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**Flow Path Design and Reliability of Automated Guided
Vehicles in material handling**

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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 automatic guided vehicle system is an important element in the computer integrated manufacturing facility. 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 flow path design and reliability of AGV system. Various journal articles were reviewed for this purpose. 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.

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I would like to dedicate this thesis to my parents, who have always stood behind me and supported me in whatever I have pursued.

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Chapter 1

Introduction

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 component can vary from 10-80% of the total cost. 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.

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, miniload, deep lane and storage carousel systems.

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, Sweden. 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:

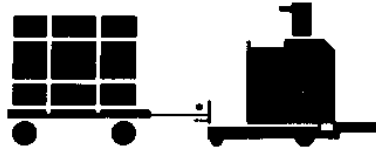


Figure 1. Towing Vehicles [1]

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 be taken 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:



Figure 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:



Figure 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:

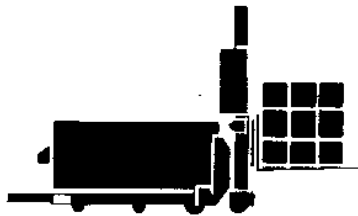


Figure 4. AGV Fork Truck [1]

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 to 2.3 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:



Figure 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 work stations 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 by 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 which have many on board controls [1].

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 miniload system for order picking and distribution.

Chapter 3

Flow Path Design Issues

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

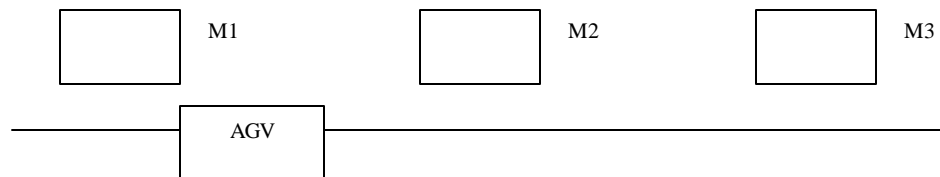


Figure 6. Single line AGV systems [49]

3.1.2 Single Loop AGV Systems

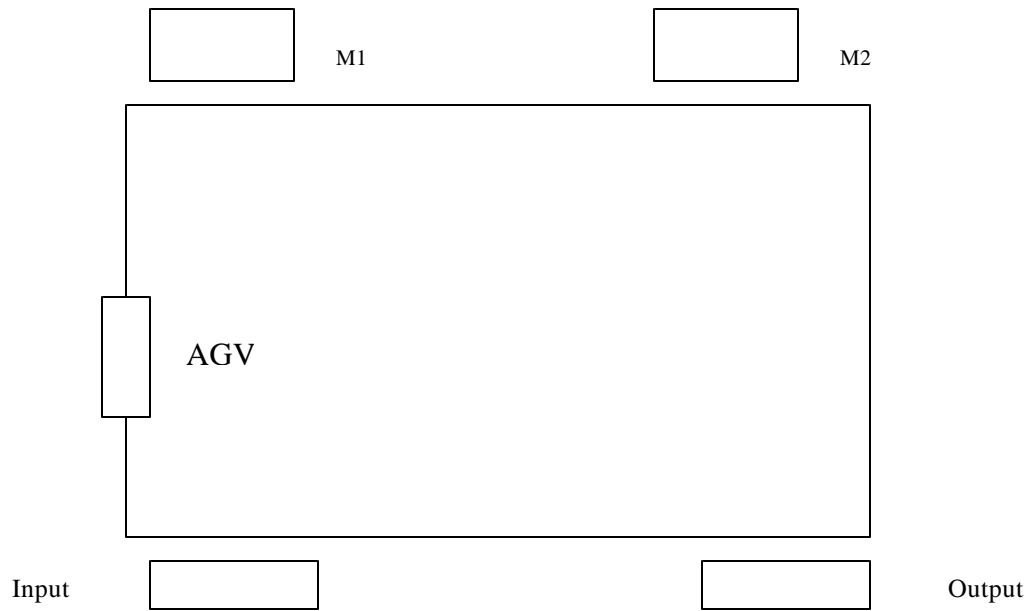


Figure 7. Single Loop AGV Systems [49]

