AGV Path Planning Using Dijkstra's Routing Algorithm

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Abstract— Automated guided vehicles (AGVs) are widely used in container terminals for the movement of material from shipping to the yard area and vice versa. Research in this area is directed toward the development of a path layout design and routing algorithms for container movement. The problem is to design a path layout and a routing algorithm that will route the AGVs along the bi-directional path so that the distance traveled will be minimized. This thesis presents a bi-directional path flow layout and a routing algorithm that guarantee conflict-free, shortest time routes for AGVs. Based on the path layout, a routing algorithm and sufficient, but necessary conditions, mathematical relationships are developed among certain key parameters of vehicle and path. A high degree of concurrency is achieved in the vehicle movement. The routing efficiency is analyzed in terms of the distance traveled and the time required for AGVs to complete all pickup and drop-off jobs. Numerical results are presented to compare performance of the proposed model. The research provides the foundation for a bi-directional path layout design and routing algorithms that will aid the designer to develop complicated path layouts.

Keywords- Automated guided vehicles, container logistics, conflict-free routing.

I. INTRODUCTION

Automated guided vehicles (AGVs) are self-driven vehicles used to transport material from one location on the facility floor to another without any accompanying operator, and are widely used in material handling systems, flexible manufacturing systems, and container handling applications. With the advance of technology, more sophisticated machines are available, which considerably reduce machining and internal setup time. The aim of production planning has shifted from fast production to the efficient transportation of material between the workstations and in and out of storage. Flexible material handling systems are required to perform an efficient routing of material. The use of AGVs increases flexibility, since the flow path can easily be reconfigured to accommodate production changes. The design of material handling guide path has a significant implication on the overall system performance and reliability, since it has a direct impact on the travel time, the installation cost, and the complexity of the control system software.

As one of the enabling technologies, scheduling and routing of AGVs has attracted considerable attention, and many scheduling and routing algorithms for AGVs have been proposed. Routing algorithms are classified into two categories, namely, general path topology and specific path topology. While designing scheduling and routing algorithms, a number of interrelated decisions must be made; these include determining the guide path layout and characteristics, the number and type of vehicles, the location, type, and buffer capacities of pickup/deposit (P/D) stations, routing algorithms, the type of communications, the type and characteristics of the control system (e.g., centralized, decentralized, zone or distributed, etc.). In order to improve the system in terms of throughput and response time, good routing algorithms and path layouts are necessary. Much research is directed towards the development of routing algorithms and path layouts for a specific application. Current research in this area is directed toward the container handling application. Recent AGV research has focused on container handling logistics. In a container port, an AGV originates from a location near one of the container cranes at a container ship, with a specific destination within the yard area. Similarly, an AGV could reverse the direction of its travel.

Here, we consider the following routing problem. AGVs are assumed to originate from fixed

locations in a bi-directional path layout, and they are directed to a different location on the path. The AGVs can move in both directions on the same lane without turning around, as shown in Figure 1(b). Every AGV has a distinct origin as well as a distinct destination. The objective is to efficiently route all AGVs, such that they reach their destinations without conflict or congestion and within the shortest possible time. Presently, the application is being studied at a Singapore container port. However, no satisfactory solution to the problem of scheduling and routing of AGVs has been found. Hence, there is a need to discover the problem solution both in theory and in a realistic application.

The proposed research focuses on the bi-directional path layout and routing algorithm for a container handling application. A bi-directional path layout consists of two parallel lanes, L_1 and L_2, and a bridge connecting the lanes at the workstations. Vehicles are allowed to travel in both directions, and the functionality is accomplished by providing a bridge connecting two parallel lanes at the P/D station. All P/D jobs are divided into two disjoint subsets depending on the positions of the P/D jobs. Accordingly, AGVs are also classified into two disjoint subsets, which will run parallel along a bi-directional path layout in opposite directions.

In this system, the task and routes for each vehicle are determined in advance as part of the system design, not part of the controller planning function, and the system is controlled thorough a centralized control mechanism. Thus, the possible communication between an AGV and the central controller is kept to a minimum. Also, even if the loading and unloading time is not uniform, it does not affect the routing, as these operations are scheduled at the beginning and end of the P/D jobs. The proposed path layout and routing algorithm will route AGVs without conflict, and within the shortest possible time. AGVs have pervasive applications in flexible manufacturing systems (FMS). AGVs are used to move pallets, parts, and raw material among the workstations. AGV systems are used in docking terminal operations for the storage and retrieval of containers. AGVs used as a part of flexible manufacturing systems can be utilized in either of the two possible modes, namely, (a) carriers and (b) careers and workstations.

The vehicles, used as carriers, provide the transportation medium between the workstations. On arrival at the workstation, the load is delivered on the load stand. When the load processing is finished, the vehicle is called to transport the load to the next station.

