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A genetic algorithm for minimizing energy consumption in warehouses

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ABSTRACT

Green supply chain management is generally defined as integration of green thinking and environmental issues into the whole supply chain operations like product design, manufacturing process, warehousing, distribution etc. Within this context green principles should be adopted in warehouse management to minimize negative impact on the environment. In warehouse operations, picking must be analyzed attentively which is widely studied in literature for minimizing service time levels because of its close relation to the higher costs. The efficiency of picking in warehouses mainly depends on storage assignment policy that directly affects picking performance in warehouses. In this paper, picking operation in warehouses is studied to minimize energy consumption with proper storage policy other than service time. Genetic algorithm (GA) is proposed to solve the problem and numerical examples are presented to demonstrate the performance of the GA. Results show that, the GA gives efficient solutions to the problem.

1. Introduction

Supply chain contemplates the product from initial processing of raw materials to delivery to the end user [1]. The topic of sustainability and green thinking has been discussed using different terms in literature [2]. The most common term is green supply chain management. The importance of green supply chain management is well recognized by researchers, manufacturers and economic operators in recent years. Nowadays, most organizations are starting to go green in their business as concern to environmental sustainability [3]. A number of definitions are made for green supply chain management. El Saadany et al. [4] defined green supply chains as reducing energy, virgin raw material usage and waste generation, and increasing product recovery options. They stated that greening usually refers to the forward supply chain functions such as production, purchasing, materials management, warehousing and inventory control, distribution, shipping and transport logistics.

Warehouses are an essential component of any supply chain [5] and warehouse management plays a critical role in supply chain management. The customer needs in terms of the order accuracy and response time, order frequency, order quantity and order size have dramatically changed with the global economy and new demand trends (e.g., e-commerce) [6]. However customer awareness is also changed and improved about environmental issues and sustainability. Green principles and environmental management practices should be adopted in warehouse management to minimize energy consumption and to reduce negative impact on the environment. Major warehousing activities include receiving, putting away, storing, order picking, sorting and shipping [7]. Order picking, the process of retrieving products from storage (or buffer areas) in response to a specific customer request, is the most labor-intensive operation in warehouses with manual systems, and a very capital-intensive operation in warehouses with automated systems [8]. Moreover order picking is the most time and energy consuming process in warehouses, therefore should be analyzed attentively considering environmental thinking.

The scope of this study is to determine effective order picking routes in warehouses considering minimization of energy consumption and to show a way for applying green principles in warehouse operations. Order batching is applied for increasing efficiency of order picking process. Because of close relation to the performance of the picking operation, storage assignment policies are also discussed for minimization of energy consumption. A genetic algorithm (GA) is proposed as a solution approach for order batching and routing optimization in order to minimize energy

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consumption. Remainder of this paper is organized as follows. Section 2 provides literature review about order picking, storage assignment and green warehousing. In Section 3, the definition of the studied problem is presented. In Section 4, the proposed solution methodology is described. Section 5 provides numerical experiments and computational results. Finally in Section 6, conclusions are summarized.

2. Literature review

In literature, most researchers studied warehouse management and warehouse operations in order to minimize service time levels or costs. Accorsi et al. [6] developed a decision-support system for the design, management, and control of warehousing systems to provide travel distance and cost savings. Ene and Öztürk [9] designed storage assignment and order picking system using a developed mathematical model and stochastic evolutionary optimization approach in order to minimize travelling costs. Muppani and Adil [10] examined a system that includes a class-based storage method by developing a simulated annealing algorithm in order to minimize storage and order picking costs. Hsu et al. [11] developed a batching approach based on GA in order to minimize the total distance travelled. Petersen and Aaese [12] examined the effect of picking, storage and routing on order picker travel with a simulation model. Chan and Chan [13] presented a simulation study of a real case regarding storage assignment problem of a manual-pick and multi-level rack warehouse in terms of travel distance and order retrieval time. Henn [14] considered an on-line order batching problem in which the maximum completion time of the customer orders arriving within a certain time period has to be minimized. Pan et al. [15] developed a heuristic storage assignment policy that considers both the travel time and the waiting time simultaneously by minimizing the average order fulfillment time. However there are a limited number of studies that discuss green warehouse operations or sustainability in warehouse management. Dukić et al. [16] discussed order picking methods and technologies for green warehouses. Meneghetti and Monti [17] discussed energy based storage location assignment policies for automated warehouses. Meneghetti and Monti [18] studied sustainable storage assignment and dwell-point policies for automated storage and retrieval systems. Rai et al. [19] studied on assessment of CO_2 emissions reduction in a distribution warehouse by using a computer simulation program.