3.1.3 Ladder type AGV systems

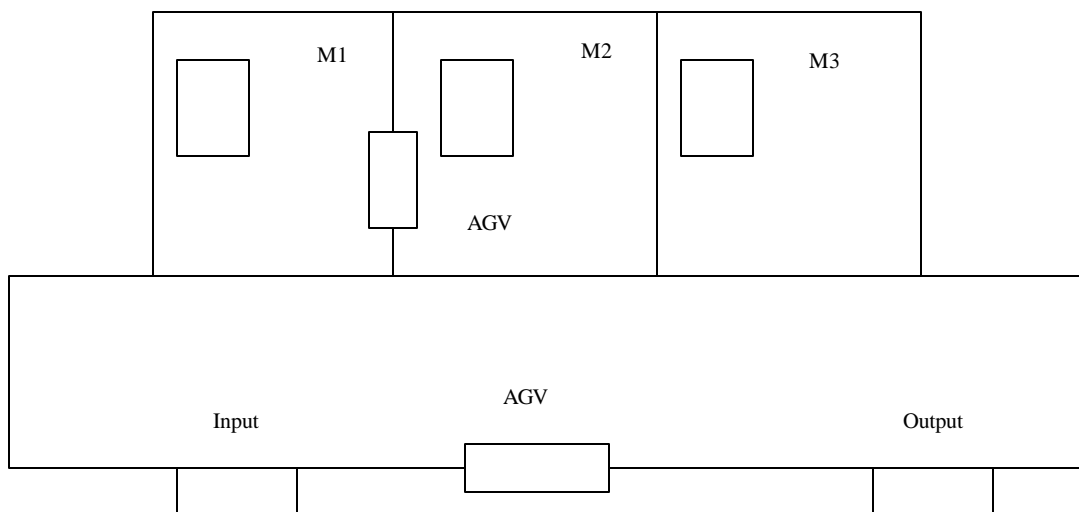


Figure 8. Ladder type AGV System [49]

3.1.4 Complex AGV network system

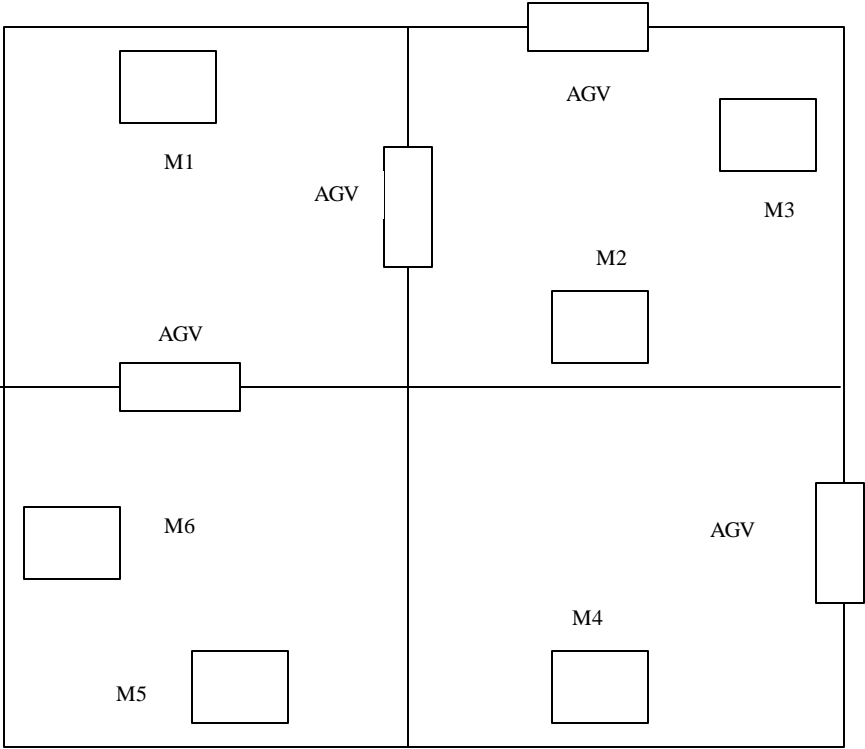


Figure 9. Complex AGV Network System [49]