The vehicles, used as carriers and mobile workstations, provide transportation service and also function as mobile workstations. The vehicle picks up a load and as it advances along the line, the operation is performed on the loaded parts. This application can be found in the automotive industry.

In recent years, AGVs have been used in seaports for container handling that greatly improves the overall operational efficiency. Container shipping has become a popular means to convey high-value products. Each container vessel entering the port is assigned to a gantry crane. All the containers assigned for transshipment are discharged from the vessel onto AGVs by gantry cranes; the AGVs then transport the containers to specific storage locations in the yard area. Outgoing containers are uploaded onto the ship after the majority of incoming ones have been unloaded from the vessel. The outgoing containers are carried by AGVs from the yard to the quay area, where they are loaded onto the ship by quay crane.

II. MODEL DEVELOPMENT

This section of research describes the formulation of an AGV system model, which consists of a bi-directional path layout and a routing algorithm. A bi-directional path layout is designed to formulate the model. In order to simplify solution to the model, we make some definitions and assumptions. The bi-directional path layout, assumptions, and definitions are as described below. The bi-directional path layout with N number of pickup and drop-off stations placed along lane L_1 is as shown in Figure 3. An AGV picks up a load from a workstation and drops to another workstation. Once the route is determined, only one AGV can drop the load at any workstation. The bi-directional path layout given by Qiu and Hsu (2001) is given in Figure 2.
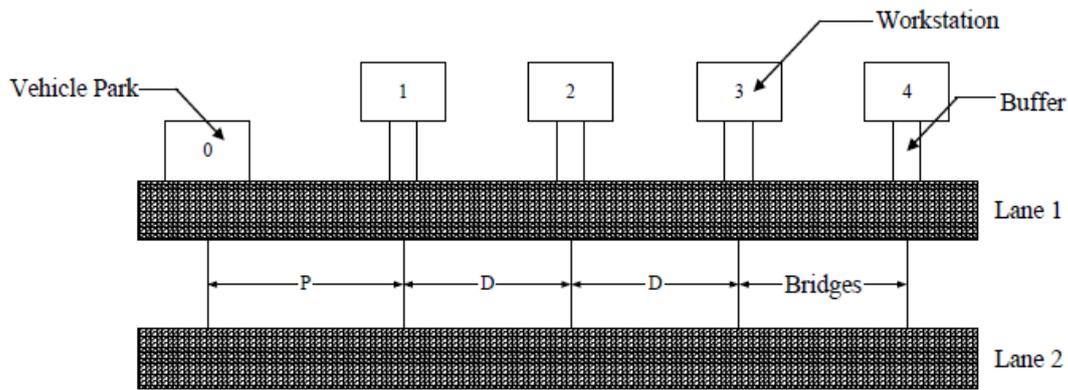
Figure 2. Bi-directional path layout

In the path layout (Qiu and Hsu 2001) as shown in Figure 2, the vehicle park (0), where AGVs rest initially, is provided. As the P/D task is assigned to each vehicle, the vehicle moves from the park to a source workstation. This empty travel trip (deadheading) reduces the routing efficiency, and hence, the system throughput. In the proposed path layout, park can be removed, and the buffer space can be enlarged, where park will be provided for the AGVs. By this modification, empty travel trip time can be saved. Also, the floor space utilization will remain the same, increasing the system throughput. The new bi-directional path layout has been proposed as shown in Figure 3. The proposed path layout is as below:
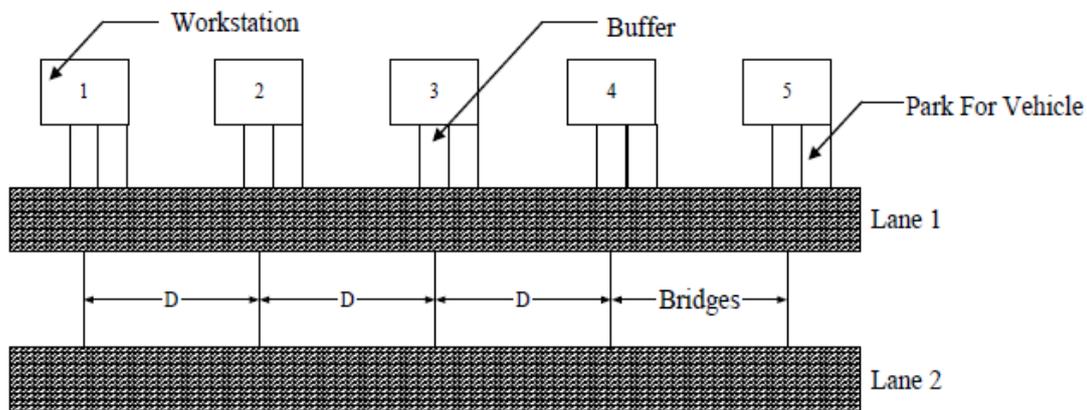

Figure 3. The proposed path layout

(1) There are two parallel lanes L_1 and L_2 . Parking space and buffer is provided at each station along lane L_1 . For simplicity in presentation, we assume that a workstation lies off the main travel area and is only entered by an AGV, when a pickup or drop-off has to be made. A vehicle can stop at the buffer to either pick up or drop-off the load. A buffer is an area off the main travel space where an AGV can wait, usually to permit another AGV to move on the path.

