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MODELING AUTOMATED GUIDED VEHICLE SYSTEMS IN MATERIAL HANDLING

OTOMATİKLEŞTİRİLMİŞ REHBERLİ ARAÇ SİSTEMLERİNİN TRANSPORT TEKNİĞİNDE MODELLEMESİ

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ABSTRACT: The study objectives are to 1) provide information regarding the use and benefits of Automated Guided Vehicle (AGV) systems in manufacturing environments, and 2) review the literature related to design, modeling and simulation of AGV systems. We classify the tools utilized in design problems of AGV systems as analytical and simulation-based tools. Then, give examples of both categories from related literature.

Keywords: *Automated Guided Vehicle Systems Design, Modeling and Simulation.*

ÖZET: *Çalışmanın amaçları; 1) Otomatikleştirilmiş Rehberli Araç (ORA, ingilizcesi, Automated Guided Vehicle, AGV) sistemlerinin kullanımı ve faydaları hakkında bilgiler vermek ve 2) ORA sistemlerinin tasarım, modellenme ve simulasyonu (benzetimi) ile ilgili kapsamlı bir literatür incelemesinin sonuçlarını sunmaktır. Öncelikle ORA sistemlerinin tasarım problemlerinde kullanılan yöntemleri analitik ve simülasyon yöntemler olarak ikiye ayrılıp, daha sonra, ilgili literatürden her iki gruba ait örnekler verilmektedir.*

Anahtar Kelimeler*: Otomatik Rehberli Araç Sistemleri Tasarımı, Modelleme ve Simülasyon.*

1. Introduction

Material handling in manufacturing systems is becoming easier as the automated machine technology is improved. Today's rapid developments in technology presents manufacturing firms a variety of alternatives for in-plant transportation. An Automated Guided Vehicle (AGV) system is such an advanced material handling system that involves a fleet of driverless vehicles (AGVs) which follow a guided path and are controlled by a computer (Hammond, 1986). The aim of this study is to 1) provide information regarding the use of AGV systems in manufacturing environments, and 2) review the literature related to design, modeling and simulation of AGV systems.

2. Automated Guided Vehicle (AGV) Systems

A typical AGV consists of the frame, batteries, electrical system, drive unit, steering, precision stop unit, on-board controller, communication unit, safety system, and work platform. AGV systems are mainly used for distribution of materials in warehouse environments, and movement of material to and from production areas and storage areas in manufacturing facilities. The first Automated Guided Vehicle

(AGV) application was for transporting groceries in a warehouse (Hammond, 1986). According to statistics in 1989 (Gould, 1990), AGV system installations with respect to their application types were profiled as following: JIT delivery systems (56%), FMS/FAS transfer system (13%), storage load transfer, non-AS/RS (12%), AS/RS interface (8%), progressive assembly (7%), mini-load AS/RS interface (1%), and others (3%). Some other applications of AGV systems in non-manufacturing environments include, but are not limited to, delivering mail, messages, and packages in offices, and delivering meals and laundry in hospitals.

AGVs can be used in two different ways (Hammond, 1986). The first approach is to attach a workpiece to the AGV having all manufacturing processes done while the AGV carries the workpiece from station to station. In this approach, the AGV is freed only after all the processes for the workpiece are completed. The second approach is to use vehicles only for moving the workpieces from one station to another. Vehicle is assigned to the workpiece only for a single trip. In the former, number of vehicles required is significantly greater than in a normal AGV system. General Motors Company is the pioneer of such an assembly system built in the U.S. with 185 unit-load carriers.

AGV guidance techniques include wire guide path, optical guide path, and off-wire guidance. In the wire guide path technique, wires with varying frequencies are buried in the floor. AGVs select a path at a control point according to the assigned frequency. In the optical guide path technique, an AGV focuses a beam of light on a reflective tape or a painted strip and follows the path by measuring the amplitude of the reflected light. The disadvantages of wire guidepaths and optical guidepaths have caused the development of off-wire guidance techniques such as laser triangulation, floor-grid referencing, and gyroscopic guidance. The advantages of these techniques are that there is no need for floor cutting or painting, and the guidepaths are easily modified.