Chapter 4

Literature Review

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 maybe 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

Euclidian 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 travel in 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 to the 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 atleast 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. Majety 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 AGV 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.

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 switchable 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 uni-directional 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 switchable 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 uni-directional and bi-directional systems. In the entire network, some aisles may operate on a bi-directional mode whereas others strictly operate on a uni-directional mode. Usually less used aisles are potential candidates for the bi-directional 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 uni-directional 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 uni-directional.

All the above flow path designs require a From-To chart to estimate the total loaded travel distance. In a typical modern manufacturing firm the 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 in compliance 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 pick up and drop off points for each department [31]. The distance between points is as shown on the line segments.

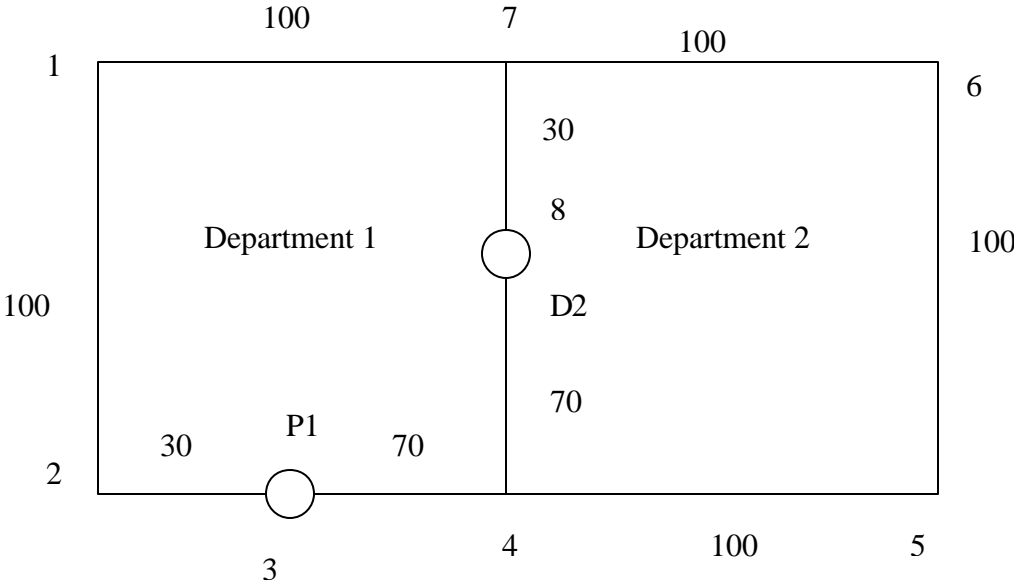


Figure 10: Hypothetical Layout [31]

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.

