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FRAMEWORK FOR THE DESIGN AND ANALYSIS OF LARGE SCALE MATERIAL HANDLING SYSTEMS

Santhanam Harit
G. Don Taylor

Department of Industrial Engineering
University of Arkansas
Fayetteville, AR 72701, U.S.A.

ABSTRACT

Automated material handling systems have become an integral part of handling and storage applications in many manufacturing and logistics sectors. The purported benefits of cost effectiveness and efficient operation have resulted in widespread acceptance of this equipment in industry. A tremendous amount of research during the last decade has focused on studying the design and control problems associated with automated material handling systems. The research focus has been on problems of "manageable" size and complexity, while a large number of applications exist in which simulation is the only method for tackling the design and control issues. This discussion is motivated by applications which indicate the need for new methodologies for handling large scale problems. The design constraints imposed by large scale systems and possible solution approaches for choosing the type of material handling equipment are presented in this paper. Simulation is introduced as a feasible, inclusive, and cost-effective means of evaluating alternative solution approaches and equipment components.

1 INTRODUCTION

Automated Guided Vehicles Systems (AGVS), Automated Electrified Monorail Systems (AEMS), and Automated Storage and Retrieval Systems (AS/RS) are among the major components of automated material handling systems. Johnson and Brandeau (1994) describe AGVS and AS/RS as examples of an asynchronous system used for discrete part movement in a light traffic environment. Equipment like conveyors are examples of synchronous systems used in medium to heavy traffic environment. Usually the type of traffic condition is one of the major factors which determine the type of material handling equipment chosen.

Design of equipment such as AS/RS systems are not greatly affected by the size of material handling system in terms of parameters such as the number of P/D (Pickup/Deposit) stations and I/O (Input/Output) points. Their designs are affected more by parameters such as throughput volume, variety of parts handled, type of storage or retrieval, and hardware limitations. Extensive research has been carried-out in regard to these systems, and an excellent review of research to date can be found in Johnson and Brandeau (1994). The discussion in this paper is limited to asynchronous handling systems such as AGVs and AEMs. To date analytical research in this area has been limited largely to systems in which only one type of handling methodology (such as an AGVS) is used throughout the system. In most research efforts, the number of parts handled and extreme variations in flow volumes in the systems are not a major factor in system design. Large scale handling systems are often characterized by extreme variations in the flow volumes and the types of products handled (handling different types of mail at a postal facility is a typical example). The number of P/D stations and I/O points are also large enough (greater than 20) to render current analytical design and control methodologies ineffective. In this paper, the next section presents a brief review of relevant research literature in regard to the design and control of AGVs and AEMs. In Section 3, two examples involving design and control of large scale handling systems are briefly discussed. Problems associated with large scale systems in general are also discussed in this section. Section 4 suggests possible solution approaches and current research efforts underway in this area.

2 AGVS AND AEMS - RESEARCH EFFORTS TO DATE

An AGVS consists of automated guided vehicles moving at the floor level autonomously on pre-determined guidepaths managed by a real-time controller. The guidepath could be aisles on the plant floor. There are two types of guidepath - intersecting (conventional) and non-intersecting. Conventional systems are typically characterized by direct access to a P/D station from all other stations in the system. In non-intersecting guidepath systems (also called tandem loop systems) a direct access to a P/D station from all other

P/D stations may not be possible. Typically, a load from one P/D station may have to pass through a series of transfer stations before reaching its final destination. In conventional systems, the shorter travel distances are affected by vehicle blockage at intersections and by limitations on the number of vehicles in a particular segment of the guidepath. On the other hand, in tandem loop systems, control rules such as FEFS (first-encountered-first-served) ensure that longer travel distances (due to the need for transfer stations) are balanced by more efficient vehicle utilization. Bozer and Srinivasan (1992) show that conventional and tandem loop systems are comparable in terms of throughput and expected waiting time. Some material handling scenarios might warrant the use of a hybrid system in which the AGVs themselves move from one tandem loop to another through the transfer stations instead of the AGVs transferring loads only at the transfer stations. In the case of a hybrid design, the direct point-to-point access for AGVs in a conventional system are combined with the FEFS rules of a tandem loop system. To avoid operational bottlenecks, hybrid AGVS designers must take into account the effects of the number of AGVs in a loop, the nature of flow in the system, and the economics of an AGV transfer system during the design process.

