Flow Path Design, Knowledge Based Selection and Reliability Analysis of Automated Guided Vehicles

A major thesis submitted
In partial fulfillment of the requirements for the award of the degree of

Master of Engineering
In
Production Engineering

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Session 2003-05

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Abstract

Material handling is an integral part of any manufacturing activity. Given the high costs involved in the equipment and the safety issues, it is imperative to design a good material handling system. The automated guided vehicle system is an important element in the computer integrated manufacturing facility. Like Flexible manufacturing system. Automated guided vehicles provide considerable advantages as compared to other material handling equipment. Design concerns involve issues regarding the flow path design and the number of vehicles in the fleet. The objective of this thesis is to review the literature dealing with Automated Guided Vehicles and the various issues involved in the selection, flow path design and reliability of AGV system. Various journal articles were reviewed for this purpose.

Right material handling equipment selection and good design of the material handling system and facility layout can increase productivity and reduce investments and operations' costs. In this study, after describing the material handling equipment selection and pre-design of material handling systems problems and explaining their complexity and solution approaches, it is shown that material handling equipment selection and pre-design of a material handling system can be combined by using a knowledge-based approach.

The Automated Guided Vehicle System is very complex and incorporating the reliability aspects in the design process is very important. There is a need to identify the critical components in the system which account for the severe failure of the system. Failure Mode and Effects Analysis and Fault Tree Analysis are useful techniques in identifying these critical components. Once identified, the individual reliabilities can be calculated and block diagrams can be used to calculate the overall system reliability.

Key Words: Automated Guided Vehicles, Flexible Manufacturing System, Knowledge-Based System, Reliability Analysis, Linear Programming.

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CERTIFICATE

This is to certify that the project entitled ***"Flow Path Design, Knowledge Based Selection and Reliability Analysis of Automated Guided Vehicles"***, which is being submitted by **Hayat Khan,** is a bonafide record of student's own work carried by him under my guidance and supervision in partial fulfillment of requirement for the award of the Degree of **Master of Engineering in Production Engineering, Department of Mechanical Engineering, Delhi College of Engineering, University of Delhi.**

The matter embodied in this project has not been submitted for the award of any other degree.

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Acknowledgement

It is a great pleasure to have the opportunity to extent my heartiest felt gratitude to everybody who helped me throughout the course of this dissertation.

It is distinct pleasure to express my deep sense of gratitude and indebtedness to my learned supervisor **Mr. A K Madan**, Lecturer in the Department of Mechanical Engineering, Delhi College of Engineering, for his invaluable guidance, encouragement and patient review. His continuous inspiration only has made me complete this major dissertation.

I would also like to take this opportunity to present my sincere regards to my teachers for their kind support and encouragement.

I am thankful to my friends and classmates for their unconditional support and motivation during this project.

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Xij : Path node for AGV's from i Station to j station.
P1 : Pick up point for department 1

P : Drop off point for department 2

n_o : Identical items are under test

t : Time

$n_f(t)$: Items fail

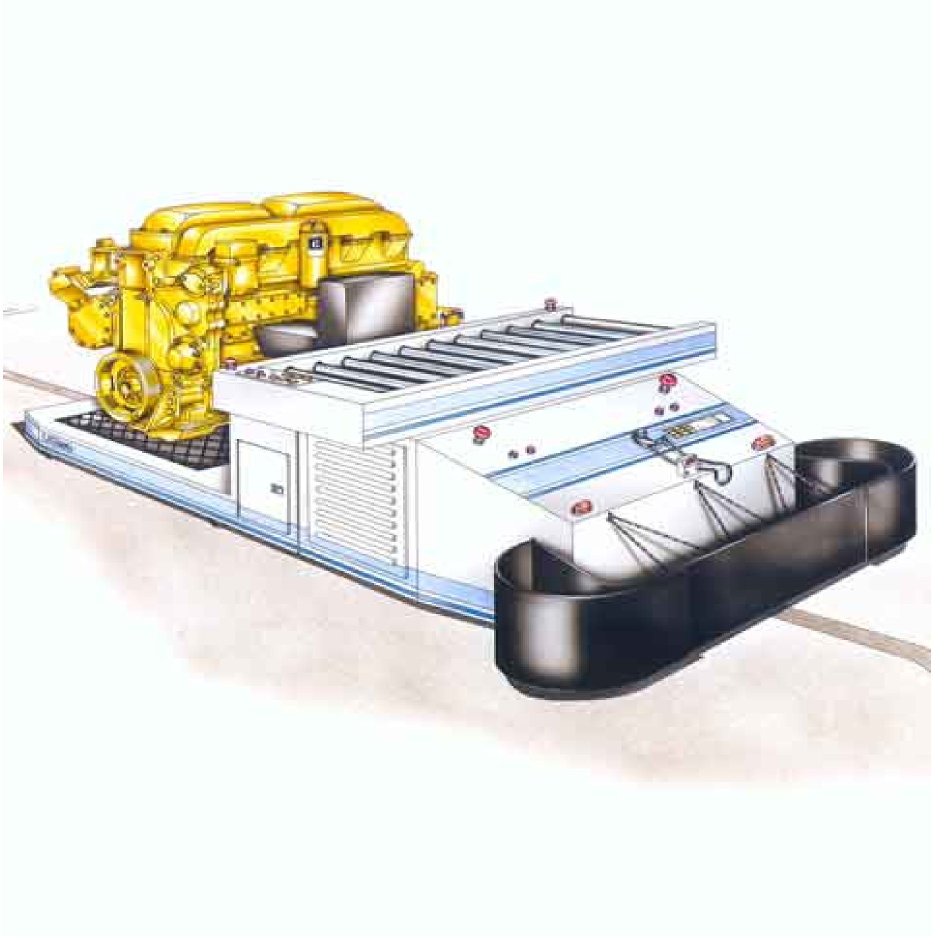
$n_s(t)$: Items survive

$R(t)$: Probability of survival

$F(t)$: Probability of failure

Chapter 1

Introduction



Manufacturing has changed radically over the course of the last 20 years and rapid changes are certain to continue. The emergence of new manufacturing technologies, spurred by intense competition, will lead to dramatically new products and processes. New management and labor practices, organizational structures, and decision-making methods will also emerge as complements to new products and processes. Manufacturing enterprises in 2020 will bring new ideas and innovations to the marketplace rapidly and effectively. Individuals and teams will learn new skills rapidly because of advanced network-based learning, computer-based communication across extended enterprises, enhanced communications between people and machines, and improvements in the transaction and alliance infrastructure. Collaborative partnerships will be developed quickly by assembling the necessary resources from a highly distributed manufacturing capability in response to market opportunities and just as quickly dissolved when the opportunities dissipate.

Manufacturing in 2020 will continue to be a human enterprise that converts ideas for products into reality from raw and recycled materials. However, enterprise functions as we know them today (research and development, design engineering, manufacturing, marketing, and customer support) will be so highly integrated that they will function concurrently as virtually one entity that links customers to innovators of new products.

In this thesis, we design a flow path of an automated guided vehicle for a hypothetical case. The knowledge based selection of material handling system and the reliability analysis for AGV’s is also carried out. [53] A knowledge-based system was devised to assist facility designers in the selection and configuration of materials handling equipment. The system utilizes preference directed search to capture improved designs by dynamically acquiring new preferences throughout the design process [Gabb 1989].[50]

An Automated Guided Vehicle (AGV) is a driverless vehicle which can accomplish material handling tasks (i.e. load, transport and unload). An Automated Guided Vehicle System (AGVS) consists of a number of vehicles operating in a facility, usually controlled by a computer. The computer takes the dispatching and the routing decisions. AGV technology is a key factor in reducing material handling operating costs and increasing the reliability of material handling systems. However, the purchasing and installation costs are significant; hence the design is an important decision that should be made carefully.

"*A material handling system can be simply defined as an integrated system involving activities such as handling, storing and control of materials*".

The word material has a very broad meaning, covering all kinds of raw materials, work in process, sub-assemblies and finished assemblies. The primary objective of using a material- handling system is to ensure that the material in the right amount is safely delivered to the desired destination at the right time and at a minimum cost. Material handling is an integral part of any manufacturing activity. The material handling cost can comprise between 30% to 70% of the total manufacturing cost (Sule, 1988).Furthermore, the equipment is also prone to accidents. Thus it is imperative that the material handling system is properly designed from efficiency as well as safety point of view.

Many manufacturing industries are adopting a Computer Integrated Manufacturing CIM) strategy, an important part of which features computer control and a high level of automation. In doing so, the selection and pre-design of the MHS and facility layout design form an important stage, which is a long-term costly proposition. Also any modification or rearrangement of existing systems represents a large expense and can often not be accomplished easily. [52]

In this study, a knowledge-based system for material handling equipment selection and pre-design of these equipments in the facility layout will be discussed. The study comprises two sections. The first is the selection of material handling equipment for related product requirements. The second is decision making for equipment between departments.

Material handling was once defined very narrowly, as simply handling of materials. However, it is defined more comprehensively as using the right method to provide the right amount of material, at the right place, at the right time, in the right sequence, in the right position, in the right condition, and at the right cost (White and Apple, 1985). From this most comprehensive definition it can be deduced that there are many aspects which impact upon the MHS design relating to both strategic and detail considerations. Detail consideration of the specific equipment starts with a consideration of the specific parts to be handled, whereas strategic design focuses on more general aspects which comprise the following (Matson et al., 1992):

- The characteristics of the material to be moved,
- The attributes of the method,
- The physical facility constraints under which the task is to be done.

Material Handling Equipment can be classified into the following basic categories:

- Industrial Trucks which include hand trucks and forklift and powered trucks. Hand trucks have platforms with wheels for manual movement of items whereas powered trucks have mechanized movement of items.
- Conveyors such as belt, roller, wheel, chain, bucket.
- Monorails, hoists and cranes such as bridge, gantry, tower.
- Automated guided vehicles.
- Automated storage and retrieval systems such as unit load, mini load, deep lane and storage carousel systems.

Motivation

Several factors are changing the use of information technology to integrate operations in a manufacturing enterprise. These include: (a) the global manufacturing enterprise, which often requires quick evaluation of the effect of moving manufacturing operations to other facilities, (b) reuse of existing information pertaining to manufacturing in the context of a new manufacturing facility, and (c) pervasive use of "what-if" analyses to evaluate opportunities for cost reduction in the face of more intense competition in manufacturing. To address the needs imposed by these factors, manufacturing corporations need models that represent their operations. Included is a need for specifications and decision aids for material handling that are well integrated with other information resources pertaining to manufacturing.

Problem Statement

The problem that studied in this work is the flow path design of automated guided vehicles, knowledge based selection and reliability analysis of AGV’s. Here, a hypothetical problem considered for that states two departments. The AGV pick material from pick-off point and put it at drop off point. The distance is fixed between each node in manufacturing system. The objective function of this work is to minimize the distance traveled by AGV’s through constraints.

Organisation of Thesis

This thesis work is mainly focused to "Flow Path Design of Automated Guided Vehicles". Besides, we discuss Knowledge Based Selection and Reliability Analysis for AGV's. The thesis is organized in the following manner. In chapter 2, we present the overview of automated guided vehicles that will tell about different types. Chapter 3, focuses on the flow path design issues those plays very important role in better flow path design. In Chapter 4, work carried out on the historical review of AGV's. Chapter 5 is Mathematical model for flow path design, here is the problem taken for flow path design. Chapter 6 is Knowledge based selection of AGV's that tells about knowledge based approach, task for selection and finally evaluation of AGV's. Chapter 7 is presented for the reliability analysis of AGV's. Chapter 8 is conclusion and future scope of this work. Finally, the appendix is attached, that contains the Excel work sheet of solution for flow path design problem.

Chapter 2

Overview of Automated Guided Vehicles

A variety of advanced technologies are now emerging to expand the capabilities of computer controls into the creation of automated factories. The automatic guided vehicle system is an important element in the computer integrated manufacturing facility. The essential capability of an AGV is the ability to transfer loads to remote locations or through complex paths under computer control. This is a unique capability in the automated guided factory. Robots cannot provide the mobility of the automated guided vehicle system, and conveyors do not offer the flexibility. The primary growth of a new systems development associated with material handling has been in the areas of robotics and automated guided vehicle systems. As processes and processing methods are developed, new techniques of manipulation and control are implemented. This provides automated machining centers, flexible manufacturing stations and robotic work stations. With the surge in application of automation in a multitude of industries today, one of the first reactions to the automation of material movement is to use an Automated Guided Vehicle. The AGV as a means of material movement or delivery is perceived as leading edge state of the art. The AGVS Product Section of the Material Handling Institute defines an automatic guided vehicle as:

"A vehicle equipped with automatic guided equipment, either electromagnetic or optical. Such a vehicle is capable of following prescribed guide paths and may be equipped for vehicle programming and stop selection, blocking, and any other special functions required by the system"[1].

Automated guided vehicle (AGV) systems are extremely important part of many low to medium volume manufacturing operations including flexible manufacturing systems, warehousing and service industries where they are used for moving different kinds of jobs. An automated guided vehicle is a driverless, battery operated, computer controlled and independently addressable vehicle [1]. They move either along wire guide paths or by magnetic or optic guidance. They are used to move jobs between workstations on a factory floor. The relatively inexpensive guide paths do not interfere with other material flows and offers several advantages over other systems. The first large scale manufacturing application of an AGV system occurred in 1974 at a Volvo plant in Kalmar, Sweeden. The largest application in North America is at a truck assembly plant of General Motors in Oshawa, Canada [47], where 1012 AGV's transport truck bodies, engines and chassis across the 2.7 million square feet plant.

2.1 Types of Automatic Guided Vehicles

1] AGVS towing vehicles

2] AGVS unit load vehicles

3] AGVS pallet trucks

4] AGVS fork trucks

5] Assembly Line Vehicles.

2.1.1 Towing Vehicles

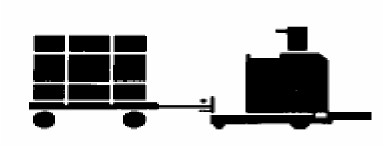


Figure2.1: Towing Vehicles [1]

AGV towing vehicle is an automated version of the manual tugger vehicle. Towing applications were the earliest and are still the most prevalent type of applications. These applications generally involve the bulk movement of product into and out of warehouse areas. Proportional or stepped speeds are available in both directions in the manual operations. Loads are transported on trailers. The number of trailers towed in each train is dependent on total weight and the trailing characteristics of the trailer. Tractors are available that will guide around curves with a radius as small as 4 feet, although curve radii are typically 8 to 20 feet due to trailer tracking requirements [44]. Trailers can be either conventional or automated. Automated trailers can have powered roller conveyor decks for automatic transfer of loads to and from the stands. Powered trailers are not common standard products and are usually custom built. Care should also betaken in placement of load stands such that the train does not block an intersecting path while executing a station cycle. Side path spurs are generally placed in receiving or shipping areas so that trains can be loaded or unloaded off the main line and thereby not hinder the movement of other trains on the main path. Station cycle times for automatic load transfer using powered vehicles is approximately 30 seconds per load in addition to vehicle train positioning times.

Chain movement of product with AGVS trains is also popular. In this case, the AGVS trains are loaded with product destined for specific destinations along the guide path route. The train will make several stops in order for the product to be unloaded at the correct locations. Train systems are generally used where product is moved over long distances, sometimes between buildings, outdoors, or in large distributed systems where runs are long [44]. Since each train can move many pallets at a given time, this system becomes an efficient method.

2.1.2 Unit Load Vehicles

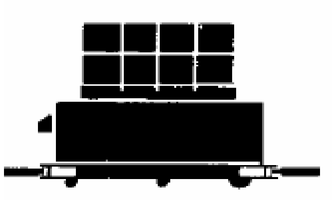


Figure2.2: Unit Load Vehicles [1]

Unit load vehicle is perhaps the most versatile application of AGV types. It has the widest range of load decks and application configurations. The unit load vehicle is a symmetrical vehicle that is fully capable of operating in either direction in automatic mode. Unit load applications generally involve specific mission assignments for individual pallet movement. When configured for single direction operation, the unit load vehicle is generally capable of reversing into pickup and delivery stands for load transfer [44]. Load transport decks are available as lift/ lower, roller conveyor, belt conveyor, chain conveyor and even multi compartment decks. The unit load carrier, over moderate distances, can move material linking other automated subsystems in a totally integrated facility. The travel speeds are generally restricted to approximately 2.27 miles per hour.

In addition to conventional steering systems, the unit load configuration also allows pivot steering operation. Station cycle times usually range from about 15 seconds to one minute [44]. These times are in addition to the vehicle positioning times. The unit load systems usually involve an automatic pickup and delivery of product with remote management of vehicles in the system. Unit load carriers are normally used in warehousing and distribution systems where the guide path lengths are relatively short, but the volumes are high [44]. The unit load carriers have the ability to maneuver in tight areas where AGVS trains would be too awkward to use. Load transfer to conveyors or load stands is easily accomplished with unit load carriers. This system provides good versatility for product movement.

2.1.3 Pallet Trucks

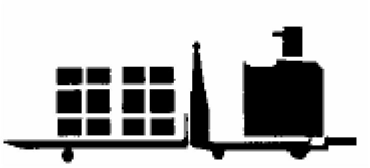


Figure2.3: Pallet Trucks [1]

AGV pallet truck is often referred to as a Stop and Drop vehicle. This is a guided version of the manual pallet jack and typically has extended forks to carry loads at a time. These are generally loaded manually. Then they are placed on guide path, given a destination and then released. The capacity of these vehicles is anywhere between 4000 and 6000 pounds. The load carrying device is either a set of forks or a tongue that has a short lifting ability. Since these vehicles are very long, they have a larger turning radius. Usually the curve radius is about 15 feet for the pallet trucks [44]. Loads are picked up and dropped off on from the floor height. Once dropped the loads remain on the floor and have to be moved manually. Hence in operations where the AGV traffic intensity is very high, the unloading takes place on side spurs. These types are usually used in warehouse delivery systems of long distances where load stands and other interactive forms of automation are not required.