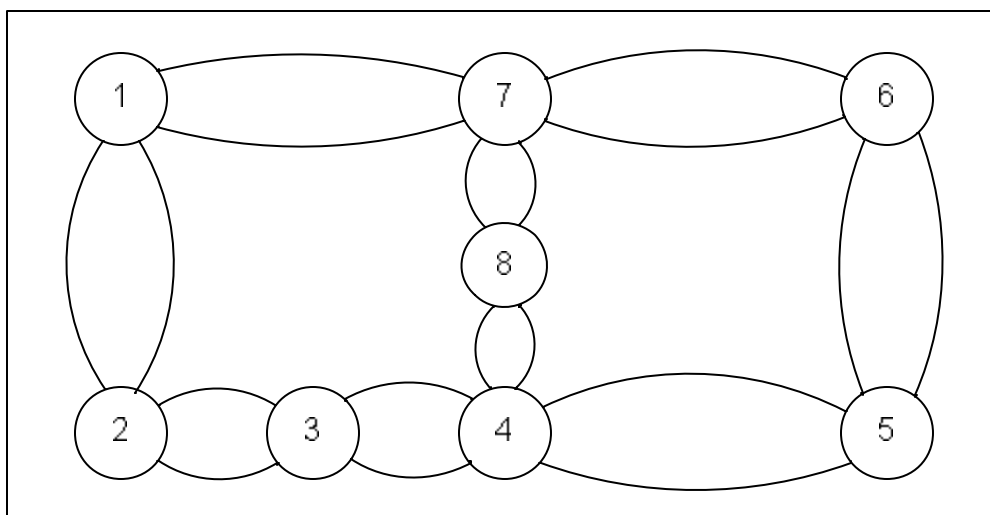


Figure 11: Node Arc Network

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 is 400 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:

$$x_{12}+x_{21} = 1 \quad (2)$$

$$x_{23}+x_{32} = 1 \quad (3)$$

$$x_{34}+x_{43} = 1 \quad (4)$$

$$x_{45}+x_{54} = 1 \quad (5)$$

$$x_{48}+x_{84} = 1 \quad (6)$$

$$x_{56}+x_{65} = 1 \quad (7)$$

$$x_{67}+x_{76} = 1 \quad (8)$$

$$x_{71}+x_{17} = 1 \quad (9)$$

$$x_{78}+x_{87} = 1 \quad (10)$$

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

$$x_{12}+x_{17} \geq 1 \quad (11)$$

$$x_{71}+x_{21} \geq 1 \quad (12)$$

$$x_{12}+x_{32} \geq 1 \quad (13)$$

$$x_{21}+x_{23} \geq 1 \quad (14)$$

$$x_{32}+x_{34} \geq 1 \quad (15)$$

$$x_{23}+x_{43} \geq 1 \quad (16)$$

$$x_{34}+x_{54}+x_{84} \geq 1 \quad (17)$$

$$x_{43}+x_{48}+x_{45} \geq 1 \quad (18)$$

$$x_{54}+x_{56} \geq 1 \quad (19)$$

$$x_{45}+x_{65} \geq 1 \quad (20)$$

$$x_{56}+x_{76} \geq 1 \quad (21)$$

$$x_{65}+x_{67} \geq 1 \quad (22)$$

$$x_{76}+x_{78}+x_{71} \geq 1 \quad (23)$$

$$x_{67}+x_{17}+x_{87} \geq 1 \quad (24)$$

$$x_{78}+x_{48} \geq 1 \quad (25)$$

$$x_{87}+x_{84} \geq 1 \quad (26)$$

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:

$$x_{67}+x_{54} \geq 1 \quad (27)$$

$$x_{76}+x_{45} \geq 1 \quad (28)$$

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.

$$x_{12}=1, x_{23}=1, x_{34}=1, x_{48}=1, x_{87}=1, x_{71}=1, x_{76}=1, x_{65}=1, x_{54}=1,$$