In this paper minimization of energy consumption in warehouses is studied for integrating environmental thinking into warehouse operations. In warehouse operations order picking has the highest priority because of its energy and time consuming and repetitive form. As summarized above, most researchers adopted service time, distance or cost as a performance criteria in order picking optimization. Differently from previous studies, this study takes into account minimization of energy consumption in picker-to-part warehouse systems and proposes a GA for minimizing energy consumption in order picking operation with considering both batching and routing.

3. Problem description

In this paper a generic warehouse structure is considered in order to demonstrate solution approach and numerical experiments. Manual warehousing and picker to part system is adopted in the warehouse. In this system, order pickers are guided with order pick list. An order pick list that includes, order arrival time, order due time, order storage location is joined to the orders and these orders may contain the items of a single customer order or of a combination of customer orders. Picking operations are carried out with forklift by pickers and starts with input/output point. The picker collects items from different storage locations. Batching is applied according to forklift capacity for the collected items.

The studied warehouse has 13 picking aisles and 12 shelves. Each shelf has four layers and two sides for picking. One side of a shelf has total 100 storage locations. And totally 2400 storage locations are included in the warehouse. Only one product can be stored in each location. The layout of the warehouse is illustrated in Fig. 1.

The width of a picking aisle is 5 m and the length of a picking aisle is 62.5 m. The width of the shelves is 2 m. The horizontal distance between storage locations is 2.5 m and the vertical distance between the storage locations is 1.5 m.

The horizontal speed of the forklift is assumed as 10 km per hour and vertical speed of the forklift is assumed as 0.53 km per hour.

4. Solution methodology

4.1. Basics of genetic algorithms

Genetic algorithms are search algorithms based on natural selection and genetics [20]. To apply the genetic evolutionary concept to a real-world optimization problem, two issues must be addressed: encoding the potential solutions and defining the fitness function (objective function) to be optimized [11]. Genetic algorithms work with coding of parameters, instead of the parameters themselves. The genetic algorithm, encodes decision variables of a search problem into strings, which are called as chromosomes. The chromosomes are candidate solutions to the search problem. The algorithm founds on a population of candidate solutions differently from traditional search methods. The size of population is a user-defined parameter. To evaluate the solutions or distinguish good solutions from bad ones, a measure referred as fitness function is employed. The algorithm starts with an initial population of candidate solutions and evolves the solutions of the search problem using genetic operators like, selection, crossover and mutation, until one or more stopping criteria are met [21].

4.2. Genetic algorithm for order batching and routing optimization

In this paper, a GA for order picking optimization in warehouses is proposed. The algorithm optimizes both routing and batching problem for minimization of energy consumption. Details of the GA are described in the following subsections.

4.2.1. Chromosome encoding

In the GA, genetic representation of the problem solution is encoded through a string composed of orders locations similar to encoding approach of Ene and Öztürk [9]. To illustrate solution representation a chromosome representation is presented in Fig. 2.

In the example chromosome representation, there are 20 orders in the order pick list. Each gene in the chromosome represents location numbers of the orders and the position of the gene in the chromosome represents batch number that the order belongs. In this example it is assumed that the capacity of the batch is 5 and assigned orders cannot exceed this capacity level.

4.2.2. Fitness function

The fitness function is a computation that evaluates the quality of the chromosome as a solution to a particular problem [22]. A fitness function measures a distance between good and bad solutions by mapping the solution to a non-negative interval [23].

In this paper, fitness function is formed according to total energy consumption in the warehouse for order picking operations. As it is stated in Section 3, in the warehouse order picking is carried out