2.1. Basic Vehicle Types

Types of AGVs can be categorized as towing vehicles, pallet trucks, and unit-load carriers. *Towing vehicles* pull a series of trailers that are attached to the vehicle. The trailers are attached to and detached from the vehicle manually at the stations. The vehicle does not have lifting capabilities nor a transfer mechanism. It can be used for any type of load. *Pallet trucks* are used for palletized loads and can have high lifting capabilities. They can pick up and deposit loads at the floor level. *Unit-load carrier* may carry single or multiple loads on their deck. Some are capable of traveling sideways. The transfer mechanism of the carrier can be either an active or passive conveyor, such as a roller, belt, or chain conveyor, or it may be a lift/lower deck.

2.2. Benefits of an AGV System

According to case studies of AGV applications provided by the Material Handling Institute (1993), benefits of building and using AGV systems include labor costs saving, better schedule of WIP, flexible material handling, effective inventory control, greater quality assurance and safety, increased production, improved utilization of space, and flexible routing.

3. AGV Systems Design Problem

Typical objectives in design of AGV systems include 1) evaluation of the feasibility of an AGV system, 2) evaluation of the dispatching rules, 3) elimination of traffic problems, 4) maximizing the throughput, 5) maximizing the vehicle utilization, 6) minimizing the inventory level, 6) minimizing the transportation costs, and 7) maximizing the space utilization. Tools used in AGV system design can be classified in two main categories: analytical tools and simulation-based tools. Analytical tools are mathematical techniques such as queuing theory, integer programming, heuristic algorithm, and Markov Chains. A number of analytical approaches to the design of AGV systems have been proposed in the literature.

3.1. Analytical tools

Tanchoco et al. (1987) compared the effectiveness of CAN-Q, an analytical model based on queuing theory and used for analyzing work flows through a manufacturing system, with a simulation-based model built in AGVSim (Egbelu and Tanchoco, 1982). CAN-Q underestimated the actual number of vehicles required. Their analysis indicates that the results obtained through CAN-Q provide a good starting point for the simulation study.

Bozer and Srinivasan (1991) introduced the concept of 'tandem configuration' to the design of AGV systems. The tandem configuration is based on partitioning all of the workcenters into non-overlapping, single vehicle closed loops. It offers less complicated control systems, but has less tolerance for vehicle breakdowns and requires additional floor space. The authors also developed an analytical model to estimate the throughput capacity of a single vehicle in a closed loop. Mahadevan and Narendran (1993) developed an analytical model for estimation of the number of AGVs. They suggested to start with rough-cut analytical methods, followed by the use of sophisticated mathematical models and then to apply simulation if the level of complexity of the AGV system was high. As the number of parts in the system increases, the problem becomes intractable and needs to be analyzed by simulation method.

Johnson and Brandeau (1993) modeled an AGV system as a queuing system and the design model was formulated as a binary integer program with non-linear waiting time constraints. They then developed two different enumeration algorithms to solve the analytical model. Analytical models are generally based on steady-state flow systems (Tanchoco, 1994). Therefore, analytical techniques may fail when they are applied to real industrial cases. These techniques may give inaccurate estimates under random environments. In conclusion, analytical techniques may be best suited for *obtaining initial estimates* in the design of an AGV system (Egbelu, 1987).

3.2. AGV Systems Simulation

Simulation software that can be used for AGV system simulation can be grouped in three categories (Tanchoco, 1994 : 1) General-purpose simulation languages (e.g.

SLAM II, SIMAN IV, etc.), 2) Simulation packages designed for the general simulation of manufacturing systems (e.g. SIMPLE++, AutoMod II, ProModel, SIMFACTORY II.5, etc.), and 3) Simulation software specially created for analyzing AGV systems by using general programming languages such as C, FORTRAN, BASIC, LISP, etc.

3.2.1. General-purpose Simulation Languages

Several AGV system simulation models have been developed using general-purpose simulation languages such as SLAM II (Pritsker, 1995), SIMAN (Pegden et al., 1990), and GPSS/H (Henriksen and Crane, 1989). Seifert et al. (1995) developed a discrete-event simulation model written in SLAM II to analyze the operation of an AGV system under a variety of vehicle routing strategies. Their model handled multiple layouts and pedestrians in the system. It was a mixed-language model that was written in SLAM II with event-processing functions written in the C programming language. A specific performance measure was employed by their simulation model. It was the difference between AGV's actual travel time and the corresponding theoretical travel time of the AGV with respect to its speed and the travel length.

Ulgen and Kedia (1990) built a simulation model using SLAMSYSTEM to analyze the main effects of the design and operational variables on the performance of a cellular assembly system employing AGVs. The factors and alternatives considered in their model were alternate track layout designs, the effect of scheduling rules, and the effect of different cycle time ratios. The measure of the system performance was the average throughput per shift. They stated that the simulation was easy to implement, especially, the scheduling rules in the SLAMSYSTEM.

