms developed are illustrated through a case study which helps in developing business insights for the warehouse and MHS design planners and decision makers.

1. Introduction

Material handling is defined as the movement of materials (raw materials, scrap, emballage, semi-finished and finished products) to, through, and from productive processes; in warehouses and storage; and in receiving and shipping areas (Frazelle, 1992). Material handling systems (MHS) are an integral part of the supply chain of any business involved in the production, consumption, or transformation of one or more goods. Typical examples of MHS include warehouses, distribution centers and even manufacturing plants. MHS are also an important part of service systems like hospitals, retail malls, and restaurants. MHS can be manual, like restocking the shelves in a grocery store, or automated like distribution centers for the wholesale of frozen meats. Warehousing is an important part of the MHS that is concerned with activities like receiving of goods, storage, order-picking, accumulation, and sorting and shipping (Berg and Zijm, 1999).

The design and management of large and automated MHS and warehouses exhibit all the characteristics of designing engineered systems under uncertainty. When designing such systems, the planning horizon is typically 5–10 years. Decisions about the structure of the system and operational policies are taken based upon the data available at the design time. However, at the design time the future conditions are not known with certainty, hence it is important to develop a robust MHS model that incorporates the uncertainty in the system. The overall goal is to determine the system configuration that has the best tradeoff according to the system owner between the expected cost and the risk of the system.

The uncertainty of the future is typically captured in a number of possible scenarios, each of which has a different probability of occurrence. An individual scenario has a set of values for each of the uncertain parameters and hence the performance of the system under that scenario can be computed. MHS are required to satisfy one or more service requirements based on the parameter values of the scenario, and the performance objective is generally to minimize the total system cost over the planning horizon.

In this paper, we develop a model to design MHS under uncertainty and optimize the tradeoff between the reward and risk of the system. The reward or the expected efficiency of the system is

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represented by the expected value of the net present values of the scenarios. For the MHS design maximizing the efficiency of the system is equivalent to minimizing the total cost of the system. The risk of the system can be represented by one of the following risk measures that have been used extensively while modeling risk in financial models. Common measures of risk used are the variance and standard deviation. The classic example is the use of variance in the construction of equity portfolios by Markowitz (1952). More complex measures of dispersion such as the downside risk, value at risk, and the conditional value at risk are used in the financial industry but have not yet been used for the evaluation of MHS (see Fishburn, 1977). In our work, we have investigated three risk measures, which are standard deviation, variance, and downside risk, because of their simplicity and frequency of use in the supply chain industry.

The paper is organized as follows. In the remaining part of Section 1, a literature review is presented, which has two parts, one in which tradeoff between risk and reward is discussed and the other in which MHS design is discussed. In Section 2, we will model the general warehouse design problem considering risk measures. In Section 3, we will use the standard deviation and variance as the risk measures, showing the insights of the model, and propose an efficient algorithm. The downside risk model for warehouse design and the corresponding algorithm are discussed in Section 4. We present a case study which analyzes the manual and automated warehouse design in Section 5 and end up with the conclusions in Section 6.

1.1. *Multi-objective performance evaluation: risk versus reward*

The total time-discounted system cost of a MHS is a stochastic performance variable, since each of the different scenarios has a different cost and a probability of occurrence. The combination of all possible scenarios yields a cost distribution for a particular MHS. One objective of this research is the computation of the first and second moments of this distribution, i.e. the expected value, standard deviation, variance, and the downside risk. The expected value of the costs is denoted as the “reward” of the system when using the cost minimization objective. The dispersion of the costs is often interpreted as a measure of the risk associated with the system; see for example the ISO standard on risk management (ISO, 2011). The majority of the prior research on design considering risk focuses on “continuous” systems, where the decision variables can be varied in small increments. Examples are the construction of equity portfolios by Markowitz (1952) and the development of mean-downside risk and mean-variance models for newsvendor systems by Choi and Chiu (2010). In our work, we investigate the use of variance, standard deviation and downside risk as risk measures in the design of MHS which have a limited number of “discrete” system configurations.