2.1.4 AGV Fork Truck

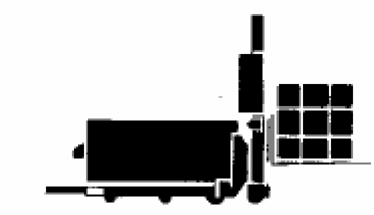


Figure3.4: AGV Fork Truck [1]

This vehicle is a relatively new addition to the family of automated guided vehicles. Two basic configurations are available: one with forks that trail in the direction of travel and other with forks mounted on the sides. The side mounted type offers the advantage of directly interfacing with the load racks and load stands of various heights. These vehicles carry only one load at a time and load envelopes are restricted unless slave pallets or special containers are used [44].Vehicle travel in the normal transport direction is about 1.36 miles/ hour with top speeds of up to2.3 miles/hr. These vehicles are significantly larger than unit load carriers with lengths up to six feet. Vehicles with side forks can directly access racks adjacent to the aisle but require turning the vehicle to access the other side of the aisle. The cycle times are usually very long compared to other unit load vehicles due to fork swing clearances and basic vehicle dimensions. Station cycle times are variable from one to two minutes per load transfer cycle.

2.1.5 Assembly AGV

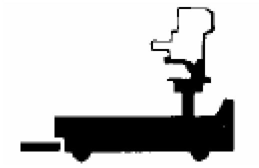


Figure3.5: Assembly AGV [1]

This is a specialty vehicle designed to carry a portion of a product through various work areas in an assembly process. The assembly vehicle can be small enough to transport one engine or one transmission or large enough to transport an entire automobile body. They generally have a load carrying mechanism which is custom tailored for a specific product to be transferred. They also have a little on-board battery capacity since travel distances between workstations are relatively short [44]. These vehicles offer flexibility to a manufacturing process by allowing parallel operations. They also allow for individual tracking of items and measured work rates. Normally these systems are integrated into an overall production system which requires computer control and extensive planning.

2.2 Functions of AGV

There are 5 basic functions of an automated guided vehicle system:

1. Guidance
2. Routing
3. Traffic Management
4. Load Transfer
5. System Management

2.2.1 Guidance

Guidance allows the vehicle to follow a predetermined route which is optimized for the material flow pattern for a given application. The physical maneuvering of the vehicles takes place by the steering control system in the vehicle. Usually two types of steering control are available namely, differential speed steer control and wheel steer control [1].

Differential speed control uses two fixed wheel drives and varies the speeds between the two drives on either side of the guide path to permit the vehicle to negotiate a turn. An amplitude detection type of guidance sensor is used to provide the information [1]. It gets the signals from the left and right sensor and compensates be correcting the difference till both the amplitudes are the same. Steered wheel control uses automotive type of control in which a front steered wheel turns to follow the guide path. Phase detection guidance is used for this type of steering. Steered wheel control is used in all types of automated guided vehicles whereas differential control is not used in towing applications or on vehicles [1] which have many on board controls.

2.2.2 Routing

AGV routing techniques center around two methods namely the frequency select method and the path switch select method. In the frequency select method the AGV approaches the decision point and reads the marker in the floor that tells the vehicle its location [1]. The markers are usually passive code devices in the form of buried magnets, metal plates, and other code devices. The vehicle uses frequency selection to choose the appropriate path. When the vehicle is approaching the decision point there are two frequencies available in the same slot. The vehicle depending on which direction it wishes to go, selects the frequency to follow and the routing is automatically accomplished. Normally two-three frequencies are used and they can be used over and over again. In the path switch selection method, the vehicle approaches the decision point and passes an activation device which causes one path to be turned on while the other paths at the point are turned off. Thus the vehicle has only one live path to be followed and routing is automatically accomplished. The only important thing is that the vehicle has to communicate in advance, which direction it wants to go. This method uses only one frequency and the paths for divergence and convergence are switched in and out as required by the vehicle in the area.

2.2.3 Traffic management

Usually in any AGV system a fleet of vehicles is used. These vehicles have to be dispatched in a sequence and managed well. Traffic management is achieved in three ways namely by zone control, forward sensing and combination control [1]. In zone control, when a vehicle occupies a zone, the closest a trailing vehicle can get is into the next completely unoccupied zone. The lead vehicle must proceed into the next zone before the trailing vehicle can move into its next zone. In forward sensing, the vehicle uses an onboard sensor that detects the presence of a vehicle in front of it. Sensors can be either of *"sonic"*, *"optical" or "bumper"* type [1]. In practicality no one method is completely used. Usually a combination of these methods is used to bring about effective traffic management.

2.2.4 Load Transfer

AGV's achieve load transfer by one of the following methods: Manual Load transfer, Automatic couple and uncouple, Power Roller, Power Lift/Lower or Power Push/Pull [1].

2.2.5 System Management

Vehicle dispatching can either be facilitated through an on-board dispatch, off- board call systems, remote terminal, Central Computer or a combination of any of those [1].

2.3 Advantages of Automated guided vehicles

Automated guided vehicles have many advantages over other material handling systems. Following is a list of those:

- ***Flexibility***: AGV's are much more flexible than the other automated material handling systems. This flexibility manifests itself in the form of number of vehicles and the alterable guide path. The AGV permits better utilization of the existing space. The changes in the number of vehicles, movement of vehicles as well the location of pick-up or drop-off points can be easily accomplished by programming [1]. The changes in the guide path can be made when the system is not operating, thus there is no loss of efficiency. The control program can be modified without interfering with the operations. It is much easier to fit an AGV into an existing space as compared to a conveyor.

- ***Higher reliability:*** In case of breakdown, a spare vehicle can be used as a replacement [1]. This may not be true for other material handling systems. Thus, if a conveyor fails, it may render the whole manufacturing facility inoperable. The degree of environmental problems is also less for an AGV.

- ***Higher operating savings and lower investment:*** The operating costs of an AGV are lower than those of the other material handling systems. AGV's are not that labor intensive as compared to the other systems and maintenance is much easier

[1].Investment cost is less than other material handling systems. The cost of vehicle, hardware and software systems is however comparable to that of many other material handling systems.

- ***Unobstructed movements:*** There is free movement of personnel and other vehicles over the guide path because the guide path is either embedded in the floor or painted on the floor [1]. This also ensures smoothness and flexibility by allowing narrower aisles and multiple uses by forklift trucks and other variable-path vehicles.

- ***Easy interfacing with other systems:*** An AGV is a natural choice for interfacing with the FMS, AS/RS and other material handling systems such as conveyors [1]. Robots or machines can be mounted on the AGV to do the desirable operations. Also AGV's can deliver unit loads of product from a distant warehouse to an AS/RS or mini load system for order picking and distribution.

Chapter 3

Flow Path Design Issues

Audi

The design of an AGV system involves flow path design and fleet size determination [41]. Flow path design studies consider the physical layout of complex layouts and a single loop. Fleet size studies estimate the total vehicle time needed in a shift and thus determine the number of AGV's required. Operational issues include job scheduling, AGV dispatching and scheduling and conflict free routing and are classified according to the AGV flow path layout [41]. The terms guide path and flow path are used in the literature to denote the same concept. The guide path layout for an AGV system is a critical component in the overall design of the system that utilizes AGV's for material handling. Flow path design is an important consideration in the design of an AGV system. The choice of a flow path determines the total distance traveled by the vehicle, the total time required to carry out the particular task and in turn determines the efficiency of the material handling system. Designing the vehicle guide path is approached in one of the three ways depending upon what elements of the system are considered to be fixed or variable. The different ways are as follows [46]:

1. Design of the guide path and pick-up/delivery station locations based on an existing facility layout.
2. Design of the guide path based on an existing pick-up/ delivery stations and facility layout.
3. Designing of a new facility layout, guide path and pick-up/ delivery station location.

In considering the design of an AGV system, it is assumed that the departmental layout is already given. The departmental layout is based on the volume of material flow between departments, with the objective of minimizing the total material flow. For a given departmental layout, the design of an AGV system should include flow path layout, location of P/D points for each department and the AGV fleet size [41]. The design of the guide path and the location of the P/D points have a significant effect on the installation cost, travel time and the operating expense of the system.

3.1 Different types of AGV Flow path configurations

3.1.1 Single line AGV system

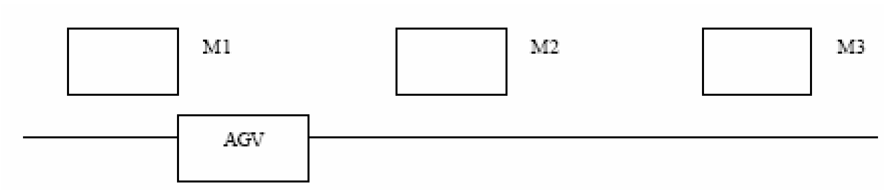


Figure3.1: Single line AGV systems [49]

3.1.2 Single Loop AGV Systems

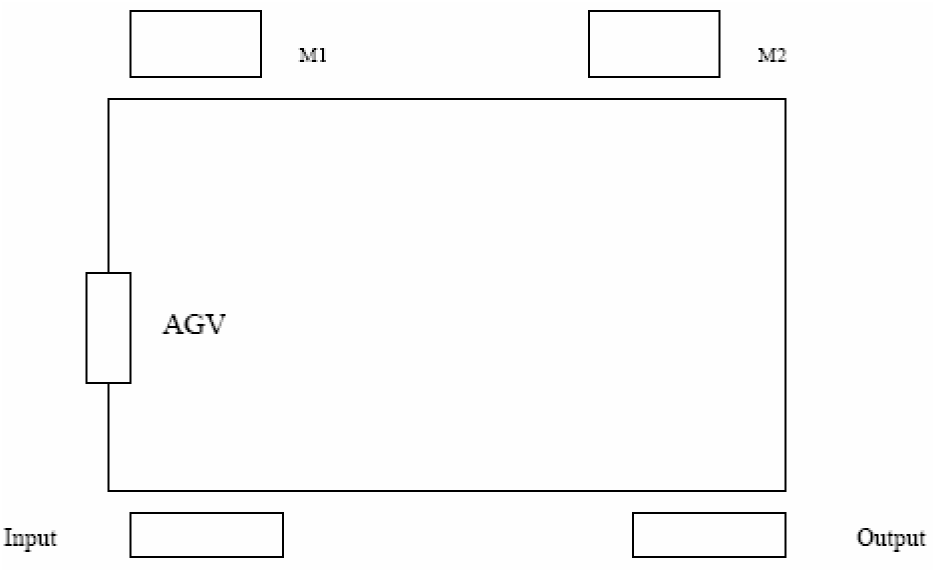


Figure3.2: Single Loop AGV Systems [49]

3.1.3 Ladder type AGV systems

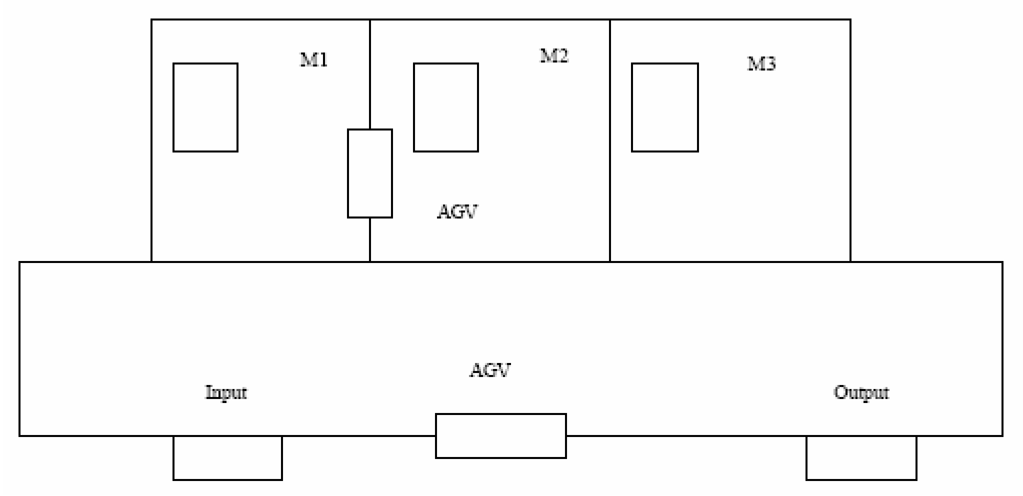


Figure3.3: **Ladder type AGV System [49]**

3.1.4 Complex AGV network system

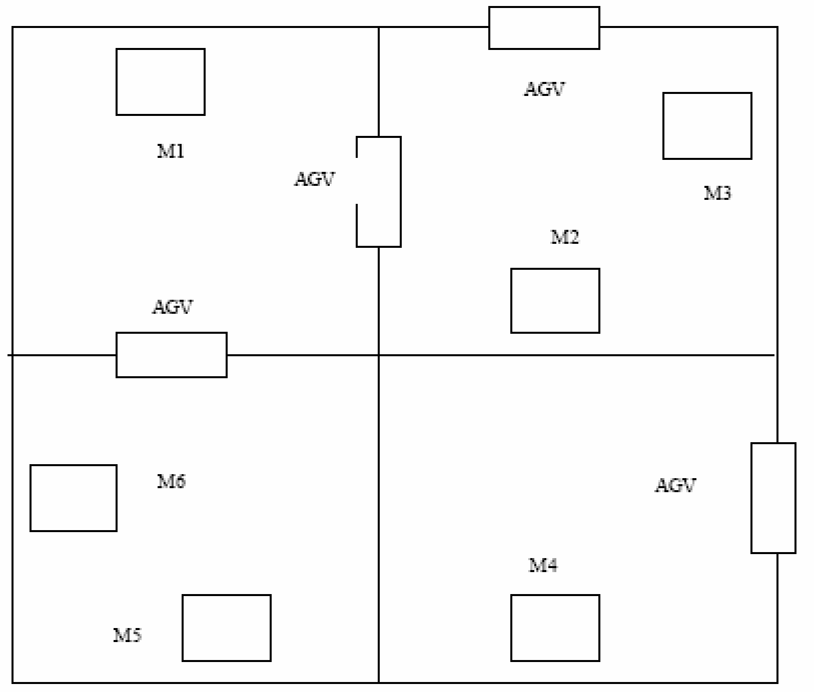


Figure3.4: **Complex AGV Network System [49]**

Chapter 4

Literature Review

Cybernet SpacePen

CyberGrasp

Boeing

Considerable amount of research has been done in the area of flow path design. In designing the flow path for the material handling system the objective may be to reduce the overall distance traveled or the time traveled or the total costs. The objective function can be defined depending on the parameter to be minimized. Kiran and Tansel [19] suggest a method to determine the optimal pick up point location for a material handling network. The pickup point may connect the material handling network to any one of the following: a machining or assembly station, load, unload or inspection station, central or local storage. They address the problem of determining the optimal pick up point so that the total cost of moving the material in the system is minimized. The problem is modeled as a facility location problem that seeks to minimize the sum of weighted network distances. The material handling system is represented by a network consisting of directed arcs that correspond to conveyor belts, tow lines, monorail or wire paths. Since the network is directed, the distances are asymmetric. They infer that the pick up point may be located at the node of the material handling network to minimize the total cost function defined as sum of the products of material flow and travel distances. Gaskins and Tanchoco [31] suggest a method for determining the flow path design for AGV systems. The objective of the problem is to find the path which will minimize the total distance traveled by the loaded vehicles. They assume that the vehicle flow is restricted to certain areas only. When a vehicle travels from one point to the other the shortest distance is usually the straight line from the first point to the second. This straight line distance is known as the Eucledian distance. But in a departmental layout it might be impossible for the vehicle to travel this path since the vehicle travel is confined to the aisles. Another measure of the distance is the rectilinear distance. For a two dimensional layout, the rectilinear distance between two points is defined as the sum of the absolute differences in the x co-ordinates of the points and the absolute differences in the y co-ordinates of the points. However when trying to minimize vehicle traveling a unidirectional environment, rectilinear distance is not always acceptable since the vehicle may have to travel further than the rectilinear distance to get from one point to the other. Thus since neither measures are full proof the objective is to minimize the path distance. The path distance is defined as the distance the vehicle travels along a feasible path when moving from one point to another [31]. The path can be a straight line, rectilinear, or of some other form depending upon the location of points and the shape of the departments. It is assumed that shortest routes are always taken [31]. The problem is formulated as a zero-one integer program. Before the formulation is done, a layout of departments, aisles and pick-up and delivery points, location of these points and a from-to chart containing the material flow intensities between the departments is needed. Since this method is dependent on the material flow intensities between departments, the path can be modified to take into account the dynamic nature of the material flow. Thus the optimal path can be revised periodically. Goetz and Egbelu [9] consider the case of determining the guide path as well as the pick-up and drop-off points simultaneously for an automated guided vehicle system. The main principle is based on Gaskins and Tanchoco [31] paper. They use a heuristic algorithm to reduce the size of the problem. This reduction helps in making the approach more amenable for use in the design of large layouts. The location of the pick-up and drop-off points is crucial as it can significantly influence the traffic intensity on the aisles, the distances between the departmental P/D stations and traffic control. The authors reduce the problems by considering only the major flows within the department. The methods described above have considered only the flow of loaded vehicles. They do not account for the travel of empty vehicles from the last drop off point. Sinriech and Tanchoco [36] account for the impact of empty vehicle flow on the performance of single-loop AGV system. Incorporating the empty vehicle flow in the system adds dynamics tothe system. Consideration of empty vehicle travel more affects the estimation of the number of vehicles than the guide path design.