Takakuwa (1993) created a simulation model in SIMAN to measure the cost effectiveness of large scale AS/RS-AGV systems based on the number of AGVs to install. First, the overall layout of the system was determined, and then, specifications of the system such as number of AGVs, number of conveyors, the buffer size on each conveyor, and so on, were defined. Their main system measure was the total flow time. Lee (1996) developed a discrete-event simulation model in SIMAN to evaluate the performance of a number of composite AGV dispatching rules which could be implemented in manufacturing or assembly systems. The number of AGVs needed was determined based on a preliminary simulation study. The performance measures were the throughput, flow time, and the WIP level.

Although material handling features have been added to the general-purpose simulation languages, such as SLAM and SIMAN, these features do not provide sufficient flexibility to simulate the great diversity of many different material handling systems (King and Kim, 1995). Simulation of AGV systems can be more easily accomplished by starting with simulation packages specifically developed for manufacturing systems.

3.2.2. Simulation Packages Specific for Manufacturing Systems

The second category of simulation software includes some general-purpose manufacturing simulation systems such as AutoMod II, ProModel, XCELL+, SIMFACTORY II.5, SIMPLE++, etc.

Prasad and Rangaswami (1988) developed a graphic simulation model of an integrated semiconductor sort, assembly and test facility by using AutoMod as the primary tool. AutoMod is a 'macro' language which is based on the GPSS simulation language. Two different AGV control systems, a global control system versus a local control system, have been analyzed with the simulation model. They stated that AGV bottlenecks, congestion and deadlocks could be easily identified by using AutoMod's animation feature.

Quinn (1985) created a simulation-based system with AutoMod for development and testing of AGV control software. Data from a CAD system was used to describe the guide path. Output from the model was interfaced to an emulator that imitated network protocol to controller for testing the software. A generic blocking scheme was used in the model. Quinn (1985) stressed the fact that AGV vendors had unique blocking designs of their own.

Jayaraman (1993) developed an AGV system design for a company manufacturing antilock breaking systems by using ProModel. He compared manual transportation with AGV transportation. Input data to the system included a file containing the plant layout in AUTOCAD drawings of each assembly cell, forecast requirements, processing times, material handling information, and the bills of materials. The system throughput and the AGV utilization were used as the measure of system performance. Dewsnup and Bollenbach (1995) discussed the use of ProModel for Windows for modeling AGV systems. They studied two separate but overlapping systems. The model needed special intersection logic to avoid collisions. The objective was to determine the number of AGVs and to identify control logic for AGV system.

3.2.3. Simulation Software Specifically Created for AGV Simulation

There are some simulation software packages that are specifically developed for analyzing AGV systems. In this section, we will briefly review these AGV simulation programs. The initial part of the section will describe codes developed by traditional programming methodologies while the later part of the section identifies efforts that are based on object-oriented approaches.

3.2.3.1. Simulation Based on Traditional Programming Approaches

Egbelu and Tanchoco (1982) developed AGVSim, a simulation package for designing AGV systems. The package was developed in the FORTRAN language. It was a tool for analyzing, planning, and designing AGV systems. In this package, a network was modeled as a collection of nodes and arcs. Only the unidirectional flow pattern was considered.

Sinriech and Tanchoco (1992) used AGVSim to evaluate the performance of a single loop guide path under different dispatching rules. They stressed the impact of empty vehicle flow on the system performance. AGVSim consists of two separate routines. The first routine calculates the shortest path between pairs of points in the network. The second routine is the main simulator which executes the simulation and reports the results. AGVSim provides support programs to enter and remove data.
Anderson (1985) created SattControl, an AGV simulation package, which was used as a tool for planning and testing of an AGV route layout. Input parameters to the package included AGV track layout, number of pallets per hour, number of AGVs, loading/unloading times, AGV speed (separate for loaded and unloaded vehicles), alternative routes, etc. Some of the output statistics were waiting time at a certain point, the number of jobs performed by each AGV, and the average time the AGVs have been idle.

Araki et al. (1987) developed a simulator that could handle 68 kinds of AGV path patterns including station, entrance, exit, direct line, curve, T-cross, etc. The simulator consisted of path editor, numerical data input editor, shortest path calculator, simulation executor, animation section, and results output section. The shortest path calculator and the simulation executor were programmed in FORTRAN, and the rest were programmed in BASIC. The simulation executor had the initial setting, time management, AGV dispatch management, machine tool management, and data management functions.