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

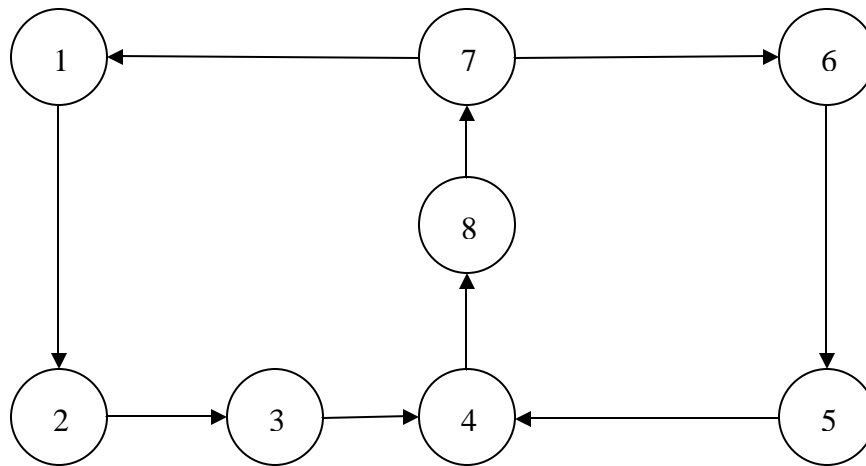


Figure 12: Final guide path design

Although in this case it was very obvious that the vehicle would travel along the path 3-4 and 4-8 as 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 an overview of the use of mathematical techniques.

Chapter 6

Reliability Analysis in the design of flow path for AGVS:

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.

6.1 Reliability Concepts

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.

Reliability is defined as the ability of an item to perform the required 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]:

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

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

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

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]:

$$F(t) = 1 - \frac{n_s(t)}{n_0} = \frac{n_f(t)}{n_0} \quad (31)$$

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 $R(t) = e^{-\int_0^t I(t) dt}$ where, $I(t)$ 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.

6.2 Hazard Rate Curve:

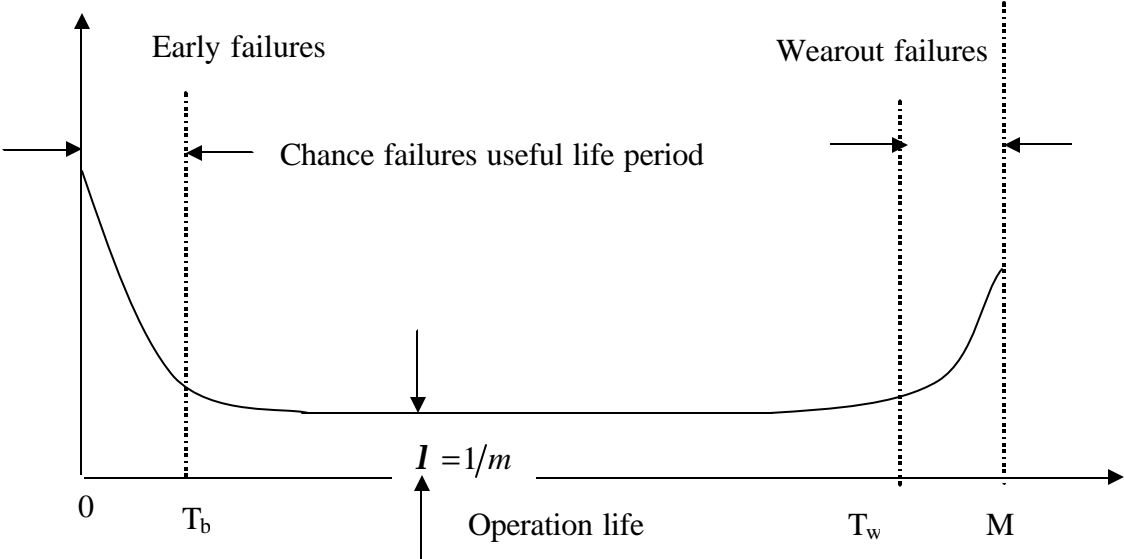


Figure 13: Hazard rate curve [35]

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. 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 a 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.

6.3 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.

6.4 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 or 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.

6.5 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.

Types of Block Diagrams:

A] 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.