The complex AGV path found out by the flow path design models discussed above may result in AGV conflicts, at the intersections and along the aisles. One way to solve this problem is to have a unidirectional single loop that passes through all the departments. Tanchoco, Sinriech [27] study the problem of designing a single loop system. The single loop design problem involves, first, finding a loop that passes through all the workstations and that minimizes the total time the AGV has to travel to complete its assignments, and second, locating the P/D points for each workstation. The problem is formulated as a large scale zero-one integer program. The problem is solved using heuristics. The problem is solved in three phases. Phase I contains a program to find a valid single loop i.e. a loop that contains at least one arc of each department in the layout.
Phase II includes two complete enumerations: the first begins with a valid single loop found in the first phase and explores all the possible loops that extends it and the second eliminates loops that are dominated by others. Phase III is another mixed integer programming model which is applied to all remaining loops to find their P/D point locations. By comparing the total AGV travel distance of all remaining loops, the best

single loop is selected. The above formulations assume that the vehicle remains idle at the point of delivery till another material handling task is assigned to it. Upon receiving the message from the central station, the vehicle proceeds to the new task location. Majesty and Wang [21] propose a terminal location system in addition to the flow path design problem. The layout of the vehicles is assumed to be known with directed links. It is also assumed that the locations of all pickup stations and corresponding delivery stations are identified on the layout. An automatic guided vehicle receives a call from the pickup location whose location is known on the layout. As soon as the service of an AGV is requested, the operator at a pickup station places a call. The next available responds to the call and proceeds to the pickup station along a predetermined guide path. From there it proceeds to the delivery station. The AGV always returns to its terminal after serving a call before attending to another call from any pickup station. The proposed method is better when the idle times are significant. In the above method, the vehicle uses the idle time to move from a delivery point to the terminal, which is closer to the pickup point next in line and thus saves time in reaching the next pickup point.

Bozer and Srinivasan [3] have suggested a tandem configuration for flow path design. The configuration essentially breaks down the entire guide path into non-overlapping loops where each loop is serviced by a single vehicle. The advantage of this type of system is that it eliminates congestion, blocking and interference. [53]

Almeida and Kellert (2000) study job shop like Flexible manufacturing system (FMSs) with a discrete material handling device and machine transfer blocking. They propose an analytical queuing network model to evaluate the quantitative steady-state performance of such FMSs. The FMS complex devices are structured in order to prevent deadlocks from occurring. So, in this paper, they suppose a light load. In our paper, the system is heavily loaded. Bozer and Kim (1996) determine optimal or near optimal transfer batch sizes in manufacturing systems and develop an analytical relationship, issued from queuing theory, between the material handling capacity and the expected work in process in a manufacturing system. The models developed by Almeida and Kellert (2000) and Bozer and Kim (1996) are not applicable to our problem because the aim is not the same. But the methodology is identical. They present an analytical model based on queuing theory and the results are validated against discrete event simulations.

Direction of travel along the guide path is another area of interest in guide path design. Most of the studies have considered unidirectional flow paths. The main reason for the consideration of unidirectional networks is the simplicity in design and control. Egbelu and Tanchoco [7] have studied the potentials for bidirectional paths for guide path design. In the design of a bidirectional layout, several alternatives are possible. These are as follows:

1] Have parallel wire tracks with reverse orientation on each aisle.
2] Have a single switch able wire track on each aisle. The switching of the guide path is dependent on the flow demand.
3] Have a mixed guide path that is comprised of both unidirectional and bi-directional aisles with bi-directional flows allowed only on selected aisles.

Case 1

In this case, except at the points of intersection, the system is unidirectional. With sufficient clearance space left between parallel tracks, there is virtually no interference between vehicles on the same aisle and traveling in the opposite direction [7]. Assuming that the layout is not symmetric, the distance traveled between two points is reduced. Consequently, this improves the response time of the vehicles. On the other hand, there is a lack of space economy in the design. Aisles are required to be wide enough to allow vehicles to pass side by side. The important problem is the traffic congestion at the intersections. For a unidirectional system, only two turns or interchange ramps are required at the intersections [7]. In this case, assuming all turns are permitted, eight interchange ramps are required. The cost of acquiring a control for such activity is very high.

Case 2: Single switch able track

For each aisle in the network, flow takes place in both the directions. However, each aisle segment operates as a gate or switch. If the flow signal is being transmitted to one direction, a signal in the reverse direction is automatically turned off or made inactive. Thus vehicles are allowed to travel only in one direction at any point of time. This type of bidirectional flow presents lot of challenging traffic flow control problems [7]. Not only does the system controller have to contend with the difficult intersection control problems, but also with vehicle interference within the aisles. It requires also the design of temporal vehicle buffering areas throughout the guide path to hold blocked vehicles. The number of buffering areas designated to hold blocked vehicles and their capacities are themselves the decision variables that depend upon the applicable fleet size, vehicle routing strategy, guide path layout and facility size.

Case 3: Mixed Design

The design combines the characteristics of unidirectional and bi-directional systems. In the entire network, some aisles may operate on a bi-directional mode whereas others strictly operate on a unidirectional mode. Usually less used aisles are potential candidates for the bidirectional aisles.

One of the operational issues involved in bi-directional networks is to resolve the vehicle conflicts in the use of an aisle. Buffers are provided to account for this. The location and design of a buffer requires a compromise of several factors among which include space economy, design simplicity, ease of vehicle control and investment on the guide wire and control system [7]. Requirements of a good buffering area include accessibility, space economy, minimum interference between vehicles in the area and minimum investment on guide wire controls.

Different designs have been tested till now. Those are namely the loop, sliding and spur designs. In loop design, there are two unidirectional loops per each aisle and located at the ends of the aisle [7]. Hence the number of buffering capacities required at the node is equal to the number of directions in which the vehicle can enter. In a sliding design, there is a unidirectional sliding at each end of an aisle close to the end nodes. A sliding serves vehicles traveling only in its direction of orientation [7]. The spur design is characterized by dead end spurs. These spurs are capable of being excited in any direction. The vehicles entering into a spur will depart according to the last in- first out rule [7]. Research has shown that the use of bi-directional traffic flow network can lead to an increased productivity in some AGV system installations, especially the ones which have few vehicles. The best bet is to use simulation to evaluate the aisles which are frequently used. Once these are determined they are made bidirectional and the remaining ones are strictly kept unidirectional. All the above flow path designs require a from-to chart to estimate the total loaded travel distance. In a typical modern manufacturing firm, from-to chart changes over time when the part mix changes. A flow path designed using the initial from-to matrix is no longer feasible now. This condition illustrates the infeasibility of physically guided AGV's. To prevent this from happening, researchers [14] have developed free ranging AGV's. For free ranging AGV's there does not exist a physical path but the path is there in the computer's memory. Sinriech and Tanchoco [26] suggest an intersection graph method for determining the flow path for the automated guided vehicle. They describe a branch and bound procedure, which considers a reduced subset of all the nodes in the flow path network. The procedure uses only the intersection nodes to obtain the optimal solution. In a facility layout problem, a node representing a pickup or a delivery station is connected only by two arcs (unless at the intersection). One arc is an incoming arc and other is an outgoing arc. Therefore the direction of the arc is dependent on one another and there is no need to branch on them separately. This leads to a significant reduction in the number of arcs to be included in the branch bound algorithm. In order to improve the branching procedure even further, the arcs are arranged in a descending order of the incoming and/or the outgoing arc containing the largest flow. By doing so, the first solution obtained will be a very good one. Since only the intersection nodes are used in the branching process, the algorithm is denoted as the Intersection Graph Method.

In the dynamically changing manufacturing environment, flexibility is the key to success. This puts a high pressure on the material handling system to be flexible enough. Seo and Egbelu [23] address this problem in their paper. The concept of path orientation categorizes the flow paths in accordance to their directions at the starting and ending points of the flow path. First, the flow path selection is formulated to design the guide path layout with the objective of minimizing loaded vehicle movements. It does so by selecting a set of flow paths containing one path for each flow link such that the selected paths are consistent in direction, with the objective of minimizing total travel time for all loaded vehicle trips. Then the selected set of flow paths can easily be converted into a unidirectional AGV guide path layout by directing the aisle segments to be the same as those of the arcs included in the selected paths. For cases where, when an incomplete or unclosed layout is produced from this step, a complementary layout design approach to convert the incomplete layout into complete one with the consideration of empty vehicle movements is considered in the second step.

In all the above examples, it is assumed that the departmental layout is given. The problem is to locate the optimal pick up and drop off points and the flow path. Designing the guide path incompliance with the given facility is a major issue. The problem is to integrate facility planning and material handling. Apple and Mcginnis [32] underlined the need for close cooperation and a continuous interface between facility layout and MHS design and planning, since the layout of the facility greatly influences the design and control of the material handling system. Montreuil[33] has also introduced a modeling framework for integrating the layout and material flow network design problems. The model seeks net layouts i.e. facility designs which comprise the location of the input and output stations of resource groups, the material flow patterns and the physical aisle system. The author proposes a two step procedure for the facility layout and flow path design problems. The first step determines the adjacency relations between the manufacturing departments using a design skeleton which may either be a flow graph, a cut tree, or a set of location of cell centroids. The second step employs a linear programming model to geometrically define the layout and the material flow network.

Banerjee and Zhou [37] have presented a two-step approach for the same problem. However their method considered the fact that the overall material handling effort is affected by the topology of the flow path. Thus, given an initial layout and the flow network, the proposed method automatically identifies qualitative layout anomalies, i.e. segments of the flow path which are the best candidates for improvements.

Chapter 5

Mathematical Models for Flow Path Design

Mathematical programming is widely used in the modeling of guide paths for automatic guided vehicles. Gaskins and Tanchoco [31] have formulated a zero-one integer programming model to arrive at an optimal flow path. The formulation explained below is adapted from Gaskins and Tanchoco [31] paper. Consider the layout shown in the figure. It is assumed that the layout of the factory is already provided, the departmental layout is given and also the location of the pickup and drop off points for each department [31]. The distance between points is as shown on the line segments.

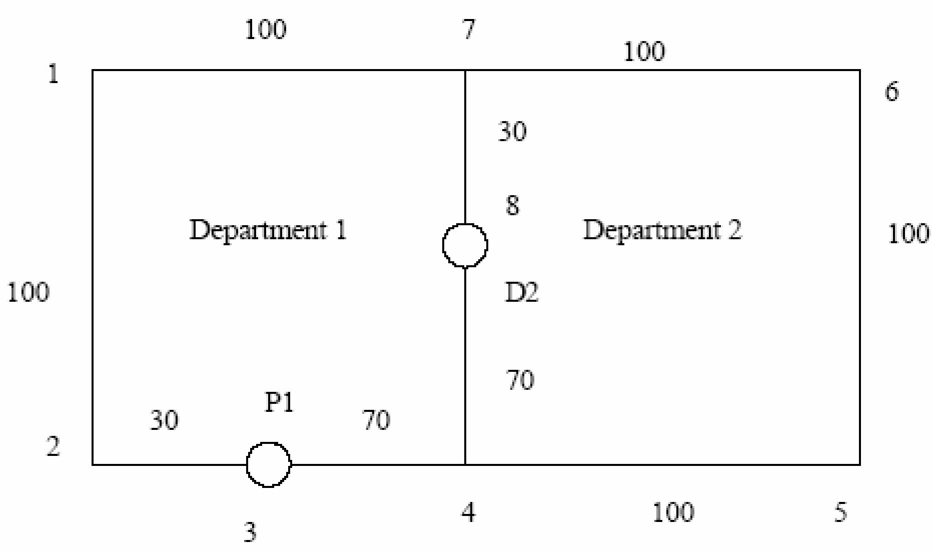


Figure 5.1: Hypothetical Layout [31]

P1 is the pick up point for department 1
D2 is the drop off point for department 2

It is given that the vehicle makes 50 trips from department 1 to department 2 throughout the day. There are certain assumptions which go into the formulation of the problem: [31]

1] The departmental layout is given and does not change.
2] The vehicle travels along unidirectional paths.
3] The vehicle always takes the shortest path during its course.
4] The from- to matrix does not change over the course of the time.

To solve this problem, the given layout of the department is considered as the network. The departmental limits and the intersections as well as the pick up and drop off points are all considered as nodes of the network. Modeling in this way allows us to use the network simplex method or a simple integer programming method for the modeling purpose. All the arcs are considered bidirectional.

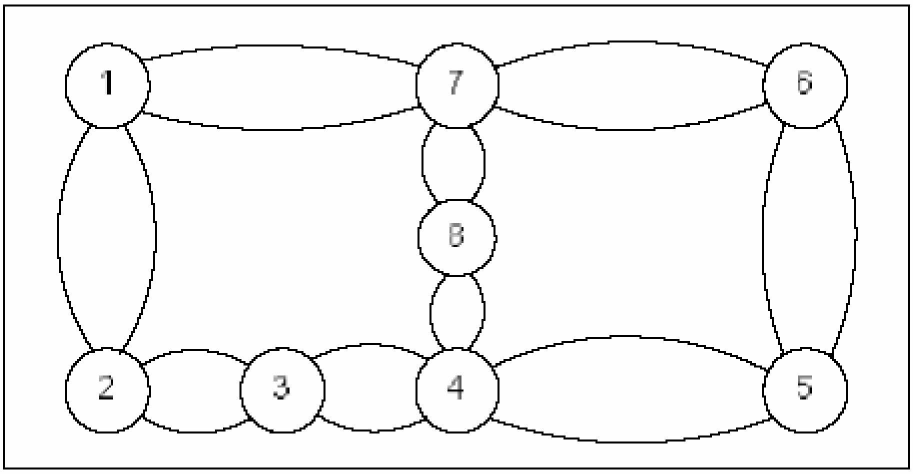


Figure 5.2: Node Arc Network

The nodes are all connected to each other. All the nodes in the network are connected by arcs. Flow can be in any direction along the arc but in this problem we assume unidirectional arcs. The objective is to minimize the total distance traveled by the vehicle from the pick up point to the drop off point while satisfying the demand requirements. The decision variables are the flow along the arcs. The flow along the arcs is constrained to be a binary variable which indicates that the flow will take place or not. In other words, this means that the decision variable associated with each arc decided whether that arc connecting two nodes is a part of the solution i.e. part of the optimal solution or not. Thus those arcs which are included in the optimal paths will have the value of 1 and those not included will have a value of 0. Since we know the starting and the ending points, the path traveled will be the shortest one.

Model Formulation

The following inputs go into the formulation of the model.

A] There is an objective function which is the criteria of interest or the goal which is to be achieved. In this case the objective function is to minimize the total distance traveled by the vehicle.

Consider the departmental layout shown in the figure. All the nodes, intersection points and the pick up drop off points are numbered. They are denoted by variables i, j. Thus x_{ij}

denotes the path from node i to node j. For the vehicle to travel from pick up point to the drop off point, following alternatives exist:

1] The vehicle exits on path 3-4 and enters along path 4-8. The shortest distance the vehicle will have to travel is 140 units.

2] The vehicle exits along path 3-4 and enters along path 7-8. The shortest distance in this case is400 units.

3] The vehicle exits along path 3-2 and enters along path 7-8. Shortest distance in this case is 260 units.

4] The vehicle exits along path 3-2 and enters along path 4-8. Shortest distance for this path is 600 units.

In each of the case the flow intensity is 50 unit loads assuming that one unit load is transferred in one trip.

Thus the objective function can be written as follows:

$$\text{Minimize:}50[140(x_{34})*(x_{48})+400(x_{34})*(x_{78})+260(x_{32})*(x_{78})+600(x_{32})*(x_{48})] \quad (1)$$

B] Given that the x variables are zero-one variables and that only one of the four combinations can be chosen, only the chosen combination will have a product of 1. All other combinations will have a product of zero. Thus to minimize the objective function, the combination with the shortest distance will be chosen. The key to the above procedure is that one and only one of the four combinations has a product of 1. To ensure this, constraints need to be added. The constraints are as follows:

1] The direction of travel along the arcs is assumed to be unidirectional [31]. Thus a constraint needs to be added for each node in the network. These are as follows:

$$x12+x21=1 \quad (2)$$

$$x23+x32=1 \quad (3)$$

$$x34+x43=1 \quad (4)$$

$$x45+x54=1 \quad (5)$$

$$x48+x84=1 \quad (6)$$

$$x56+x65=1 \quad (7)$$

$$x67+x76=1 \quad (8)$$

$$x71+x17=1 \quad (9)$$

$$x78+x87=1 \quad (10)$$

2] Its also required that each node is reachable. However nodes cannot become sink nodes. In other words, each node must have at least one incoming arc and one outgoing arc [31]. The constraints for this are as follows:

$$x12+x17>=1 \quad (11)$$

$$x71+x21>=1 \quad (12)$$

$$x12+x32>=1 \quad (13)$$

$$x21+x23>=1 \quad (14)$$

$$x32+x34>=1 \quad (15)$$

$$x23+x43>=1 \quad (16)$$

$$x34+x54+x84>=1 \quad (17)$$

$$x43+x48+x45>=1 \quad (18)$$

$$x54+x56>=1 \quad (19)$$

$$x45+x65>=1 \quad (20)$$

$$x56+x76>=1 \quad (21)$$

$$x65+x67>=1 \quad (22)$$

$$x76+x78+x71>=1 \quad (23)$$

$$x67+x17+x87>=1 \quad (24)$$

$$x78+x48>=1 \quad (25)$$

$$x87+x84>=1 \quad (26)$$

3] Finally constraints need to be added to ensure that a group of nodes don’t become a sink [31].The constraints are as follows:

$$x67+x54>=1 \quad (27)$$

$$x76+x45>=1 \quad (28)$$

The above formulation is solved using the Excel solver. The formulation is shown as a part of the appendix. The solution yields the following answers.

$x12=1$, $x23=1$, $x34=1$, $x48=1$, $x87=1$, $x71=1$, $x76=1$, $x65=1$, $x54=1$,

Thus the final flow path design for the given network is as follows:

Although in this case it was very obvious that the vehicle would travel along the path 3-4 and 4-8as it is the shortest route, the mathematical model provides an insight into how optimization techniques can be used. The same principle can be applicable for many departments. The advantage of this method is that since we know that there are certain paths the vehicle would not traverse frequently, these paths can be made as unidirectional [31]. Thus it is not necessary to make all the paths bi-directional. Thus the traffic along the routes can be easily managed. At the same time, the objective function does not consider the flow of empty vehicles. The objective function can be modified to incorporate the return path of the vehicle after the load is delivered. Numerous factors can thus be incorporated in the formulation of the mathematical models. Many complex models have been formulated in the literature. The above example was explained to give on overview of the use of mathematical techniques.