Egbelu and Tanchoco (1984) study the impact of various dispatching rules for an AGVS in a conventional layout setting using simulation analysis. Egbelu (1987) and Venkataraman and Wilson (1991), among others, have study the conventional AGVS using non-simulation approaches such as Branch-and-Bound methods. Johnson and Brandeau (1994, 1993, 1992) have modeled the AGVS design problem as a stochastic system. In all these and other methodologies, only problem sizes of 20 or less P/D stations have been analyzed. In some methods, the problems become more and more intractable as the problem sizes increase. Even simulation methodologies for large problem sizes are not very effective in fully analyzing an AGVS. In most cases, the run-times are too long to conduct effective statistical analysis (Johnson and Lofgren 1994). To our knowledge, published literature on the design and control issues of large scale AGVS or AEMS is limited. Taylor and Meinert (1995) and English et al. (1994) are among the first published efforts aimed at tackling these large scale problems. The above two research efforts will be discussed in some detail in Section 3. In a related note, Johnson and Lofgren (1994) discuss the simulation analysis approach for a distribution center (system) design. They discuss a decomposition approach for tackling a large scale simulation project consisting of a variety of automated handling equipment.

3 LARGE SCALE HANDLING SYSTEMS - CASE STUDIES

The task of designing large scale material handling systems presents two specific constraints during the early decision making stage, namely, the type of material handling equipment to choose and partitioning the layout for the handling equipment chosen. More often than not, extensive feasibility studies, simulations models, and pilot systems are used as the decision tools. Some of the analytical tools and methodologies discussed in Section 2 are used during the design process. The design complexities encountered in large scale systems are overcome by making simplifying assumptions or decomposing into sub-problems, making it difficult to get a "system" view. The following simulation based case studies exhibit the typical constraints faced in tackling large scale handling systems. The first case study from English et al. (1994) presents the problem of partitioning a layout and choosing the ideal AEMS material handling system for a facility encountering a highly stochastic product size and flow. The second case study from Taylor and Meinert (1995) presents the operational and control problems faced in a system in which AGVs are the primary material transfer equipment.

3.1 An Automated Monorail System

Figure 1 (English et al. 1994) shows the schematic layout of a large scale AEMS. The automated carriers travel on guide tracks. The system consists of eleven loops servicing fifty five machines and seventy three P/D stations. The loops are of non-intersecting tandem design interlinked through transfer stations. The location of loop-to-loop load transfer stations are on-line or off-line based on the volume of carrier traffic. There are eighteen transfer stations, and load input is from loop 1 on the lower right corner of Figure 1. The flow of material is from loop 1 to loop 7 through the intermediate loops 2, 3, and 4. Flow also takes place from loop 2 to loop 7 through loops 5 and 6. Material output from the systems is from the equipment supplied by loops 8 through 11.

The system design problem in this case study involves the determination of the number of loops, the location of the loops (in terms of P/D stations covered), the location of the transfer stations, determination of type of transfer (on-line or off-line), and the number of carriers in each loop. As in most cell design algorithms, the grouping of P/D stations in a loop follows the general process flow of the product. For example, loop 1 services the input side of the machines and loop 2 services the output sides. The same logic applies for all the other equipment. Starting from this first pass cell allocation, simulation modeling is used to determine the other system parameters indicated above. Because of the highly stochastic nature of flow and the very high volumes handled, tremendous obstacles exist during simulation runs. Due to the interdependence of the equipment, it is not possible to divide the systems into smaller subsystems. This results in very large runtimes (upto twelve hours per run on a SUN4 machine). In addition, the number of carriers and off-line transfers are systematically increased to improve the throughput limitations imposed by carrier travel times, load