Schulze and Rosenbach (1987) built MATSIM, a special simulation software-tool with a module library, for material flow systems. MATSIM input data included route, vehicle data, priority strategies, and sequence of processing. Output data were the total output of the system, number of loaded and empty travels, blocking time, battery charge time, vehicle waiting time, and temporal using of workstations.

Ozden (1988) developed a discrete-event simulation program by using LISP to investigate the effect of key factors, such as number of pallets, number of vehicles, and carrying capacity, of multiple-load-carrying AGVs on the overall performance of a FMS. The simulation program provided an animated color view of the FMS operation upon the user's request. He also stated that the predefined functions of LISP enabled the user to design simulation models with modularity similar to special-purpose simulation languages.

Mosca et al. (1991) constructed and utilized a transporting network simulator inside a large dimensions fruit and vegetable market utilizing AGVs. The discrete and stochastic simulator was programmed in FORTRAN 77 language. Its general objectives were to plan choices to minimize investment costs, to minimize service times, and to maximize AGV utilization in the system. Gaskins and Tanchoco (1989) presented AGVSim2, a discrete-event vehicle system simulator, for evaluating the control strategies of real-time free-ranging vehicle controllers. This simulator was directly linked to the supervisory controller software so that it could be used to test the intelligent AGV supervisory controller.

AGVSim2 allows for bi-directional flow, multiple vehicle types, and multiple loads on a vehicle. A graphic animation module is also a part of the software package. For free-ranging vehicles, virtual control points are used. The only difference between regular and virtual control points is that regular control points have attributes that are stored in the simulator's data structures. Otherwise, they are both treated the same way. Dutt (1991) developed GVSim, a generic C-based discrete-event simulation package, for modeling alternative AGV system configurations. Various control concepts in the design of guided vehicle systems could be tested by the generic program. It also extended the shortest path concept to develop the quickest path concept for reduction of bottlenecks.

Wilson (1992) developed a C-based discrete-event simulation framework for analyzing AGV systems. The functions in the framework were based on the discrete simulation portion of CBST. The functions of CBST form a modular toolkit including executive control, variable initialization, list management, entity management, resource management, random variate generation, data collection, and reporting. Brazier and Shannon (1987) presented a knowledge-based modeling system, SIMTOOL, for automatic programming of AGV system simulation models. It was an automatic programming system, written in Turbo-Prolog, which generates computer code in the SIMAN language for the required model. Vehicle parameters defined by the user were number of vehicles, empty and loaded vehicle speeds, initial vehicle positions, processing times, AGV track zone length, etc.

Gong and McGinnis (1990) described a simulation code generator (SCG) that converts input data from a designer into a SIMAN program for evaluating an AGV system with unidirectional guide path network. The SCG compiled the description file into a simulation code which then was itself compiled into executable code. The input data were in two categories: geometric data and non-geometric data. The geometric data consisted of the guide path network and location of P/D points. The non-geometric data included vehicle specifications, workstation characteristics, part process routes, etc. In their model, a process-oriented approach was applied in which parts and vehicles were treated as entities and machines and buffers were treated as resources.

3.2.3.2. Object-Oriented AGV Simulation Studies

In general, the above simulation programs specific for AGV systems are flexible and reduce the complexity of the task of simulating AGV systems. However, they do not offer flexibility, extensibility and reusability. King and Kim (1995) developed AgvTalk, an object-oriented simulation tool for the design and analysis of AGV system configuration and control. The model was composed of an AGV system, a material handling system, production system, and an interface through which the material handling system and the production system communicated with each other. AgvTalk includes 25 object classes and more than 300 object methods in its library. Smalltalk-80 has been used as the programming language. Window-based user interface in AgvTalk is supported by MVC (Model-View-Controller) triad in Smalltalk-80 (1990). Defining and changing the system requirements and specifications is done by using Graphical User Interface in AgvTalk.

4. Conclusion

Automated guided vehicle systems are particularly useful in material handling in manufacturing systems. Along with their increasing use, design problem of AGV systems has been a major concern of study. Simulation is widely used to evaluate the system performance for both real and proposed AGV systems. Many attempts have been made for developing AGV simulators either for specific problems or as generic --applicable to any AGV system--simulators. However, there is still a strong need for a generic and *extensible* (by using object oriented programming approach) AGV simulator with broad capabilities. Hence, future research efforts can be directed to create such simulation systems.

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