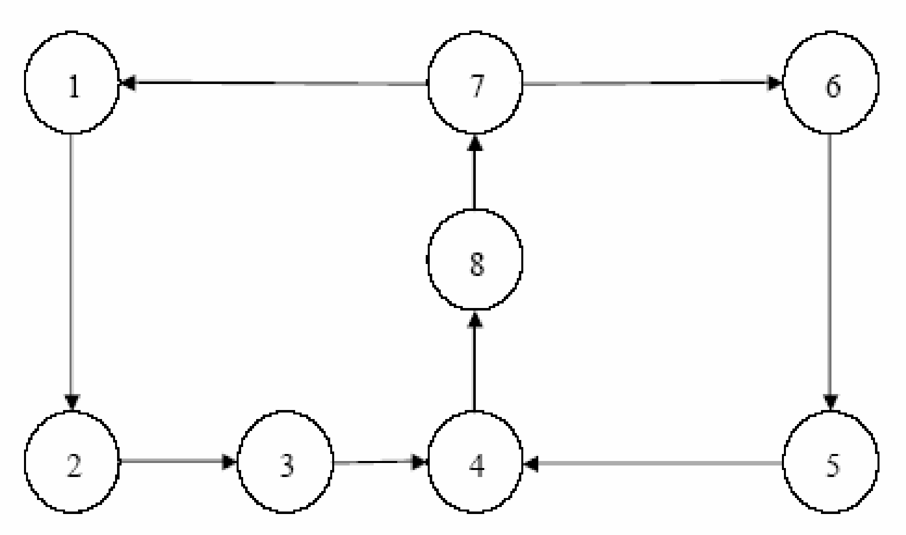


Figure 12: Final guide path design

Chapter 6

Knowledge Based Selection of AGV’s

6.1 General Approach for Selection

The challenge in this work is to achieve a balance between the rich and diverse data requirements that material handling system designers seek and the practical situation faced by the typical product/process design engineer, while at the same time reflecting the need for rapid prototyping at a level sufficiently detailed to select technologies and obtain budget cost estimates. The method presented relies on *task specifications* of individual and system material handling requirements, and the definition of *topologies* applicable to various material handling technologies. These concepts relate to the goal of developing a *specification framework. [*50]

Related to the second goal of developing tools, we show how to derive *decision rules* for screening technologies, and *rapid prototyping* methods to obtain performance and cost estimates. In some sense we are beginning to develop a *knowledge-based approach.* Each of these concepts is explained in more detail below. [50]

The selection of equipment of the MHS [52] can be done using four ways:
1. By means of a traditional selection method.
2. Using an analytical model.
3. By knowledge-based approaches.
4 .Hybrid approaches (analytical and knowledge based approaches).

In traditional selection, the designer relies principally on handbooks and experience. This approach may not be cost-effective because of the limitation of personnel experience. Only consulting agencies and large companies are likely to have a specialized planner with full-time facility planning responsibilities. In medium and small size companies, facility layout forms a part of the responsibilities of an industrial or plant engineer's activities. Analytical models have not often been applied in industry, because they generally consider only quantifiable factors such as cost and utilization and are often difficult to implement (Matson et al., 1992).

However, a knowledge-based approach involves the use of expert guidelines and 'rules of thumb' and allows extensive matching of equipment characteristics to application requirements. Practically, this expertise needs to be established over a period of time, based on operational experience.

There are tools other than a checklist to assist the engineer in the selection of MHS equipment. Knowledge based approaches have been developed since 1985; however the concept of computerized material handling equipment selection was established in about 1966 (Edt. Art.,1966).

In this first approach (traditional selection method), described in an editorial article published in Modern Material Handling (Editorial Article,1966), the equipment selection problem and MHS equipment attributes were converted to numerical values using special codes and from among the alternatives the best solution was selected. This best solution was based on a numerical match between the requirement value and the equipment score.

In 1971, the difficulties and complexity of the problem were brought out in a mathematical formulation presented by Webster and Reed (1971).In their study, equipment selection was viewed as an assignment problem where the handling equipment was chosen to perform given moves in order to minimize the material handling cost associated with those moves. The difficulty is one of finding the global optimum; however, heuristic methods may be used for feasible solutions. Both of these approaches were limited by numerical programming restrictions and computing facilities at the time. Since this early work, many articles have been published on the importance of MHS equipment selection and their design (Malmborg et al., 1986; Apple, 1972; Reed, 1976). Most of the facility layout solution articles have mentioned MHS design and its effect on the solutions (Apple and Deiseenroth, 1972). When CIM gained importance, the MHS design problem was again recognized as a key issue since automation and flexibility requirements for manufacturing systems have grown. White and Apple (1985) has brought out the importance of the MHS design and CIM problem together. Multi-criteria selection techniques for MHS design have been summarized by Frazelle (1985). He divided the specifications into five different major areas: return on investment, flexibility, safety, compatibility and maintainability. He also offered decision hierarchy and a graph for decision making. In 1988, Fisher et al. developed an expert system material handling equipment selection, which is based on rules which have been gathered from an expert.

The equipment types are selected by applying heuristic selection rules and equipment types have certainty factors. A hybrid approach (1997) was recently published by Velgama et al. The approach combines knowledge-base and optimization procedures with selection of the material handling system.

These existing approaches help to speed up the design process and to extend personal abilities. However, these approaches and prototypes need to be extended and improved with regard to flexibility and simplicity. In this study, the MHS equipment selection will be defined as a matching problem between product, process handling requirements and equipment specifications using rule sets. A new development will be added with a view to rationalization of handling equipment between centers, since in a manufacturing system, equipment rationalization must be adopted to simplify the system and reduce total investment and operation cost.

This work is complementary to previous work (Fisher et al., 1988) because its rationalization stage reduces selected equipment types to reduce the investment cost of the system. Also, when compared (Welgama and Gibson, 1997), it is more simple and Leaves the final stages of the selection and design to the designer.

6.2 Planning Procedures for Selection

A number of rule-based systems have been developed for selecting appropriate types of material handling equipment for in-factory moves. Applications include sort conveyors [Luxh 1991], industrial trucks [Malm 1987], and general equipment [Fish 1988, Park 1996, Pete 1998].

The first two situations assume that the system operator has already selected the equipment type, and desires to narrow the specification within that type. In addition, detailed work has been performed on palletizing systems [Ram 1991, Ram 1992], sort conveyors [Boze 1985, Boze 1988, Shar 1992c, Xie 1996], person-aboard AS/RS [Boze 1990], walk-and-pick systems [Gibs 1992, Shar 1992b], AGV systems [Shar 1990], pick-to-light technology [Shar 1996a, Shar 1996b], and forward pick area specification [Amir 1996, Berg 1998]. [50]

A knowledge-based system was devised to assist facility designers in the selection and configuration of materials handling equipment. The system utilizes preference directed search to capture improved designs by dynamically acquiring new preferences throughout the design process [Gabb 1989].

A more involved system consists of an inference engine that branch through a tree guided by collected data essential for solving the material handling equation: Material + Move_ Method. The equation is solved using rules developed to handle relationships between elements and factors of the equation. Plans were for the final system to provide its user with access to vendors specialized in particular handling operations [Hosn 1989, Park 1996].

A construction algorithm for selecting and assigning material handling equipment was developed; the method is computationally attractive and tends to achieve other goals, such as maximizing equipment utilization and minimizing the variations in equipment types as well as the primary goal of cost minimization. The problem is solved using a heuristic that exploits some conceptual similarities to both the knapsack and the loading problem [Hass 1985].

Many companies use materials shipped in bulk and must solve material handling problems associated with these materials. A mathematical programming decision model and methodology are presented that can assist a decision-maker in designing a bulk material handling system and in selecting the specific type of handling or transportation equipment. [50]

Model inputs include the following:

1. Capacity of the equipment,
2. Equipment costs,
3. Demand,
4. Budget, and,
5. Equipment compatibility [Velu 1992].

A technique which can be used to design or assist in the design of an integrated material handling system for a manufacturing facility was developed. The procedure selects the materials handling equipment to be used to perform a given set of moves in order to minimize the system costs associated with the handling, assuming the plant arrangement remains fixed [Webs 1971].

Integration efforts have been focused on a design procedure for a distribution center. Technology selection and operational issues are discussed in terms of input, selection, and evaluation stages along with iterative aspects of top-down decomposition and bottom-up modification [Shar 1991, Shar 1992a]. Included are managerial considerations; transaction data description; replenishment fulfillment; overall structure and detailed subsystem specification in reserve, picking, and sorting areas; and subsystem reconciliation and evaluation [Yoon 1995].

The growing importance of order pick systems (OPSs) has been recognized in both distribution and manufacturing systems. Most studies of conventional warehouse and OPS design imply prescribed sequences of steps in the design process. An important feature of OPSs is the diversity of the material flow, which is transformed by warehouse operations in terms of product and information [Yoon 1996].

Another issue related to the proposed work is that of avoiding too much detail, especially at the early stages. Recent work in a related, but different, domain of facility layout evaluation shows some approaches that may be useful in integrating different types of information. The traditional approaches to facility layout evaluation involved a hundred or more factors in one long list. By eliminating duplicates and focusing on those factors that were based either on the *geometry* of the layout or on other *measurable* elements, it was possible to reduce the long list to18 criteria, organized into 7 subclasses and 3 main classes [Lin 1999a, Lin 1999b].

6.3 Task Description of Material Handling Requirements

The research addresses four issues relating to integration of material handling (MH) equipment into a manufacturing environment. These four major tasks are shown in Figure 13.The first is task extraction to extract information about individual material handling tasks. The second is filtering and matching of individual tasks with individual resources, without regard to system performance and economy. The third is aggregation of tasks into sets that are then matched with technologies.

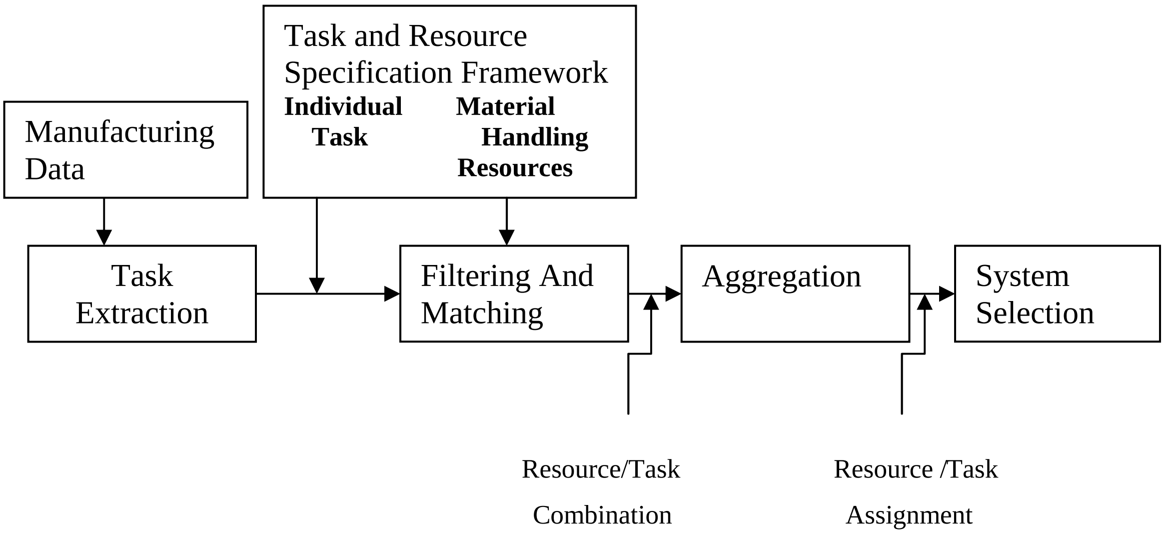


Figure 6.1: Major steps of procedure for selecting and specifying MH equipment for manufacturing

The fourth is system selection and specification. This last step requires a suite of fast analysis tools that allow the designer to obtain performance and cost information for technology selection. An optimization routine is then used to select among the combinations.

6.3.1Task Extraction

A fundamental approach to describing the tasks to be performed by a material handling system is individual task specification. Here the physical attributes of the load, such as weight, size, fragility, etc., and the task, such as vertical displacement, horizontal displacement, positioning accuracy, etc., are important. An example of an *individual task specification* is given in Table 1. The *individual task specification*, whether it is a move, storage, inspection, sequencing, or other operation.

Here the physical attributes of the load, such as weight, size, fragility, etc., and the task such as vertical displacement, horizontal displacement, positioning accuracy, etc., are important. The main function in this step is to eliminate technologies that are not capable of satisfying the requirements of individual tasks and to match single-task resources with the needs. [50]

Table6.1. Example of individual task specification (partial list)

Pick-up point 3D	Horizontal, vertical access?
Deposit point 3D	Weight of item
Time for move, min, max	Value of item
Size of item	Orientation requirements
Unit load configuration	Max acceleration on item
Temperature control needs	Balance/stability needs
Vibration control need	Static or dynamic interface with MH equipment
Static electricity protection	Supports at MH interface
Lifting aids, handles on item	

Each item in Table 1 would be specified by a numerical value(s)(e.g., 50 kg), a qualitative scale value (2 on a scale of 1 to 5), or logic value (yes or no). The focus clearly is on the mechanical ability needed to perform the task.[51]

Parallel to the individual task specification is the development of individual resource specifications. The approach here is to classify material handling technologies into groups that have similar geometric functionality. In a hierarchical system, this is the first level. A preliminary analysis shows that the following classes are needed: [51]

1. Containers, including pallets, slip sheets, wire cages, and tote boxes of corrugated and other materials.

2. Accessories, including mechanical grippers, suction grippers, slings and ropes, magnets, pallet forks, clamps, booms.

3. Cranes, including bridge crane, gantry crane, jib crane, mobile crane, single-point hoists, monorail hosts.

4. Vehicles, including unpowered carts and dollies, platform trucks, forklift trucks, automated guided vehicles (AGV), overhead electrified monorails (OEM). Subclasses are based on manual/powered, floor supported/overhead supported, path-bound/path-free, horizontal travel only/vertical travel, and position of operator: at floor level, elevated.

5. Conveyors. Subclasses are based on synchronous/asynchronous, accumulating/non-accumulating, spur capability or not, load supported above/below, bulk/discrete, and open/enclosed.

6. Sorting devices, including transfer cars, fully populated conveyor loops, conveyor loops with individual carriers or trains of carriers.

7. Storage/retrieval devices, including unit load and bulk load. Subclasses are based on pallet systems, item pick systems used in distribution centers

6.3.1.1 Extraction of Data, Information and Knowledge

Ideally, the data collection would be part of the manufacturing process specification. Certainly, the elements related to item characteristics and access to the manufacturing process interface should be available to the process designer. If not, then that person should develop the data. Location data for pick-up/deposit points would depend on the availability of a manufacturing facility layout. If none is available, then a more conservative approach with respect to material handling system design is needed. The format of the data requirements needs to be compatible with that for specifying the manufacturing process, such as IDEF-3, for example. [50]

A major challenge in data extraction is to determine exactly what data is really needed and what is redundant. The approach followed here parallels that developed in a different domain: facility layout evaluation. The traditional approaches to facility layout evaluation involved a hundred or more factors in one long list. *By eliminating duplicates* and focusing on those factors that were based either on the *geometry* of the layout or on other *measurable* elements, it was possible to reduce the long list to 18 criteria, organized into 7 subclasses and 3 main classes [Lin 1999a]. Included were subjective factors such as worker environment, human related safety, impact on the community, and property-related security. [50]

The data extraction involves the following three steps:

1. Prepare data on individual task specification for early screening of technologies.

2. Prepare data on individual task specification for narrowing the search to specific models with associated cost and performance parameters. This requires a statement of capability for different material handling equipment. An example of such a capability Table is shown in section 4. After the ineligible technologies have been eliminated by screening, there may remain several options. A filtering procedure is used here, based on the criterion ranking of the user. For individual task specification, the criteria that could be used include: *Closest match* of load characteristics to move with equipment load capacity *Best economy* of a repetitive move; here a productivity analysis is needed, based on the number of movements and equipment cost data. Any or all of the criteria in Tables 1 and 2 can be used in a multi-criterion evaluation, with appropriate penalties in the plus/minus directions.

3. Specification of *system task requirements* for selecting technology types that are economical and flexible, and for performing the rapid prototyping. Part of this step focuses on identifying the particular characteristics of *favorite* technologies that result in their repeated selection. For example, in the auto industry the power-and-free overhead conveyor is a *favorite* technology, perhaps due to the combination of item weight, size, and need for buffering and sequencing in the manufacturing process. In clean-room applications the AGV is a popular *favorite*.

Another part of this step is a broad-based examination of factors in an effort to identify good candidate technologies based on system task requirements. A more elaborate filtering process is used here, based on the following criteria:

- Matching of physical characteristics of the load to equipment load capacity
- Flexibility of path selection

- Flexibility in reconfiguring system for changed needs
- Throughput capability with respect to need
- Economy of system
- All of these criteria would be used in a multi-criterion evaluation.

6.3.2 Filtering and Matching

Parallel to the individual task specification is the development of individual resource specifications. A filtering and matching process then eliminates technologies that are not capable of satisfying the requirements of individual tasks and to match single-task resources with the needs. Table 2 shows a partial list of attributes for a technology; the attributes would have numerical, scale, or logical values similar to Table 1.

Table6.2. Example of individual resource capability, overhead electrified Monorail (partial list)

Pick-up point, min positions from floor, wall, ceiling	Vertical access with hook/hoist
Horizontal access with load carrier	Max travel, 3D
Speed, min, max	Weight capacity
Size capacity	Longit. control: ± 1.5 cm
Axial control: ± 0.5 cm	Max inclines: 2 deg.
Floor quality required: none	Orientation: can rotate item
Temperature: ambient	Acceleration
Vibration: frequency	Pendulum swing: amplitude
Balance/stability: good	Static electricity: can protect
Interface with mfg. process equipment: static	Recirculate carriers: yes
Minimum load spacing, m	Asynchronous control: yes
Switching: yes	

Table 3 shows an example where movement tasks eligible for fork lift truck are identified. Figure 14 is a symbolic representation of how the tasks and resources are matched (upper part of figure) to match candidate technologies with tasks. The output of this step is a list of individual resource task-combinations, such as r1t1, r1t5, r1t12... r2t1, r2t3, r2t14... r7t3, r7t9, r7t24, r7t29...

Table 6.3. Example of screening movement tasks eligible for fork lift truck (shaded entries represent conflicts; only tasks 12 and 15 are eligible.

