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Optimal location of dwell points in a single loop AGV system with time restrictions on vehicle availability

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Abstract

Since the workload of a manufacturing system changes over time, the material handling equipment used in the facility will be idle at certain time intervals to avoid system overload. In this context, a relevant control problem in operating an automated guided vehicle (AGV) system is where to locate idle vehicles. These locations, called dwell points, establish the response times for AVG requests. In this article, a dynamic programming algorithm to solve idle vehicle positioning problems in unidirectional single loop systems is developed to minimize the maximum response time considering restrictions on vehicle time available to travel and load/unload requests. This polynomial time algorithm finds optimal dwell points when all requests from a given pick-up station are handled by a single AGV. The proposed algorithm is used to study the change in maximum response time as a function of the number of vehicles in the system.

Keywords: Dynamic programming; Automated guided vehicles; Dwell points

1. Introduction

In recent years, manufacturing companies have focused their resources, capabilities, and energies on building sustainable competitive advantages. Such advantages can be gained by applying new concepts related to manufacturing processes and system automation. In particular, automated guided vehicle (AGV) systems may provide a noticeable replacement alternative for conventional material handling devices. An AGV is a driverless vehicle, whose movement can be controlled by wires, strategically positioned radars, or special tapes. AGVs provide automated loading, transportation, and unloading capabilities (Heragu, 1997). The use of AGV systems has evolved drastically from traditional distribution-oriented applications at one end of the spectrum to complex computer-controlled automobile assembly systems with robotic interfaces at the other end. They can be stand-alone systems, an integral part of another system, or aid in pulling together islands of automation. This paper presents an algorithm to improve the efficiency of an existing AGV system by locating idle AGVs with the objective of minimizing the maximum response time while considering available vehicle time.

Current literature in facility layout and material handling encompasses a wide range of logistics problems for AGV systems. In a loop layout, manufacturing cells are represented by rectilinear polygons combined to form a block layout. Afentakis (1989) introduced the sequencing problem of determining the relative order of cells in a unidirectional loop to minimize transportation costs. No consideration is given to the size, shape, or orientation of the cells in the block layout for Afentakis's problem called the sequence stationing problem. However, the cell location problem addresses physical characteristics of cells in designing a layout. Montreuil (1991) presents a mixed integer linear programming (MILP) model

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for the cell location problem. Asef-Vaziri and Laporte (2005) provide an extensive literature review on loop based facility planning and material handling with an emphasis on AGVs.

For the single loop configuration within a block layout, Tanchoco and Sinriech (1992) provide the foundation for research on AGV systems. This research addresses two different objectives for the problem of loop design in an existing block layout. First, in the loop configuration problem, the objective is to minimize the loop distance while covering at least one edge in each cell. They propose an integer linear programming formulation for this problem. Secondly, for the loop distance flow problem, the objective is to optimize total distance traveled by loaded vehicles. The authors provide an enumeration procedure based on non-dominated solutions. Sinriech and Tanchoco (1993) and Asef-Vaziri et al. (2001) also consider unidirectional loop designs that minimize the total loaded vehicle trip distance. In addition to loaded vehicle trips, Asef-Vaziri et al. (2003) include empty vehicle trips in the objective function. Their study concludes that ignoring empty vehicle trips may yield a suboptimal solution requiring many empty vehicle trips. Asef-Vaziri et al. (2007) extend the research on this problem by developing a decomposition procedure and neighborhood search heuristic to quickly solve instances of large problems to near optimality. In other research for loop design, Sinriech and Tanchoco (1992) locate pick-up and drop-off stations in a fixed loop while considering inter-cell and intra-cell movement.

Since the workload of a manufacturing system or distribution center varies over time, vehicle idleness should be allowed to avoid system overload (Chang and Egbelu, 1996). For a given loop design, the management of idle vehicles is an important control issue that affects the performance of an AGV system. For single vehicle loop guide path systems, Egbelu (1993) found a simple algorithm to minimize the maximum response time. The problem of minimizing the mean response time has also been solved optimally for a single vehicle loop (Kim, 1995; Chang and Egbelu, 1996). Egbelu (1993) also developed a heuristic algorithm to minimize the maximum response time for the case where multiple vehicles are allowed in a circular layout. An algorithm for minimizing the mean response time was developed by Kim (1995) to find the optimal location of adding one new vehicle at a time when some other vehicles are already located in the system. For a discrete stationary Markov chain model of the system, Kim and Kim (1997) present an algorithm to minimize mean response time. To optimize an arbitrary regular cost function, Gademann and Van de Velde (2000) derive a polynomial dynamic programming (DP) algorithm for multiple vehicles in a unidirectional single loop. Ventura and Lee (2003) and Lee and Ventura (2001) provide optimality properties and develop polynomial time algorithms based on DP to find the optimal locations of dwell points for the objectives of minimizing the maximum response time and the mean response time in single loop systems, respectively.

In this study, a polynomial time algorithm is developed to minimize the maximum response time in a unidirectional single loop system with multiple vehicles subject to restrictions on the time vehicles are available to service requests. Prior research studies on this dwell point location problem for an existing layout have never considered this type of constraint. If time restrictions are not considered, a single AGV could service several requests during a shift. Each of these requests requires travel time to the pick-up station (response time), loading time, time to transport the load to the delivery station, unloading time, and time to return to the dwell point. It is possible that an AGV would not have enough time during a shift to complete all of the requests. This study considers time restrictions to guarantee that the vehicles can complete all of their deliveries for a shift. Section 2 shows some properties for this problem and presents a mathematical model. Sections 3 and 4 provide a polynomial time algorithm based on DP to determine an optimal set of dwell points. Theoretical results to identify an optimal first station to initiate the DP recursive process and to find out the minimum number of vehicles required to achieve feasibility are also developed in Section 4. Section 5 provides an example to illustrate the algorithm and to show the change in maximum response time as a function of the number of AGVs in the system. Conclusions are presented in Section 6. In the Appendix, an integer linear programming (ILP) formulation is shown as an alternative to the DP procedure. The results of a computational comparison of these two approaches are also provided in the Appendix.

2. Assumptions, properties, and mathematical formulation

The following notation and assumptions are necessary to formulate a nonlinear integer programming model for the unidirectional single loop system. This model is convenient to develop the DP procedure. Let s_E be the speed of a vehicle when it travels empty and s_B the speed when it is busy carrying a unit load. Let t_L be the load time when an AGV picks up a unit load and t_U the unload time when the AGV drops off the unit load. The speeds of empty and busy vehicles, and the load and unload times are assumed to be constant. It is assumed that, when an AGV is either idle waiting at its dwell point or is picking up or unloading an item (unit load), it is parked on the side of the guide path and does not block other AGVs traveling around the loop. No traffic interference between vehicles is taken into consideration. AGVs carry unit loads from pick-up stations to drop-off stations. It is assumed that each station can serve as a pick-up and drop-off (P/D) station, i.e., any station can submit a request to pick-up a unit load and receive the delivery of a unit load. Let n be the number of vehicles employed by the system and m the number of P/D stations. The stations are numbered as $i = 1, 2, \ldots, m$, in sequence, and the vehicle dwell points are also sequentially indexed as $j = 1, 2, \ldots, n$. Thus, let $M = \{1, 2, \ldots, m\}$ and $N = \{1, 2, \ldots, n\}$ be defined as the sets of station and dwell point indices, respectively. Let v_i denote the location of station