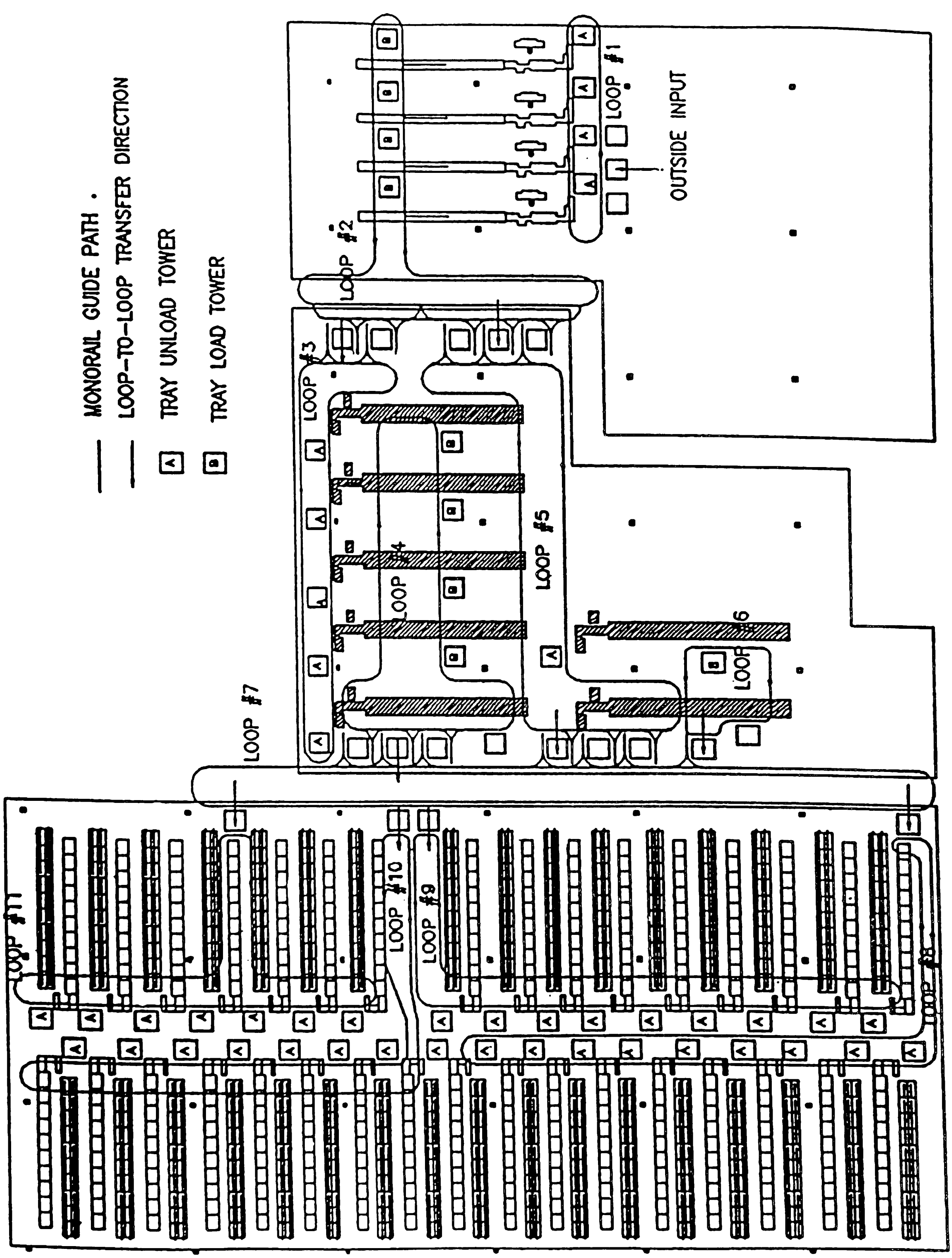

Figure 1: Monorail System Layout for Case Study One

transfer times, and the number of carriers that can be accommodated in a travel segment (the portion of the guidepath between any two P/D stations).

The highly stochastic nature of the material flow requirements and the very large problem size preclude the use of the existing design methodologies discussed in the previous section. Other problems encountered while conducting the analysis include:

a) Space limitations on the number of transfer stations.
b) Space limitations on the number of off-line carrier tracks.
c) Limitations on the storage capacity at a P/D station.

We will discuss some of the research problems motivated by this case study and some initial solution methodologies in Section 4.