Task	Weight		Size,m3		Lifting aid possible		Stability needed	
No.	>100	<100	>0.03	<0.03	Pallet	Hook	<1 deg.	None
1	×		×		×		×	×
2		×	×			×		×
3		×		×				×
4		×	×		×			×
5	×		×			×	×	
6		×		×		×		×
7		×		×				×
8		×	×					×
9	×			×				×
10		×		×				×
11		×		×		×		×
12	×		×		×			×
13		×		×				×
14		×		×				×
15	×		×		×			×

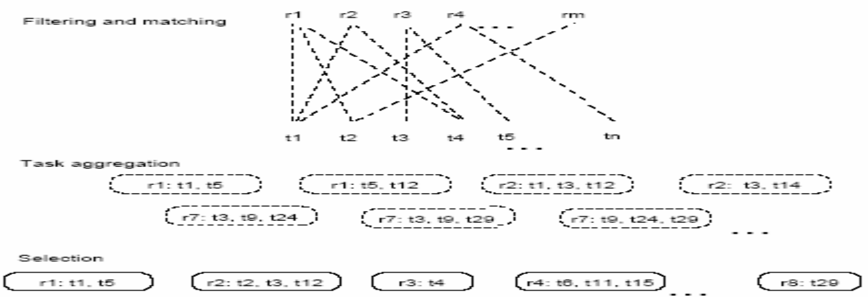


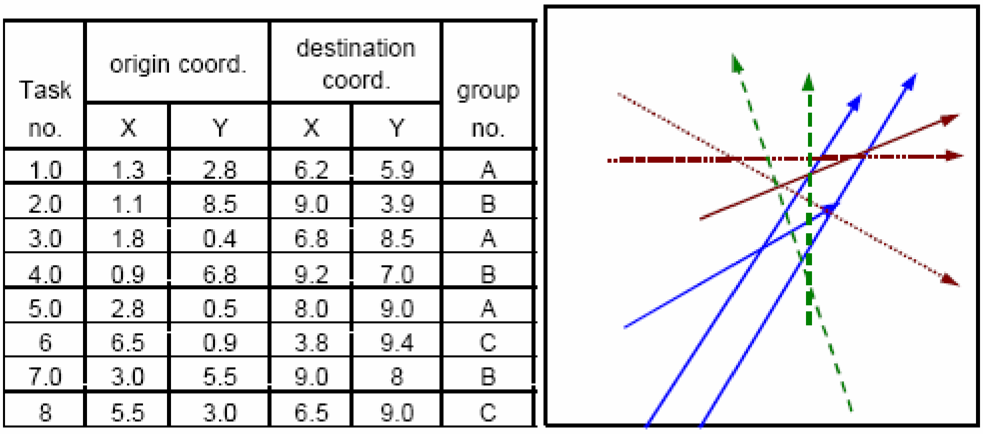
Figure6.2 : Filtering and Matching, Task Aggregation, and System Selection and Specification

6.3.3 Task Aggregation

This step involves the selection and aggregation of material handling tasks and their assignment to a candidate technology. Because of the flexibility of material handling equipment with respect to load type and placement/movement within the factory, there will be considerable overlap among the (individual resource-multiple task) combinations. For example, pallets can be transported by pallet jack, platform truck, fork lift truck, automated guided vehicle, and pallet conveyor. Lifting can be accomplished by hoists, jib cranes, gantry cranes, and bridge cranes; depending on the application, a fork lift truck may be used for lifting. [51]

Some typical *system task requirements* include: number of movements per time period, mean and variance of demand rates, number of pick-up/deposit points and locations, capability for change in pick-up/deposit points, synchronous travel need, sequencing capability need, and accumulation capability need. In such situations it is more difficult to select technologies because of the wide variety available and the time needed to estimate performance and costs. To address these issues, aggregation techniques for combining individual tasks are being developed.[51]

One form of aggregation is clustering based on the physical attributes used in task and resource specification. There may be more than 20 attributes, and this number may overburden a statistical clustering technique [11]. One approach is to identify the more important attributes and select these for aggregation or let these drive the aggregation in the initial stages.



Task no.	origin coord.		destination coord.		group no.
	X	Y	X	Y	
1.0	1.3	2.8	6.2	5.9	A
2.0	1.1	8.5	9.0	3.9	B
3.0	1.8	0.4	6.8	8.5	A
4.0	0.9	6.8	9.2	7.0	B
5.0	2.8	0.5	8.0	9.0	A
6	6.5	0.9	3.8	9.4	C
7.0	3.0	5.5	9.0	8	B
8	5.5	3.0	6.5	9.0	C

Figure6.3: Example of clustering by origin-destination coordinates.

Another approach is to allow the critical attributes to depend on the material handling resource. Some of the attributes [51] may be used to filter resources to be matched to the tasks, such as synchronous travel, sequencing capability, and accumulation capability

A third form of aggregation is based on origin/destination coordinates to form sets of tasks to be served by conveyor. Figure 15 shows an example for two-dimensional clustering; the techniques can also be applied to three dimensions, for applications of transporting items between floors. The outcome of this step are sets of resource tasks combinations: {r1: t1, t5}, {r1: t5, t12}, {r2: t1, t3, t14}, {r2: t3, t14}, {r7: t3, t9, t24}, {r7: t3, t9, t29}, {r7: t9, t24, t29}, ...

6.3.4 System Selection

The step of selecting from among the overlapping sets of *resource-tasks combinations* is accomplished within an optimization framework, specifically a covering problem. Each material handling task *ti* forms a row of the constraint matrix. The columns correspond to application sets *sk* of specific technologies. Column generation thus involves selecting a resource-task combination, for example {r7: t3, t9, t29}, and performing fast analysis to obtain the number of fixed resource units to accomplish the tasks in the set.

The resource units needed for each application set are translated to cost coefficients for the objective function, reflecting both fixed and variable costs of installation and variable costs of operation. The importance of a realistic cost structure cannot be overemphasized. It is not unusual for the fixed installation cost, representing system design and control system but no moving hardware, to exceed $100,000. Further, the moving hardware often can accommodate additional tasks with little increase in variable costs of installation and variable costs of operation.

The approach is then to optimize over a given set of available columns (resource-task combinations) so that each individual task is covered only once. Infeasibilities may occur because a task is covered more than once; this can be resolved by generating a new column without that task. Other possibilities exist here, including starting strategies, and pair-wise exchange of (compatible) tasks.

To obtain the cost coefficients for each resource-task combination a suite of *fast analysis tools* are needed. Such tools are being developed for each topology, with variations within a topology governed by selection of numerical parameters. The tools are less burdensome than simulation or combinatorial optimization, but more realistic than steady-state performance with no interference or idle time. Some examples of such tools are given here. [51]

The first three methods represent a series of more detailed procedures that apply to all types of vehicle systems, including forklift, automated guided vehicles, and overhead electrified monorail. The last two methods apply to conveyor systems.

- Development of from-to chart based on unit loads but incomplete product routing data. One of the challenges in material handling specification is that the transport data is not known with certainty, or if it is then the number of product routings is unmanageably large. A tool currently under development will enable the designer to specify a limited number of product routings, based on Pareto analysis, and develop the from-to portion in unit loads (constrained by weight and volume). These product routings are then used to develop a transition matrix that is used to generate additional routings and flows to compensate for those not entered by the designer. Perturbations of the transition matrix allow for robustness analysis.
- Empty vehicle requirements analysis by factoring, or by first-order approximation followed by factoring. The simple factoring method reflects an assumption of first-come, first-served (FCFS) vehicle dispatching, which usually results in pessimistic performance estimates. The first-order approximation method, involving only arithmetic operations in spreadsheet cells, approximates better the typical proximity-based dispatching rules in a vehicle system. A version of this tool has already been developed for educational purposes.
- Vehicle requirements analysis by representing the vehicle fleet as a single multi-server queue. Once both loaded and empty vehicle trips are known for a design period, then the stochastic behavior of the system can be modeled as a queue. Since the desired fleet utilization is usually below 85%, to avoid downtime of expensive manufacturing process equipment, the modeling shortcut of using a single, multi-server queue, should not result in any gross distortions. Buffers at the manufacturing process interfaces can be represented by a finite queue capacity.

- Network flow models together with mean-variance analysis can be used to specify configuration of conveyor systems in manufacturing. Reserve capacity is usually considerably greater than in vehicle based systems, with design factors of 0.4 to 0.85 (actual handling capacity compared to theoretical capacity) not being unusual [12, 13]. The design factor can be included in the decision rules, since different applications may have different inherent variabilities of demand.
- For the cranes and hoists it is possible to adapt cycle time formulas from the automated storage/retrieval systems that have been studied so much. [10]

6.4 Example for Task and Equipment Specifications

In the context of a manufacturing plant, it would be useful to extract material handling task specifications from existing manufacturing engineering and plant data. This idea is presented via an example. Also, in order to select equipment to accomplish material handling tasks, concise and functional specifications for material handling equipment must be available. We present an example of such a material handling equipment specification for come equipment types. [50]

6.5.1 Bharat Motor Works

The Bharat Motor Works (BMW) is a detailed fictitious example of a manufacturing plant [McKa 91]. It manufactures a line of scale model automobiles. There are three main products: GT200, GT250, and GT350. The GT200 is a relatively low cost, die cast model that is sold through large distributors via supermarket magazines and television spot ads. This is a very high volume item and made to stock. BMW constructs the GT200 and other model automobiles using a number of purchased parts and internally fabricated components transformed from raw materials.

6.5.2 Route Sheet

The route sheet is manufacturing engineering information that is essential for defining material handling requirement. The route sheet for GT 200 product in BMW is described below. The GT 200 is composed of a cast body and trim. The cast body is made from 1.5 pounds of melted compound metal that is molded into shape. The trim consists of the stand, decals and plate. The stand is rough and fine machined and the decals are externally purchased. The plate is cut, punched, pressed, and detailed. Once the body and trim are complete, the GT 200 is assembled. The route sheet is shown in Table 4 for the GT 200 model automobile.

Table6.4: Route Sheet for GT 200 in BMW

Product Name	GT 200	
Quantity	250	
	Routing Station	
Parts	From	To
Wood Component	Purchase Store	MS Load
Wood Component	MS Load	M001
Wood Component	M001	M002
Wood Component	M002	M003
Wood Component	M003	M004
Wood Component	M004	M005
Wood Component	M005	MS Unload
2XXX Stand	MS Unload	2xx Store
Cast metal compound	Raw store	F001
Cast metal compound	F001	F004
Cast metal compound	F004	Rack Bench
200 Body	Rack Bench	Assembly Bench2
Sheet Metal	Raw Store	S001
200xx plate 01	S001	S002
200xx plate 02	S002	S003
200xx plate 03	S003	200xx plate
200xx plate 03	200xx plate	SM Bench
200xx plate	SM Bench	Assembly Bench3
2xx Stand	2xx Store	Assembly bench 3
200 Decal	Purch Store	Assembly bench 3
GT 200	Assembly bench 3	Final Store

6.5.3 Factory Layout

Another important type of information that is necessary to determine material handling tasks is the spatial arrangements of manufacturing facilities. This information is provided in a 2-D layout, and height information for pick-up and drop-off points. Figure 16 shows the layout for BMW. The height information is used to determine the following task requirement: start and endpoint height, destination accuracy, and the rack depth. Table 5 shows the height, destination accuracy, rack depth, and the rack locations. The height is the vertical point at which parts are picked-up or dropped off. The destination accuracy is used to determine appropriate equipment capable of such accuracy.

Table 6.5: Height Information of plant BWM

Station	Height, m	Destination Accuracy,(in)	Rack Depth (#of UL)	Rack Locations
Raw Store	6	.5	2	L001-L020
Raw Store	66	.5	2	L021-L040
Purch Store	6	.5	1	L001-L004
Purch store	66	.5	1	L005-L008
2xx store	6	.5	2	L001-L015
2xx store	66	.5	2	L016-L030
Final store	6	.5	1	L001-L004
Final store	66	.5	1	L005-L008
MS load	36	.25	-	-
MS Unload	36	.25	-	-
M001	24	2	-	-
M002	24	2	-	-
M003	24	2	-	-
M004	24	2	-	-
M005	24	2	-	-
F001	36	2	-	-
F004	36	2	-	-
Rack Bank	48	2	-	-
S001	36	2	-	-
S002	36	2	-	-
S003	36	2	-	-
SM Bench	24	2	-	-
Assembly Bench	24	2	-	-

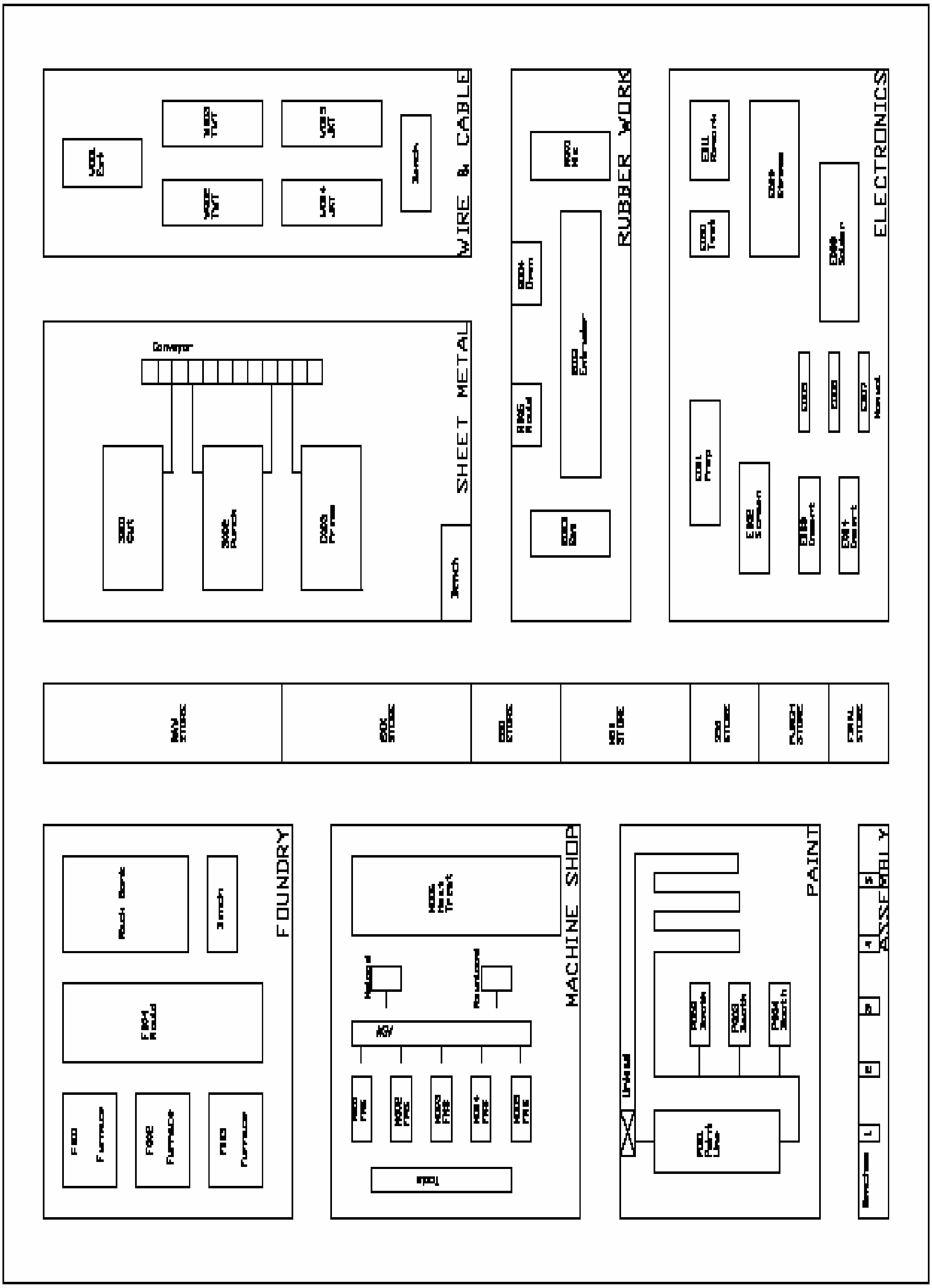


Figure6.4: Floor Plan of BMW [McKa 91]

6.5.4 Parts Information

Data on products and parts that are moved in the plant are also important in defining material handling tasks. Relevant information for GT 200 in BMW is presented in Table 6. The data includes part/product attributes that impact material handling methods.

Table 6.6: Parts information in GT 200 BMW

Parts	Weight	Unit load height, m	Unit load Size L×W		Unit Load Packing	Unit load bottom surface	Nature	Temp.°F
Wood Component	3	36	48	36	loose	flat-rough	Sturdy	70
Wood Component	2.9	36	48	36	loose	flat-rough	Sturdy	70
Wood Component	2.85	36	48	36	loose	flat-rough	Sturdy	70
Wood Component	2.8	36	48	36	loose	flat-rough	Sturdy	70
Wood Component	2.7	36	48	36	loose	flat-rough	Sturdy	70
Wood Component	2.65	36	48	36	loose	flat-rough	Sturdy	70
Wood Component	2.6	36	48	36	loose	flat-rough	Sturdy	70
2XXX Stand	2.5	36	48	36	average	flat-smooth	fragile	70
Cast metal compound	2	60	48	40	loose	flat-smooth	Sturdy	70
Cast metal compound	2	60	48	40	loose	flat-smooth	Sturdy	70
Cast metal compound	1.5	60	48	40	loose	flat-smooth	Sturdy	70
200 Body	1.5	36	48	40	Average	flat-rough	fragile	70
Sheet metal	3	24	36	24	loose	flat-smooth	Sturdy	70
2xxx plate 001	2.8	24	36	24	loose	flat-rough	Sturdy	70
2xxx plate 002	2.6	24	36	24	loose	flat-rough	Sturdy	70
2xxx plate 003	2.4	24	36	24	loose	flat-rough	Sturdy	70
2xxx plate 003	2.4	24	36	24	loose	flat-rough	fragile	70
2xxx plate	2.5	24	48	40	Average	flat-rough	fragile	70
2xx stand	2.5	48	48	40	Average	flat-rough	fragile	70
200 decal	2	48	48	40	Average	flat-smooth	fragile	70
GT 200	8.5	48	48	40	tight	flat-smooth		70

6.5.5 Task Specification

Based on the manufacturing engineering data identified above- Route Sheet, Factory Layout, and Parts Information material handling task specifications can be automatically extracted. Figure 16 illustrates this idea. Table 7 show the complete set of material handling tasks required to produce GT 200 in BMW. The information in this Table is extracted from Table 4 (Route Sheet), Figure 16 (Factory Layout) and Table 5 (Height

Information), and Table 6 (Parts Information). The list of data items in Table 7 has been selected to help decide on appropriate material handling equipment for the task.