We have two measures of performance which are of interest to the system designer, hence a tradeoff between them is required, which is the risk versus reward tradeoff. Assuming the performance measure is being minimized, a MHS configuration is said to be efficient if no other configuration has the same or lower cost and the same or smaller risk; (see e.g. Kung et al., 1975) for the definition of efficient discrete alternatives. An efficient configuration is also said to be Pareto-efficient or Pareto-optimal. Specifically, the objective of the design process is to find all Pareto-optimal configurations with respect to the reward and risk of the scenario performance measure. The configurations can be plotted in a risk analysis graph with the expected cost on the horizontal axis and the risk on the vertical axis. The set of all the system configurations dominated by a particular system configuration corresponds to a rectangle in the risk analysis graph with the system configuration as the lower left corner. Fig. 1 below shows an example of a risk analysis graph with two Pareto-optimal configurations. The dotted and the dashed lines represent the dominance regions (rectangles) of these two configurations. The risk tradeoff was based on 5 scenarios ($N=5$). Note that in this real case, the optimal configuration for the mean value of all the parameters, i.e. the mean-value problem (MVP), is strongly dominated by all other configurations.

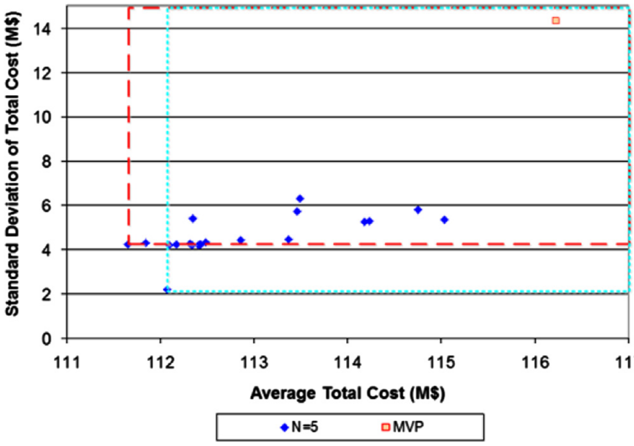

Fig. 1. Risk graph with Pareto-optimal configurations.

The second objective of this research is to develop an efficient algorithm that identifies all Pareto-optimal configurations for a MHS. The algorithm developed takes into account practical considerations about the dimensions of the warehouse which justifies the use of parametric design over other methods. This allows the selection of the final preferred alternative based on the risk versus reward preferences of the corporation that will own the MHS. The third objective of this research is to perform the risk analysis using different risk measures such as standard deviation, variance and downside risk. And the fourth objective of this research is to apply the methodology and the algorithms developed on a case study. This allows us to generate business insights that will be useful for system designers and researchers involved in the design of warehouse and MHS.

1.2. *Review of MHS design models*

Given that there is intense global competition and companies spend millions of dollars each year on MHS, a large number of system design models and systems design approaches for MHS have been developed. To present a comprehensive review of these research results is beyond the scope of this paper, but we discuss major work that has been done in this field and make some key observations. Both digital simulation and optimization have been used to find MHS with desirable performance characteristics. Early design methods based on digital simulation were proposed by Perry et al. (1984) and Ashayeri and Gelders (1985). Some of the earliest research in the area of optimization of warehousing systems was reported in Gudehus (1973) and Kunder and Gudehus (1975). Comprehensive reviews of the analysis and design of MHS have been created by Rouwenhorst et al. (2000) and Gu et al. (2010).

One of the most comprehensive models for the design and evaluation of automated storage and retrieval systems (AS/RS) is developed in Lerher and Srami (2012). Because the model is non-linear in function of the main dimensions of the AS/RS, they use a genetic algorithm to find a high quality configuration of the system. In another recent work, Sooksaksun et al. (2012) developed a warehouse design algorithm using particle swarm optimization. They developed a model for determining warehouse dimensions and used particle swarm optimization to find a design satisfying a given performance criterion. Goetschalckx et al. (2013) developed a conceptual framework to model MHS under uncertainty. The focus of this paper was to develop a methodology that people could refer to while designing MHS under uncertainty.

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