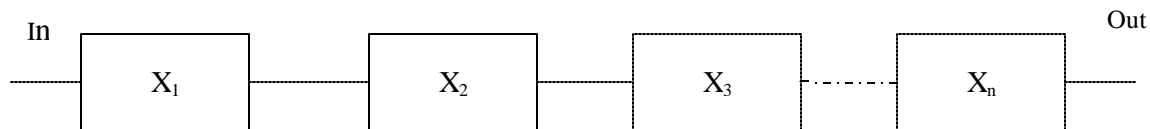


Figure 14: Series Block Diagram [35]

Let R_1, R_2, \dots, 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]

$$R_s = \prod_{i=1}^n R_i \quad (32)$$

B] 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.

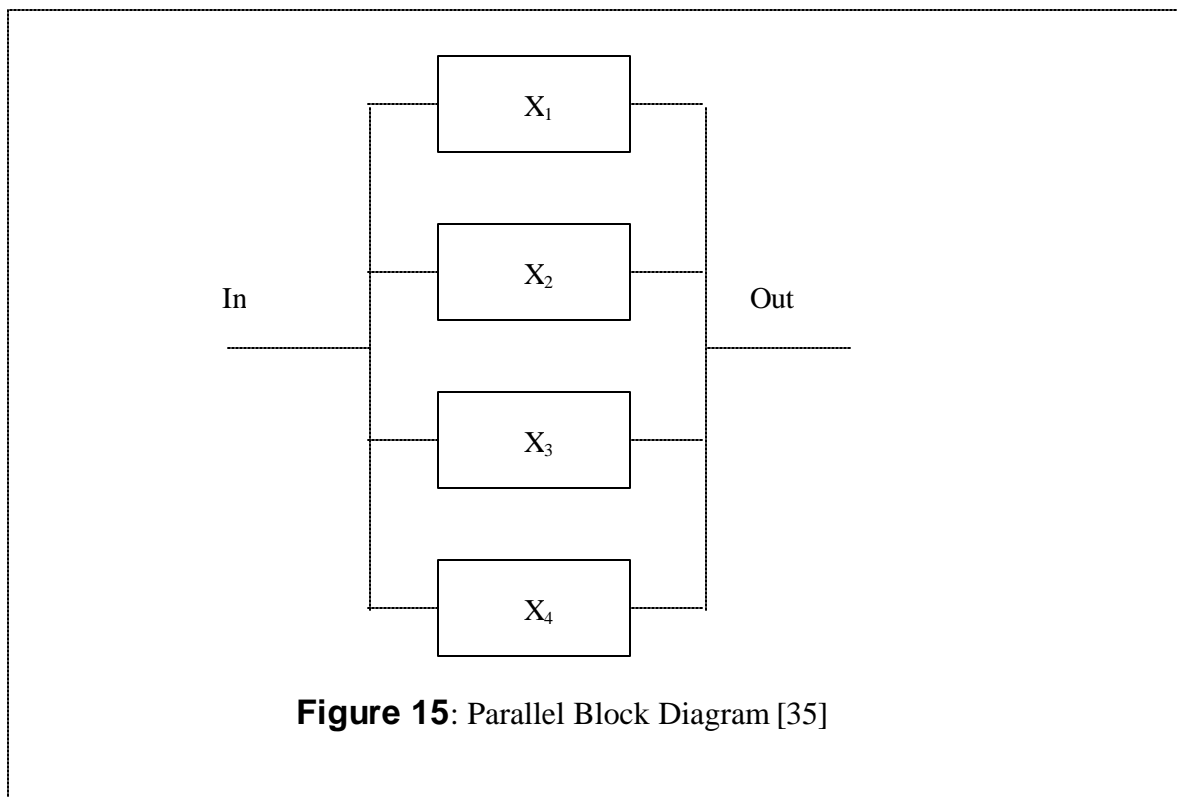


Figure 15: Parallel Block Diagram [35]

The parallel structure reliability is given by

$$R_p = 1 - \prod_{i=1}^n (1 - R_i) \quad (33)$$

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

6.6 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 7

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.