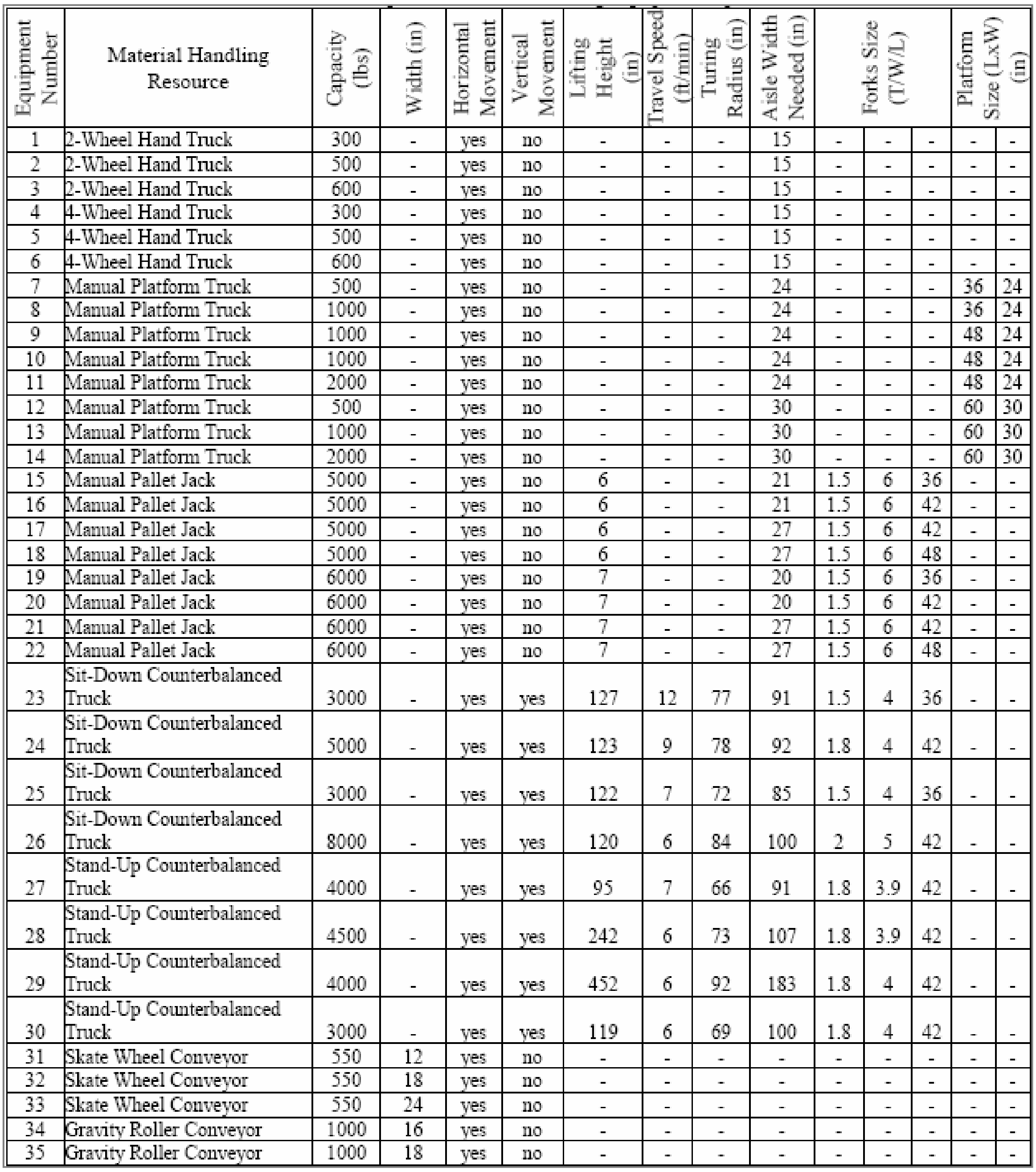
6.5.6 Material Handling Equipment Resource Specification

It is important to have material handling equipment capabilities stated in a manner that would aid in selecting specific equipment for a task. Table 8 presents an initial format for such a specification. The information in Table 8 can be used along with the task specification of Table7 to make equipment assignments. One such assignment is indicated in the last column of Table 7.

Table 6.7: task Specification for GT 200 in BMW

Material Handling Task Specifications																					
				Move								Material							Item		
Task#	Product GT 200			Start point		End Point		Start point height	End point height	Destination acc.	Rack Depth	Quantity	Weight (lbs)	Height (in)	Size (L×W) in UL		Packing (UL)	Bottom Surface (UL)	Nature	Temperature F	Equipment No.
1	Wood component	Purch Store	MS load	71	27	38	109	6	36	.25	-	250	750	36	48	36	L	F/R	S	70	22
2	Wood component	MS load	M001	38	109	22	114	36	24	2	-	250	725	36	48	36	L	F/R	S	70	15
3	Wood component	M001	M002	22	114	22	106	24	24	2	-	250	713	36	48	36	L	F/R	S	70	15
4	Wood component	M002	M003	22	106	22	98	24	24	2	-	250	700	36	48	36	L	F/R	S	70	15
5	Wood component	M003	M004	22	98	22	90	24	24	2	-	250	675	36	48	36	L	F/R	S	70	15
6	Wood component	M004	M005	22	90	22	82	24	24	2	-	250	663	36	48	36	L	F/R	S	70	15
7	Wood component	M005	MS Unload	22	82	38	87	24	24	.25	-	250	650	36	48	36	L	F/R	S	70	15
8	2xx stand	MS Unload	2 xx store	38	87	71	111	36	66	.5	2	250	625	36	48	36	A	F/S	S	70	22
9	Metal cast compound	Raw Store	F001	71	154	18	168	6	36	2	-	250	500	60	48	40	L	F/S	S	70	22
10	Metal cast compound	F001	F004	18	168	33	154	36	36	2	-	250	500	60	48	40	L	F/S	S	70	15
11	Metal cast compound	F004	Rack Bench	33	154	48	162	36	48	2	-	250	375	60	48	40	L	F/S	S	70	15
12	200 Body	Rack Bench	Assy Bench 3	48	162	35	12	48	24	2	-	250	375	36	48	40	A	F/R	S	70	15
13	Sheet metal	Raw Store	S001	71	154	97	160	66	36	2	-	250	750	24	36	24	L	F/S	S	70	22
14	2xx Plate 01	S001	S002	97	160	97	140	36	36	2	-	250	700	24	36	24	L	F/S	S	70	15
15	2xx Plate 02	S002	S003	97	140	97	120	36	36	2	-	250	650	24	36	24	L	F/R	S	70	15
16	2xx Plate 03	S003	2xx store	97	120	71	111	36	66	.5	2	250	600	24	36	24	L	F/R	S	70	22
17	2xx Plate 03	2xx store	sm bench	71	111	90	95	66	24	2	-	250	600	24	36	24	L	F/R	S	70	22
18	2xx Plate	Sm bench	Assy Bench3	90	95	35	12	24	24	2	-	250	625	24	48	40	A	F/R	S	70	22
19	2xx stand	2xx store	Assy Bench3	71	111	35	0	66	24	2	-	250	625	48	48	40	A	F/S	S	70	22
20	200 Decal	Purch store	Assy Bench3	71	27	35	12	66	24	2	-	250	500	48	48	40	A	F/S	S	70	22
21	GT 200	Assy Bench3	Final store	35	12	71	14	24	6	.5	1	250	2125	48	48	40	T	F/S	S	70	22

Table 6.8: An example of Material Handling Equipment Specification



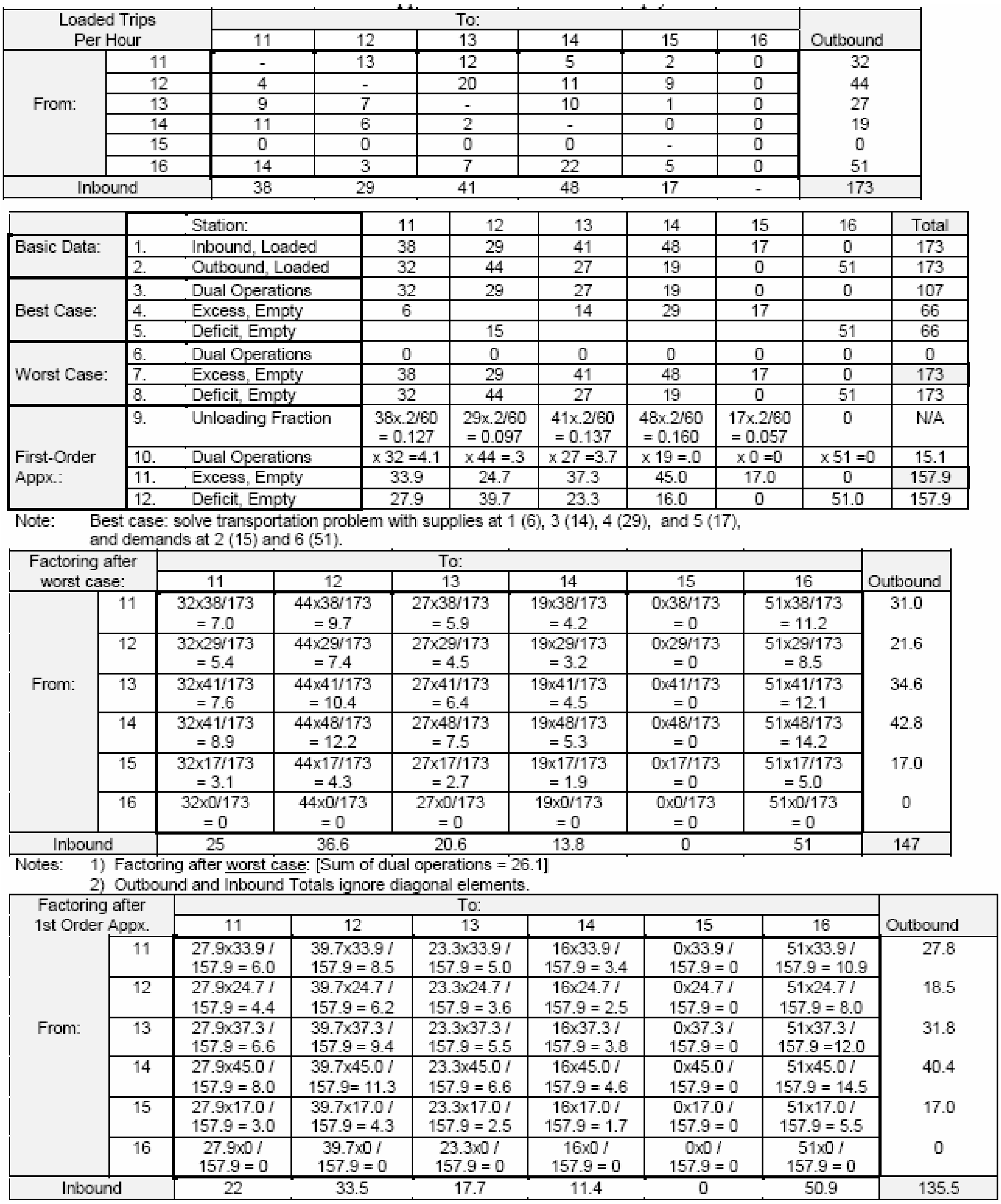
Equipment Number	Material Handling Resource	Capacity (lbs)	Width (in)	Horizontal Movement	Vertical Movement	Lifting Height (in)	Travel Speed (ft/min)	Turing Radius (in)	Aisle Width Needed (in)	Forks Size (T/W/L)			Platform Size (LxW) (in)	
1	2-Wheel Hand Truck	300	-	yes	no	-	-	-	15	-	-	-	-	-
2	2-Wheel Hand Truck	500	-	yes	no	-	-	-	15	-	-	-	-	-
3	2-Wheel Hand Truck	600	-	yes	no	-	-	-	15	-	-	-	-	-
4	4-Wheel Hand Truck	300	-	yes	no	-	-	-	15	-	-	-	-	-
5	4-Wheel Hand Truck	500	-	yes	no	-	-	-	15	-	-	-	-	-
6	4-Wheel Hand Truck	600	-	yes	no	-	-	-	15	-	-	-	-	-
7	Manual Platform Truck	500	-	yes	no	-	-	-	24	-	-	-	36	24
8	Manual Platform Truck	1000	-	yes	no	-	-	-	24	-	-	-	36	24
9	Manual Platform Truck	1000	-	yes	no	-	-	-	24	-	-	-	48	24
10	Manual Platform Truck	1000	-	yes	no	-	-	-	24	-	-	-	48	24
11	Manual Platform Truck	2000	-	yes	no	-	-	-	24	-	-	-	48	24
12	Manual Platform Truck	500	-	yes	no	-	-	-	30	-	-	-	60	30
13	Manual Platform Truck	1000	-	yes	no	-	-	-	30	-	-	-	60	30
14	Manual Platform Truck	2000	-	yes	no	-	-	-	30	-	-	-	60	30
15	Manual Pallet Jack	5000	-	yes	no	6	-	-	21	1.5	6	36	-	-
16	Manual Pallet Jack	5000	-	yes	no	6	-	-	21	1.5	6	42	-	-
17	Manual Pallet Jack	5000	-	yes	no	6	-	-	27	1.5	6	42	-	-
18	Manual Pallet Jack	5000	-	yes	no	6	-	-	27	1.5	6	48	-	-
19	Manual Pallet Jack	6000	-	yes	no	7	-	-	20	1.5	6	36	-	-
20	Manual Pallet Jack	6000	-	yes	no	7	-	-	20	1.5	6	42	-	-
21	Manual Pallet Jack	6000	-	yes	no	7	-	-	27	1.5	6	42	-	-
22	Manual Pallet Jack	6000	-	yes	no	7	-	-	27	1.5	6	48	-	-
23	Sit-Down Counterbalanced Truck	3000	-	yes	yes	127	12	77	91	1.5	4	36	-	-
24	Sit-Down Counterbalanced Truck	5000	-	yes	yes	123	9	78	92	1.8	4	42	-	-
25	Sit-Down Counterbalanced Truck	3000	-	yes	yes	122	7	72	85	1.5	4	36	-	-
26	Sit-Down Counterbalanced Truck	8000	-	yes	yes	120	6	84	100	2	5	42	-	-
27	Stand-Up Counterbalanced Truck	4000	-	yes	yes	95	7	66	91	1.8	3.9	42	-	-
28	Stand-Up Counterbalanced Truck	4500	-	yes	yes	242	6	73	107	1.8	3.9	42	-	-
29	Stand-Up Counterbalanced Truck	4000	-	yes	yes	452	6	92	183	1.8	4	42	-	-
30	Stand-Up Counterbalanced Truck	3000	-	yes	yes	119	6	69	100	1.8	4	42	-	-
31	Skate Wheel Conveyor	550	12	yes	no	-	-	-	-	-	-	-	-	-
32	Skate Wheel Conveyor	550	18	yes	no	-	-	-	-	-	-	-	-	-
33	Skate Wheel Conveyor	550	24	yes	no	-	-	-	-	-	-	-	-	-
34	Gravity Roller Conveyor	1000	16	yes	no	-	-	-	-	-	-	-	-	-
35	Gravity Roller Conveyor	1000	18	yes	no	-	-	-	-	-	-	-	-	-

6.6 Evaluation of AGV's

In order to evaluate throughput capability and economy of a system, it is suggested that *rapid prototyping* methods be developed and used for each topology, with variations within a topology governed by selection of numerical parameters. Some examples of such methods are given here. The first two methods represent a series of more detailed procedures that apply to all types of vehicle systems, including forklift, AGV, and OEM.

1. Empty vehicle requirements analysis by factoring, or by first-order approximation followed by factoring [Shar 1997]. The simple factoring method reflects an assumption of first-come, first-served (FCFS) vehicle dispatching, which usually results in pessimistic performance estimates. The first-order approximation method, involving only arithmetic operations in spreadsheet cells, approximates better the typical proximity-based dispatching rules in a vehicle system. See an example in Table 9.
2. Vehicle requirements analysis by representing the vehicle fleet as a single multi server queue. Once both loaded and empty vehicle trips are known for a design period, and then the stochastic behavior of the system can be modeled as a queue. Since the desired fleet utilization is usually below 85%, to avoid downtime of expensive manufacturing process equipment, the modeling shortcut of using a single, multi-server queue, should not result in any gross distortions. Buffers at the manufacturing process interfaces can be represented by a finite queue capacity
3. Although a simulation analysis would be recommended before installing (or configuring) any major conveyor system, it should be possible to select technology and specify configuration with simpler performance models. Specifically, *network flow models* together with *mean-variance analysis* can be used. Since the demand on most conveyor systems in manufacturing is variable throughout the day, some element of reserve capacity is needed.