3.2 An Automated Guided Vehicle System

Figure 2 (Taylor and Meinert 1995) shows the schematic of a two-floor AGVS at a large bottling facility. There are sixty three P/D stations and seven AS/RS cranes serving two floors. This case study differs from the one presented in Section 3.1 in several ways in addition to the basic material handling methodology. This is an existing facility with control and scheduling problems. Grid-lock, WIP management and traffic conflict resolution are the major control problems. Presently, the conflict resolution is done manually - ie., a person goes and manually removes grid lock by moving one of the AGVs out of the loop and restarting the system. The research effort presented in Taylor and Meinert (1995) consists of a large scale simulator that tracks sixteen or more AGVs in the system and the status of the 120 I/O and traffic management locations. The unique feature of the simulator is a built-in "gridlock buster" which systematically examines the status of all the I/O stations and AGVs to select the mode of recovery from a gridlock. The simulator is unique in that it has been developed for PC operation using PC-Unix (LINUX) which permits the use of virtual memory upto the size of the hard drive. Also, the animation supported by the SIMNET simulation engine is a practical debugging necessity because trace files of the system require approximately 40 megabytes for each minute of operation. A current research agenda using the simulator is presented in the following section.

4 GENERAL RESEARCH ISSUES

How to select the proper material handling system and how to tackle the operational problems are two of the basic design issues associated with large scale systems. Computational complexity is a major constraint in these systems. In tackling the first issue, there is a need for an analytical method to determine the threshold for moving from an asynchronous material handling equipment to a synchronous equipment like a conveyor (and vice versa). The problem consists of simultaneously determining the P/D stations to be partitioned into a control cell and the type of material handling equipment servicing the cell. Most analytical and simulation methods in the past have studied problems in which the same type of equipment is used throughout the system. Dissimilar equipment types are usually considered as independent sub-systems.

The postal case study presented in English et al. (1994) presents a situation in which some of the cells would be more efficiently served with a synchronous conveyor system. Current research by the authors is aimed at studying this problem as a tandem loop configuration with multiple servers in each loop. The number of servers in a loop are limited by the loop length and the carrier characteristics. Throughput thresholds are imposed by the carrier speed, the transfer times, and the flow pattern. Our analytical studies are aimed at using these constraints to determine the type of material handling equipment for the given set of P/D stations (synchronous or asynchronous). Based on the choice of equipment, cost and throughput factors can be calculated. A number of feasible tandem loop partitions are generated from all the P/D stations in the layout. The optimum set of stations are then chosen from this feasible set using integer programming techniques. As a first step, we are improving on the tandem single vehicle loops partitioning algorithm developed by Bozer and Srinivasan (1992) to determine the optimum multi-vehicle multi-loop AGVS design. See Harit (1995) for more information on this topic. The next step is to incorporate analytical tools for determining whether synchronous or asynchronous equipment should be used.

The AGVS simulator motivates a great deal of current research, and the case study environment of the bottling facility provides an interesting opportunity to validate findings in a large scale, actual system. Current research is focused on the examination of alternative methodologies for avoiding and defeating gridlock, and on extensive experimentation with the simulator across a broad range of scenarios involving parameters such as product mix and volume, AGV and AS/RS speed, permissible work in process (WIP) levels, alternative AGVS control rules, and alternative layout scenarios in terms of P/D location and AGV track location. It is anticipated that this experimentation will result in cost effective design solutions with less risk and higher performance.

5 CONCLUDING REMARKS

Our discussions have shown the difficulties encountered in handling large scale handling systems. We have briefly, discussed research developments in the area of asynchronous handling systems. Another promising method for tackling the problem of automated material handling system design will be to adapt the research developments in parallel distributed processing systems in telecommunications and other areas to material handling systems. Our research work using tandem