Excel Solver Formulation

						7		6	
	1								
			I		D2		II		
					8				
	2		P1						
		3		4				5	
From- To Matrix									
	1	2	3	4	5	6	7	8	
1	0	0	0	0	0	0	0	0	
2	0	0	0	0	0	0	0	0	
3	0	0	0	0	0	0	0	0	
4	0	0	0	0	0	0	0	0	
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							
Constraints									
1) Unidirectionality Constraints.									
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		Constraint 2: Each node should have atleast one input arc and one output arc							
$x_{12}+x_{21}$	0	$x_{56}+x_{65}$	0	$x_{12}+x_{17}$	0	$x_{34}+x_{54}+x_{84}$	0	$x_{76}+x_{71}+x_{78}$	0
$x_{17}+x_{71}$	0	$x_{67}+x_{76}$	0	$x_{71}+x_{21}$	0	$x_{43}+x_{48}+x_{45}$	0	$x_{67}+x_{17}+x_{87}$	0
$x_{23}+x_{32}$	0	$x_{78}+x_{87}$	0	$x_{12}+x_{32}$	0	$x_{54}+x_{56}$	0	$x_{78}+x_{48}$	0
$x_{34}+x_{43}$	0			$x_{21}+x_{23}$	0	$x_{45}+x_{65}$	0	$x_{87}+x_{84}$	0
$x_{48}+x_{84}$	0			$x_{32}+x_{34}$	0	$x_{56}+x_{76}$	0		
$x_{45}+x_{54}$	0			$x_{23}+x_{43}$	0	$x_{65}+x_{67}$	0		
Constraint 3:									
Ensure that a group of nodes dosent become a sink node									
$x_{67}+x_{54}$	0								
$x_{76}+45$	0								

File Edit View Insert Format Tools Data Window Help Type a question for help

F25 $=50*((140*E17*118)+(400*E17*121)+(260*C17*121)+(600*C17*118))$

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
13	From- To Matrix													
14		1	2	3	4	5	6	7	8					
15	1	0	0	0	0	0	0	0	0					
16	2	0	0	0	0	0	0	0	0					
17	3	0	0	0	0	0	0	0	0					
18	4	0	0	0	0	0	0	0	0					
19	5	0	0	0	0	0	0	0	0					
20	6	0	0	0	0	0	0	0	0					
21	7	0	0	0	0	0	0	0	0					
22	8	0	0	0	0	0	0	0	0					
23														
24														
25	Objective function to minimize distance					0								
26														
27	Constraints													
28	1) Unidirectionality Constraints.													
29	2) Reachability constraints. Each node should be reachable.													
30	3) Constraints to prevent a group of nodes from becoming a sink node.													
31														
32	Constraint 1: Unidirectionality of arcs			Constraint 2: Each node shc										
33	$x_{12}+x_{21}$	0	$x_{66}+x_{65}$	0	$x_{12}+x_{17}$	0	$x_{34}+x_{43}$							
34	$x_{17}+x_{71}$	0	$x_{67}+x_{76}$	0	$x_{71}+x_{21}$	0	$x_{43}+x_{54}$							
35	$x_{23}+x_{32}$	0	$x_{78}+x_{87}$	0	$x_{12}+x_{32}$	0	$x_{54}+x_{65}$							
36	$x_{34}+x_{43}$	0			$x_{21}+x_{23}$	0	$x_{45}+x_{56}$							
37	$x_{48}+x_{84}$	0			$x_{32}+x_{34}$	0	$x_{56}+x_{65}$							
38	$x_{45}+x_{54}$	0			$x_{23}+x_{43}$	0	$x_{65}+x_{76}$							
39														
40														
41	Constraint 3:													
42	Ensure that a group of nodes dosent become a sink node													
43	$x_{67}+x_{54}$	0												
44	$x_{76}+45$	0												
45														
46														

Solver Parameters

Set Target Cell: Solve

Equal To: Max Min Value of: Close

By Changing Cells: Guess

Subject to the Constraints:

- Add
- Change
- Delete
- Reset All
- Help
-

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