Table6.9: F/Order Approximation Method for Empty Vehicle Travel



Loaded Trips Per Hour		To: 11	12	13	14	15	16	Outbound
From:	11	-	13	12	5	2	0	32
	12	4	-	20	11	9	0	44
	13	9	7	-	10	1	0	27
	14	11	6	2	-	0	0	19
	15	0	0	0	0	-	0	0
	16	14	3	7	22	5	0	51
Inbound		38	29	41	48	17	-	173

		Station:	11	12	13	14	15	16	Total
Basic Data:	1.	Inbound, Loaded	38	29	41	48	17	0	173
	2.	Outbound, Loaded	32	44	27	19	0	51	173
Best Case:	3.	Dual Operations	32	29	27	19	0	0	107
	4.	Excess, Empty	6		14	29	17		66
	5.	Deficit, Empty		15				51	66
Worst Case:	6.	Dual Operations	0	0	0	0	0	0	0
	7.	Excess, Empty	38	29	41	48	17	0	173
	8.	Deficit, Empty	32	44	27	19	0	51	173
First-Order Appx.:	9.	Unloading Fraction	38x.2/60 = 0.127	29x.2/60 = 0.097	41x.2/60 = 0.137	48x.2/60 = 0.160	17x.2/60 = 0.057	0	N/A
	10.	Dual Operations	x 32 =4.1	x 44 =.3	x 27 =3.7	x 19 =.0	x 0 =0	x 51 =0	15.1
	11.	Excess, Empty	33.9	24.7	37.3	45.0	17.0	0	157.9
	12.	Deficit, Empty	27.9	39.7	23.3	16.0	0	51.0	157.9

Note: Best case: solve transportation problem with supplies at 1 (6), 3 (14), 4 (29), and 5 (17), and demands at 2 (15) and 6 (51).

Factoring after worst case:		To: 11	12	13	14	15	16	Outbound
From:	11	32x38/173 = 7.0	44x38/173 = 9.7	27x38/173 = 5.9	19x38/173 = 4.2	0x38/173 = 0	51x38/173 = 11.2	31.0
	12	32x29/173 = 5.4	44x29/173 = 7.4	27x29/173 = 4.5	19x29/173 = 3.2	0x29/173 = 0	51x29/173 = 8.5	21.6
	13	32x41/173 = 7.6	44x41/173 = 10.4	27x41/173 = 6.4	19x41/173 = 4.5	0x41/173 = 0	51x41/173 = 12.1	34.6
	14	32x41/173 = 8.9	44x48/173 = 12.2	27x48/173 = 7.5	19x48/173 = 5.3	0x48/173 = 0	51x48/173 = 14.2	42.8
	15	32x17/173 = 3.1	44x17/173 = 4.3	27x17/173 = 2.7	19x17/173 = 1.9	0x17/173 = 0	51x17/173 = 5.0	17.0
	16	32x0/173 = 0	44x0/173 = 0	27x0/173 = 0	19x0/173 = 0	0x0/173 = 0	51x0/173 = 0	0
Inbound		25	36.6	20.6	13.8	0	51	147

Notes: 1) Factoring after worst case: [Sum of dual operations = 26.1]
2) Outbound and Inbound Totals ignore diagonal elements.

Factoring after 1st Order Appx.		To: 11	12	13	14	15	16	Outbound
From:	11	27.9x33.9 / 157.9 = 6.0	39.7x33.9 / 157.9 = 8.5	23.3x33.9 / 157.9 = 5.0	16x33.9 / 157.9 = 3.4	0x33.9 / 157.9 = 0	51x33.9 / 157.9 = 10.9	27.8
	12	27.9x24.7 / 157.9 = 4.4	39.7x24.7 / 157.9 = 6.2	23.3x24.7 / 157.9 = 3.6	16x24.7 / 157.9 = 2.5	0x24.7 / 157.9 = 0	51x24.7 / 157.9 = 8.0	18.5
	13	27.9x37.3 / 157.9 = 6.6	39.7x37.3 / 157.9 = 9.4	23.3x37.3 / 157.9 = 5.5	16x37.3 / 157.9 = 3.8	0x37.3 / 157.9 = 0	51x37.3 / 157.9 =12.0	31.8
	14	27.9x45.0 / 157.9 = 8.0	39.7x45.0 / 157.9= 11.3	23.3x45.0 / 157.9 = 6.6	16x45.0 / 157.9 = 4.6	0x45.0 / 157.9 = 0	51x45.0 / 157.9 = 14.5	40.4
	15	27.9x17.0 / 157.9 = 3.0	39.7x17.0 / 157.9 = 4.3	23.3x17.0 / 157.9 = 2.5	16x17.0 / 157.9 = 1.7	0x17.0 / 157.9 = 0	51x17.0 / 157.9 = 5.5	17.0
	16	27.9x0 / 157.9 = 0	39.7x0 / 157.9 = 0	23.3x0 / 157.9 = 0	16x0 / 157.9 = 0	0x0 / 157.9 = 0	51x0 / 157.9 = 0	0
Inbound		22	33.5	17.7	11.4	0	50.9	135.5

Notes: 1) Factoring after first-order approximation: [Sum of additional dual operations = 26.1 ==> 37.4 Total]
2) Outbound and Inbound Totals ignore diagonal elements.

This reserve capacity is usually considerably greater than in vehicle-based systems, with design factors of 0.4 to 0.85 (actual handling capacity compared to theoretical capacity) not being unusual [Boze 1985, Boze 1988]. The design factor can be included in the *decision rules*, since different applications may have different inherent variabilities of demand.

4 For the cranes and hoists it should possible to adapt cycle tie formulas from the automated storage/retrieval systems that have been studied so much [Tomp 1996b].

Many decisions on technology are made before production plans are known completely. The purpose of the rapid prototyping methods is to enable a system planner to make intelligent choices based on uncertain data. Thus, high accuracy is not needed, or if attained, not that meaningful. The rapidly changing business climate suggests that flexibility of technology and ease of implementation may be as or more important as efficiency.

Chapter 7

Reliability Analysis in the design of flow path for AGV's

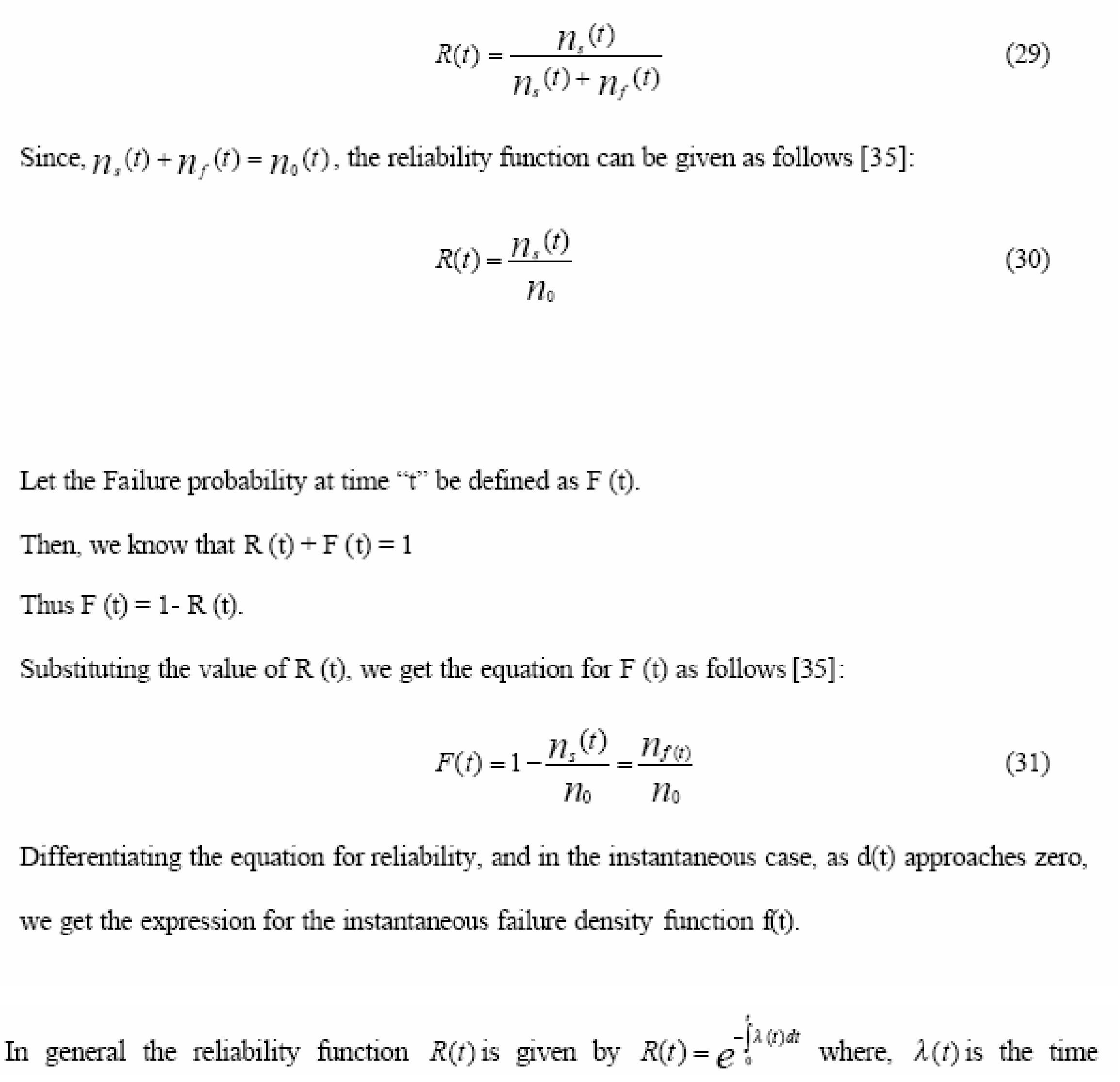
Reliability of fixed path material handling system can be a serious and costly real life problem particularly in those environments where a single unit of material has a significant dollar value [40]. Usually the research on AGVS concentrates on the performance analysis as a function of path design, location of pick-up drop- off points and fleet sizing. An underlying assumption in all the analysis is that all the components are going to last life long. The reliability effects of these components are usually ignored. In reality, the components are not completely reliable and are subject to failures over a period of time. The failure of these components does affect the overall performance of the material handling system. The guide path design can affect the overall vehicle system reliability and the performance. There are tradeoffs between the travel distance, the reliability of the material handling components and the overall material handling components.

Consider a simple example of a layout with cutover and without cutover. A path with a cutover will result in a lesser travel distance and consequently lesser time. At the same time, intersections generally reduce the reliability of the system by adding potential sources of failure [40]. There are several reasons for this. The guide path intersections may employ mechanical branching/routing devices which allow the vehicles to change direction by the command of a control system. Secondly, intersections usually represent a merging point of two different vehicle paths which increase the probability of vehicle collisions [40].

Studies have shown that incorporating reliability analysis in the design of guide- path helps reducing the travel distance for the vehicle. A study which deals this aspect is the one by Beamon [40]. The model has been developed on the basis that intersections, pick-up/delivery stations, and vehicle operating times all affect the overall reliability of the system. Thus, it is possible to design a guide path in such a way as to mitigate the performance effects of unreliable material handling components. The study compares the given guide path with one cutover, then with two cutovers and lastly without any cutovers. The results show that the total travel distance is the lowest for the guide path with two cutovers. At the same time the unreliability measure is also the highest for the same configuration. Thus there is a tradeoff between the reliability and the objective function to be achieved while designing the guide path. Thus we see that incorporating reliability in the guide path design is important. But at this stage we are still not clear on how to estimate the reliability of the system, how do we arrive at an estimate of the value of reliability. An automated guided vehicle is a very complex system and has a variety of components involved. Hence we need to design a systematic procedure to come up with an estimate for the reliability values.

7.1 Reliability Concepts

Reliability is defined as the ability of an item to perform the require function. Suppose 'n_0' identical items are under test and after time t, $n_f(t)$ items fail and $n_s(t)$ items survive, then the reliability function is defined as [35]:



$$R(t) = \frac{n_s(t)}{n_s(t) + n_f(t)} \qquad (29)$$

Since, $n_s(t) + n_f(t) = n_0(t)$, the reliability function can be given as follows [35]:

$$R(t) = \frac{n_s(t)}{n_0} \qquad (30)$$

Let the Failure probability at time "t" be defined as F (t).

Then, we know that R (t) + F (t) = 1

Thus F (t) = 1- R (t).

Substituting the value of R (t), we get the equation for F (t) as follows [35]:

$$F(t) = 1 - \frac{n_s(t)}{n_0} = \frac{n_{f(t)}}{n_0} \qquad (31)$$

Differentiating the equation for reliability, and in the instantaneous case, as d(t) approaches zero, we get the expression for the instantaneous failure density function f(t).

In general the reliability function $R(t)$ is given by $R(t) = e^{-\int_0^t \lambda(t)dt}$ where, $\lambda(t)$ is the time dependent failure rate or the instantaneous failure rate. It is also called the hazard rate.

The above expression is a general reliability function. It can be used to obtain component reliability for any known failure time distribution. Generally the life distributions may vary. Typical life distributions in use are exponential, Erlang, Gamma, Weibull.

The reliability of an item (a component, a complex system, a computer program or a human being) is defined as the probability of performing its purpose adequately for the period of time intended under the operating and environmental conditions encountered [35]. The fundamental concept is that the component will fail sometime in its life of operation. Modeling this failure is important since it will help in getting a measure of the performance of the system. Reliability can also be looked at from the cost perspective. If the system is not reliable, it can lead to loss of revenue. On the other hand, it costs more to build higher reliability into the system. Therefore a tradeoff can be made between cost and reliability. Since reliability is a yardstick of the capability to perform within required limits when in operation, it normally involves a parameter which measures time. The unit of time may be anything which is usually preferred for continuous operation. But in many cases, the probability that no failure will occur in a given number of occurrences is a better estimate than the probability of failure in a number of hours.

7.2 Hazard Rate Curve

The hazard rate curve is typically as shown in the figure above. This is true for most of the electronic components. This may not be true for mechanical components. The decreasing hazard rate is sometimes also called the “burn- in” period. Failures during this period are more attributed to design and manufacturing defects [35]. The constant part of this curve is known as the useful life period. The wear out period begins when equipment or a component has aged or bypassed its useful operating life. Consequently the number of failures during this period of time begins to increase. Failures that occur during the useful life period are known as random failures because they occur very unpredictably.

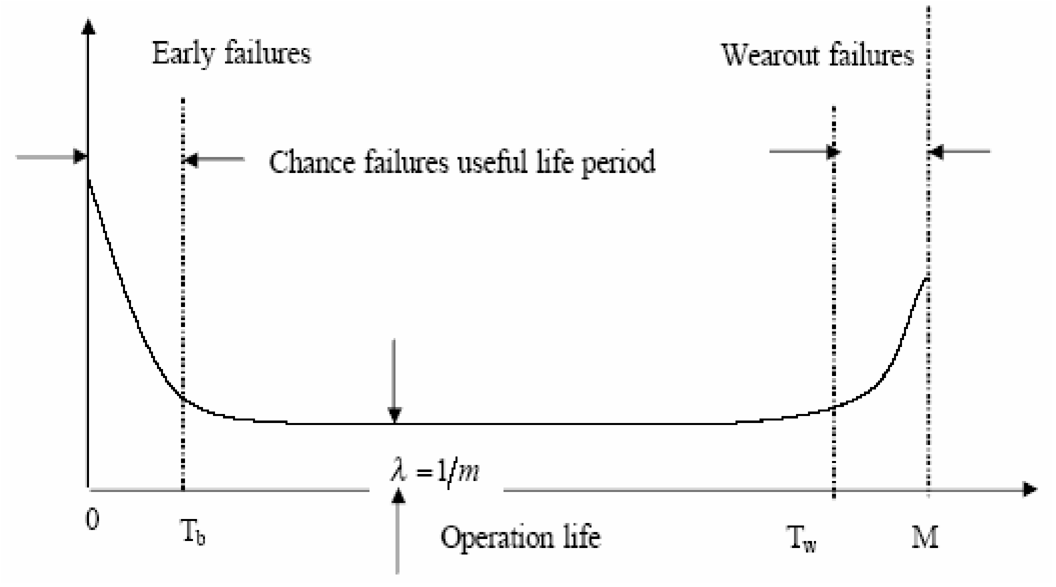


Figure 7.1: Hazard rate curve [35]

Thus while getting a reliability estimate it is also important to consider what portion of the curve the component is in. The time M is the mean wear-out time of the population. Mean time between failures tells us how reliable the component is in its useful life. This information is very important. A good policy in the useful life period is to replace the components only as they fail. Thus the rule is to replace components as they fail within the useful life of the components, and replace each component preventively, even if it has not failed, not later than when it has reached the end of its useful life [35]. The material handling industry has for many years struggled with the problem of evaluating reliability and availability of complex material handling systems. Many complex systems such as the AGVS are placed throughout the world, yet engineers are rarely able to adequately represent the system reliability and availability in a meaningful way. The major problem is that these systems upon failure of individual components can often operate at degraded levels of performance. In addition, this degraded performance is highly unpredictable.

The AGVS is a complex system and evaluating the reliability is a complex task. The Automated guided vehicle in itself is a very complex mechanism with hundreds of components varying from mechanical to electrical ones. Thus estimating the value for the reliability of the vehicle is cumbersome task in itself. There are many methods to reliability studies. Failure mode and effects analysis (FMEA) is a preliminary design evaluation procedure to identify design weaknesses that may result in safety hazards or reliability problems [35]. It is based on what- if analysis. The effects of failures are traced back to the system level. The components which might have a critical effect on the system are identified and are removed. Fault tree analysis (FTA)begins with the definition of an undesirable event and traces this event down through the system, to identify the basic causes. In systems definition, FMEA is a bottom-up procedure while the FTA is a top-down approach.

7.3 Failure Mode and Effects Analysis

A method of assessing system reliability is through a method called Failure Mode and Effects Analysis (FMEA). Failure is a fundamental concept of any reliability analysis. According to accepted standards, failure is defined as the termination of the ability of an item to perform a required function [34]. The reliability analysis results will thus depend on the analyst’s ability to identify all the required functions and hence all the failures of the item that is subject to analysis. Failure mode is an important concept in failure analysis. Failure mode is defined as the effect by which a failure is observed on a failure item. Thus the first and foremost function is to identify all the possible functions. Function is usually the normal operating characteristics of a particular item. Functions can be classified into many types [34]. An essential function is one which is the primary purpose of that particular component. A secondary function is one which acts as a kind of supporting one to the first function. Some functions are designed to protect other components.