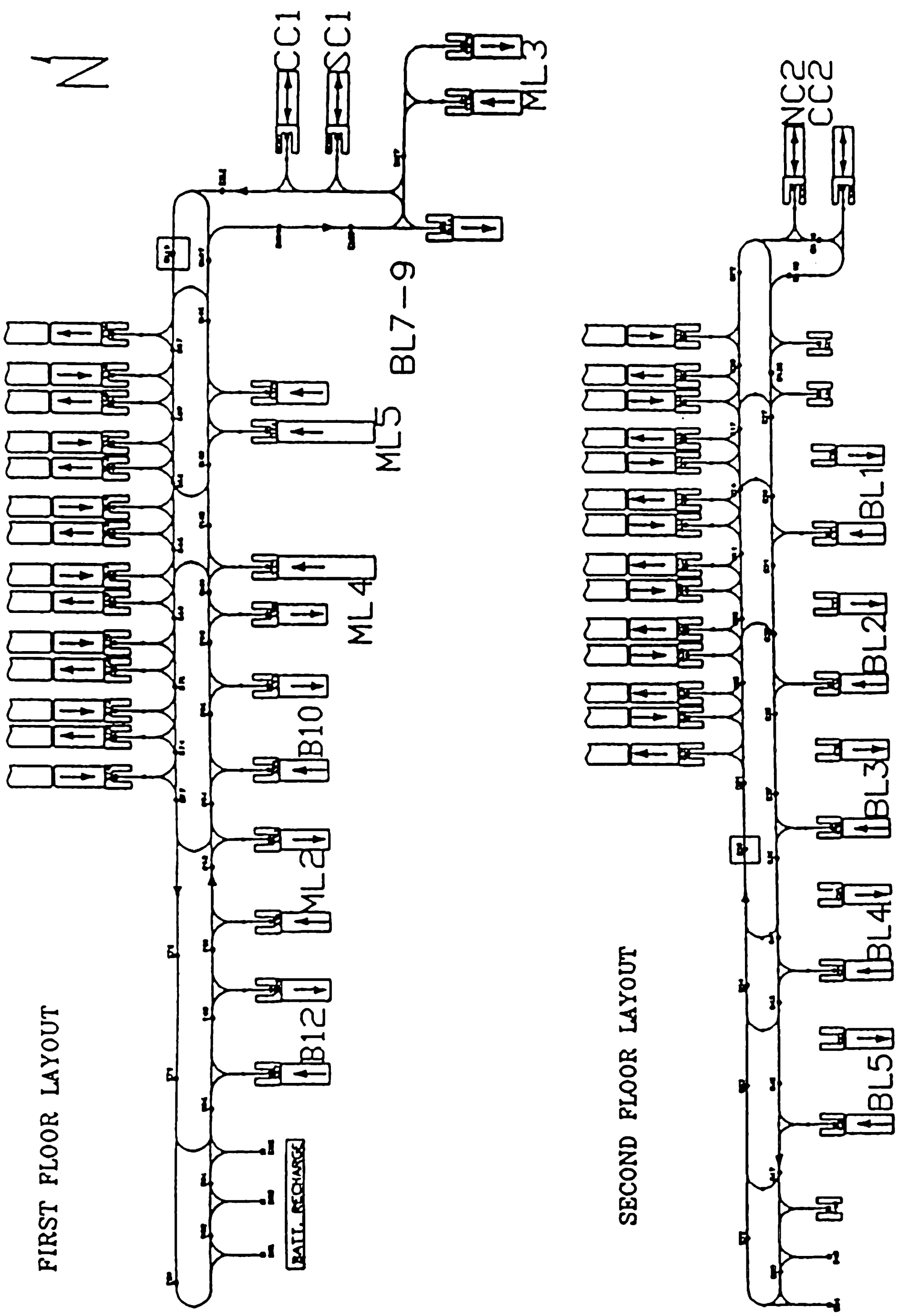

Figure 2: AGV System Schematic for Case Study Two

loop configurations is a first step in this direction.

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AUTHOR BIOGRAPHIES

G. DON TAYLOR is an Associate Professor in the Department of Industrial Engineering at the University of Arkansas/Fayetteville. He received a B.S. and an M.S. degree in Industrial Engineering from University of Texas at Arlington, 1983 and 1985 respectively, and a Ph.D. from the University of Massachusetts in 1990. His research interests are in applied research seeking solutions to problems in manufacturing systems and logistics.

SANTHANAM HARIT is a graduate student in the Ph.D. program in Industrial Engineering at the University of Arkansas/Fayetteville. He received a M.S. degree in Industrial Engineering from the University of Arkansas/Fayetteville in 1992 and a degree in Engineering from Annamalai University, Tamilnadu, India in 1982. His research interests are in manufacturing, facility planning, quality control, applied operations research and new product introduction.