These are called protective functions. Functional Analysis System Techniques are used to establish functional relationships. A decomposition strategy is used whereby functions at the top are disintegrated into the lowest level functions. The FAST diagram is then generated displaying a graphical picture of all the system functions at different levels, linking the individual functions together in the network [34]. Next a functional block diagram is generated which shows the design requirements of the item in a pictorial manner. After all the functions are identified, it is important to identify all the possible failure modes since each function can have several failure modes. A failure mode is a description of a fault. To identify the failure modes, we need to find the outputs from all functions. Failure modes can be classified in many ways. There are failures which prevent the required functioning for a small amount of time. Then there are failures which result

in loss of functioning for extended periods of time. There are failures which cannot be predicted and some which can be forecasted by regular inspection. Once the functions and failure modes are established, the next step is to identify potential downstream consequences when the failure mode occurs. This is usually a brainstorming activity. After consequences have been identified, they must be fit into the FMEA model as effects. After the effects and severity have been addressed, the next step is to identify the Causes of failure modes. Identification has to start with failure modes that have the most severe effects. A rating system is used to rate each failure mode. There are three parameters which are calculated namely the Occurrence rating, Severity rating and Detection rating [43]. Occurrence rating is the probability of the particular failure occurring. Severity rating analyzes the severity of the effects of the failure on the system performance. Lastly, Detection rating identifies the probability of identifying the failure.
Each of them is rated on a scale of 1-10. Then a final estimate called as Risk Product Number (RPN) is calculated which is the product of the three ratings [43]. A higher risk product number implies a greater possibility of failure. Thus this rating system allows us to identify the critical failures.

7.4 Fault Tree Analysis

Fault tree analysis is a risk assessment technique which starts from the consideration of specific system failure events referred to as the top events. The analysis proceeds by determining how these can be caused by individual of combined lower level failures or events [34]. This approach may involve a quantitative evaluation of probability of the various faults or failure events leading to the calculation of the probability of the top event. Also there is a possibility to single out a critical event, which contributes to the failure by itself. Another good method of evaluating the reliability of a system is through the use of reliability block diagrams. Generally when we calculate reliability, it is not confined just to a single component, but we are interested in evaluating the reliability of the system as a whole. Block diagrams are a good means of evaluating system reliability. System reliability is calculated by means of the calculus of probability. To apply the calculus to the systems, we must have knowledge of the probabilities of the components since they affect the reliabilities of the system.

In order to get reliability estimates, we need to find out the values for the life distribution of the parts. Usually, experiments in life testing of the components involve mounting the components on special equipments and subjecting the units to operation under specific conditions till failure is observed. The data obtained through this can be classified into two types. If we monitor the component continuously till it fails, we have exact information about the life of the component. The observed variable is a continuous variable and can assume any value in that time interval.

In the second type, units are observed only at discrete time points. The number of failures among the number of pieces tested is recorded for each time interval

System reliability calculations are based on two important operations:
1] As precise as possible a measurement of the reliability of the components.
2] The calculation of the reliability of some complex combination of these components.
Once we have the right figures for reliabilities of components, then we can perform exact calculations of system reliability.

7.5 Reliability Block Diagrams

A reliability block diagram is one which shows the operational relationship of various elements in the physical system, as regards the success of the overall system. It depicts the functional relationship and indicates which elements must operate successfully for the system to accomplish the intended functions.

7.5.1 Types of Block Diagrams

7.5.1.1 Series Block Diagram

Two blocks in a block diagram are said to be in series if the failure of either one of them causes the failure of the entire system. Thus it is imperative that all blocks must operate successfully in order for the system to operate successfully.

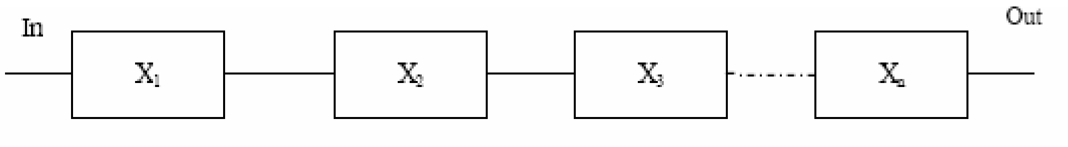


Figure 7.2: Series Block Diagram [35]

Let R_1 R_2……. R_n denote the reliabilities of components 1, 2,…, n respectively. Then, if the failures are statistically independent, the system reliability is given by [35]

$$R_s = \prod_{i=1}^{n} R_i$$

7.5.1.2 Parallel Block Diagram

Two blocks in a diagram are said to be in parallel if the operation of either one of the m results in the successful operation of the entire system.

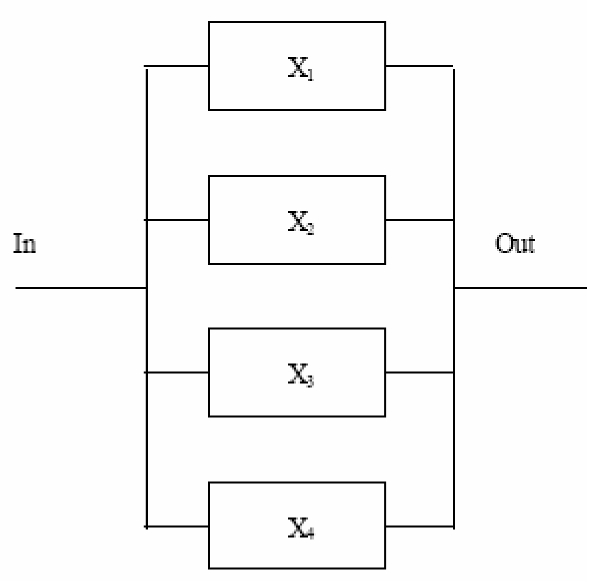


Figure 7.3: Parallel Block Diagram [35]

The parallel structure reliability is given by

$$R_p = 1 - \prod_{i=1}^{n} (1 - R_i)$$

A similar structure to a parallel block diagram is known as the "*k-out-of-m*" structure. The system is said to be successful even when *k-out-of-m* blocks perform correctly. Most systems behave in this manner so that there is some tolerance limits even if all components do not perform correctly. Series system and parallel systems can be represented by "*k=m*" and "*unity*" respectively

7.6 A General Framework for Assessing Reliability of the AGV system

In order to estimate the reliability of the AGV system, we need to have a clear definition of the system, sub system and the basic components. In General an AGV system can be thought of as having different sub systems. The guidance system which consists of embedded wire, chemical paint, etc or the navigation system used for self guided vehicles [42]. The controller which includes the hardware, software employed to control system operation including routing, scheduling, traffic management etc. the vehicular subsystem consists of one or more vehicles, which carry material and all related on-board controls [42]. The load station sub system which acts as the automatic interface between the vehicles and the workstations including automatic couple and uncouple, powered roller belt or chain transfer, etc [42].

In general the AGV system will fail if any of the subsystems fail. Thus going by the block diagram principle all the subsystems can be said to be acting in series. But for the systems, there are different criteria. A particular subsystem may perform well if a particular number of its components perform properly. Thus it can be said to be a "*k out of m*" system.

Thus Failure mode and effects analysis is a good way to identify the possible failure modes and its effects on the system. It will help us to identify which are the components which might lead to complete failure of the systems. Thus after identifying these components we can get a reliability estimate of each of them. Once we have those estimates, using block diagrams, we can calculate the reliability of the system. In order to estimate reliability of the components, we need to record certain parameters related to the component. We can summarize some of them as follows [42].

1] The amount of time the component is operating from the time it is installed. Also important are the operating conditions under which the component is performing its function. The time measures also relates to where the component is in its life cycle [42].

2] The failure data about the component can be grouped into several categories like the failure mode, cause of failure, time to repair the component, effect on the performance of the entire system [42].

Chapter 8

Results and Discussion

The results for the mathematical model were calculated by the help of MS Excel. The values for the function and variables are as follows:

$Z = 7000.20$

$x12=1$, $x23= 1$, $x34= 1$, $x48=1$, $x87=1$, $x71=1$, $x76=1$, $x65=1$, $x54= 1$

The purpose of improvement of any system is to minimize the cost of production, improvement in the quality of product and the parameters that can satisfy the customer. For theses, the system should be well designed & established. The problem for flow path design is the minimization of traveling distance between the pick off points and drop off points, as a result the cost of transportation can be minimized, and the traffic management also can be improved that will reduce the chances of collision and the traffic can run properly even in congested space. So the better transportation we need better control of movements of all vehicles and proper design of flow paths.

Chapter 9

Conclusions and future Work

Automated Guided Vehicles are nowadays an integral part of any Computer Integrated Manufacturing facilities. Their advantages in the area of material handling are numerous as described earlier. An efficiently designed guide path helps minimize time and distance and thus increasing the output. Mathematical models provide a good starting point for the system analysis. Simulation is the best means of solving these types of problems as it can add the dimension of time. Simulation is a good tool for sensitivity analysis and complex systems can be analyzed. Incorporating reliability is very important and is certainly a factor which can't be overlooked. The AGV being such a complex system, it is important to identify the different failure mechanism first. The focus needs to be on the critical components whose failure severely affects the functioning of the entire system. Failure Mode and Effects Analysis and Fault Tree Analysis are good methods to estimate this. Once this is done, the critical components can be identified. Then, operational data for these components can be collected and estimates of reliability can be found out. Since the AGV along with the guide path and other mechanisms forms a complete system, block diagrams help in arriving at a measure of system reliability. A future direction is to incorporate facility layout, location of pick-up drop-off points and reliability in choosing the actual guide path for the AGV system. This would result in better system performance and reliable estimates.

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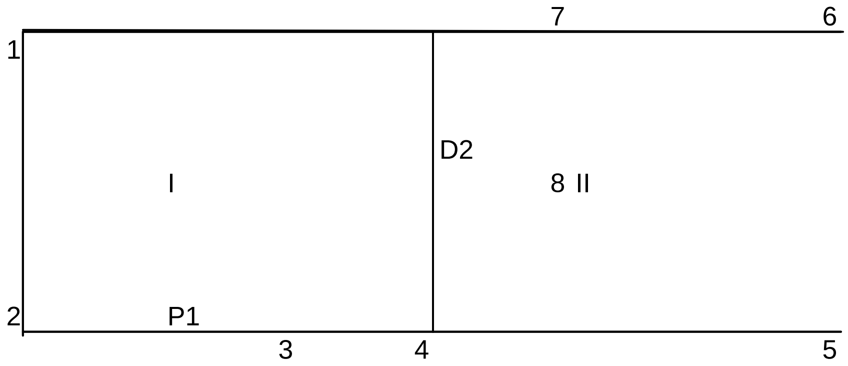

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5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0

Objective function to minimize distance	0

Constaraints

1] Unidirectionality constraint.

2] Reachability constraints.Each node should be reachable.

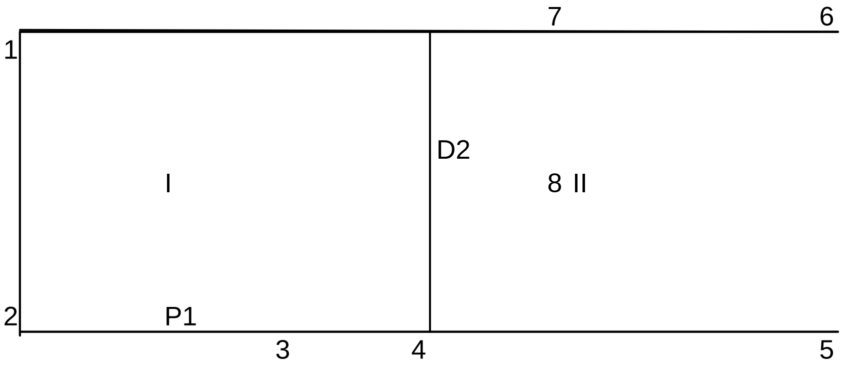
3] constraints to prevent a group of nodes from becoming a sink node

Constraint 1: Unidirectionality of arcs			
X12 + X21	0	X56 + X65	0
X17 + X71	0	X67 + X76	0
X23 + X32	0	X78 + X87	0
X34 + X43	0		
X48 + X84	0		
X45 + X54	0		

Constraint 2 :Each node should have atleast			
X12 + X17	0	X34 + X54	0
X71 + X21	0	X43 + X48	0
X12 + X32	0	X54 + X56	0
X21 + X23	0	X45 + X65	0
X32 + X34	0	X56 + X76	0
X23 + X43	0	X65 + X67	0

Constraint 3 : **Ensure that a group of nodes doesn't become a sink node**	
X67 + X54	0
X76 + X45	0

ɔne input arc and one output arc		
X76 + X71	0	
X67 + X17	0	
X78 + X48	0	
X87 + X84	0	



From to matrix

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4	0	0	0	0	0	0	0	1
5	0	0	0	1	0	0	0	0
6	0	0	0	0	1	0	0	0
7	1	0	0	1	0	1	0	1E-06
8	0	0	0	0	0	0	1	0

Objective function to minimize distance	7000.02

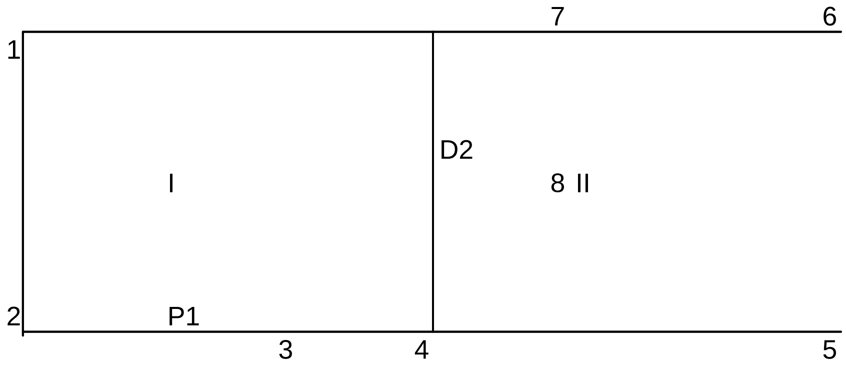
Constaraints
1] Unidirectionality constraint.
2] Reachability constraints.Each node should be reachable.
3] constraints to prevent a group of nodes from becoming a sink node

Constraint 1: Unidirectionality of arcs			
X12 + X21	1	X56 + X65	1
X17 + X71	1	X67 + X76	1
X23 + X32	1	X78 + X87	1.000001
X34 + X43	1		
X48 + X84	1		
X45 + X54	1		

Constraint 2 :Each node should have atleast			
X12 + X17	1	X34 + X54	1
X71 + X21	1	X43 + X48	3
X12 + X32	1	X54 + X56	1
X21 + X23	1	X45 + X65	1
X32 + X34	1	X56 + X76	1
X23 + X43	1	X65 + X67	1

Constraint 3 : **Ensure that a group of nodes doesn't become a sink node**		
X67 + X54	1	
X76 + X45	1	

one input arc and one output arc		
X76 + X71	1	
X67 + X17	2.000001	
X78 + X48	1	
X87 + X84	1.000001	



From to matrix

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4	0	0	0	0	0	0	0	1
5	0	0	0	1	0	0	0	0
6	0	0	0	0	1	0	0	0
7	1	0	0	1	0	1	0	1E-06
8	0	0	0	0	0	0	1	0

Objective function to minimize distance	7000.02

Constaraints

1] Unidirectionality constraint.

2] Reachability constraints.Each node should be reachable.

3] constraints to prevent a group of nodes from becoming a sink node

Constraint 1: Unidirectionality of arcs			
X12 + X21	1	X56 + X65	1
X17 + X71	1	X67 + X76	1
X23 + X32	1	X78 + X87	1.000001
X34 + X43	1		
X48 + X84	1		
X45 + X54	1		

Constraint 2 :Each node should have atleast c			
X12 + X17	1	X34 + X54	1
X71 + X21	1	X43 + X48	3
X12 + X32	1	X54 + X56	1
X21 + X23	1	X45 + X65	1
X32 + X34	1	X56 + X76	1
X23 + X43	1	X65 + X67	1

Constraint 3 : **Ensure that a group of nodes doesn't become a sink node**		
X67 + X54	1	
X76 + X45	1	

one input arc and one output arc		
X76 + X71	1	
X67 + X17	2.000001	
X78 + X48	1	
X87 + X84	1.000001	

Microsoft Excel 10.0 Answer Report
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Report Created: 7/5/2007 3:10:24 AM

Target Cell (Min)

Cell	Name
F25	Objective function to minimize distance

Adjustable Cells

Cell	Name
B15	
C15	
D15	
E15	P1
F15	
G15	D2
H15	II
I15	
B16	
C16	
D16	
E16	P1
F16	
G16	D2
H16	II
I16	
B17	
C17	
D17	
E17	P1
F17	
G17	D2
H17	II
I17	
B18	
C18	
D18	
E18	P1
F18	
G18	D2
H18	II
I18	
B19	
C19	
D19	
E19	P1
F19	
G19	D2
H19	II

I19	
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C20	
D20	
E20	P1
F20	
G20	D2
H20	II
I20	
B21	
C21	
D21	
E21	P1
F21	
G21	D2
H21	II
I21	
B22	
C22	
D22	
E22	P1
F22	
G22	D2
H22	II
I22	

Constraints

Cell	**Name**
B33	X12 + X21 3] constraints to prevent a group of nodes from becoming a sink node
B34	X17 + X71 3] constraints to prevent a group of nodes from becoming a sink node
B35	X23 + X32 3] constraints to prevent a group of nodes from becoming a sink node
B36	X34 + X43 3] constraints to prevent a group of nodes from becoming a sink node
B37	X48 + X84 3] constraints to prevent a group of nodes from becoming a sink node
D33	X56 + X65
D34	X67 + X76
D35	X78 + X87
G33	X12 + X17 D2
G34	X71 + X21 D2
G35	X12 + X32 D2
G36	X21 + X23 D2
G37	X32 + X34 D2
G38	X23 + X43 D2
I33	X34 + X54 + X84
I34	X43 + X48 + X45
I35	X54 + X56
I36	X45 + X65
I37	X56 + X76
I38	X65 + X67
K33	X76 + X71 + X78
K34	X67 + X17 + X87

K35	X78 + X48
K36	X87 + X84
B43	X67 + X54 3] constraints to prevent a group of nodes from becoming a sink node
B44	X76 + X45 3] constraints to prevent a group of nodes from becoming a sink node
B38	X45 + X54 3] constraints to prevent a group of nodes from becoming a sink node
B15	
C15	
D15	
E15	P1
F15	
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I22	

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