(2) There is a bridge connecting two lanes at each station. The points, where bridges are connected to lane L_2 are referred as mirror stations, denoted by $N+1$, $N+2$, L, $N+N$. Thus, a bridge can be identified by an ordered pair (i , $N + i$). However, there is no buffer storage at the mirror stations.

(3) The lanes and bridges are bi-directional, and the distance between any two adjacent stations is equal (D).

(4) The width of the lanes and bridges is such that the only one vehicle can pass at a time. However, a vehicle can pass by a station, while loading or unloading process of another vehicle is being carried out in the buffer.

(5) The zone length is vehicle length plus twice the safety allowance, which will protect the vehicle from collision.

The aim of route planning is to achieve maximum throughput for an AGV operations. The focus is to find an optimal (the shortest possible time path) and feasible route for every single AGV.

Three aspects are considered while making the routing decision: (a) it should detect whether there exists a route which could lead the vehicle from its origin to the destination, (b) the route selected for an AGV must be feasible, i.e., the route must be congestion, conflict, and deadlock free (Taghaboni and Tanchoco 1995), and (c) the route must be optimal (minimize idling runs of vehicles). The routing algorithm proposed by Qiu and Hsu (2001) was used as a basis for parallel processing of AGVs along the bi-directional. According to the proposed path layout, the new dijikstra algorithm is developed. Based on the path layout (Figure 3) and assumptions, the shortest path algorithm is given as below.
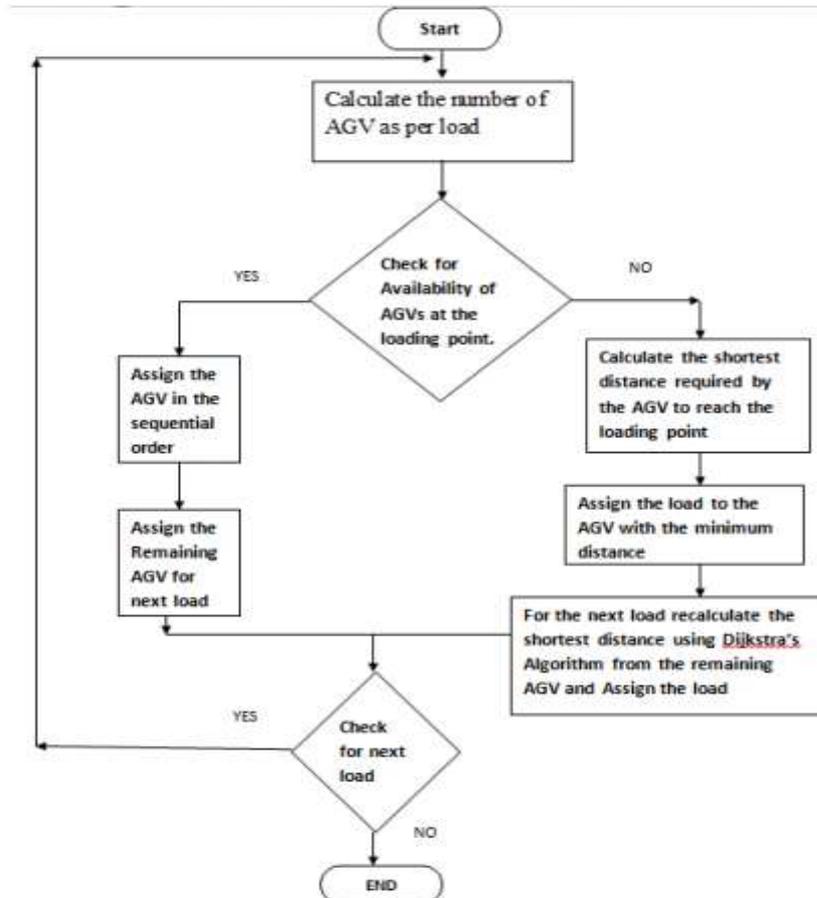
Figure 4. Routing Algorithm Flow Chart

AGV routing problem has been conceived to represent the system, which maps the proposed algorithm. Consider a container port system with fourteen serial workstations. Let a set of workstations be placed at an interval of 50 ft. The length of the bridge (L_b) is 2 ft, and the velocity reduction factor (r) on the bridge is taken as 1.2. Let the length of an AGV that protects it from collision be 1.5 ft. Consider a situation, where the load is coming from and going to the stations shown in the following set:

$J = \{(1,8), (2,11), (5,12), (6,9), (4,1), (12,6), (8,5), (9,2), (7,3), (10,4)\}$.

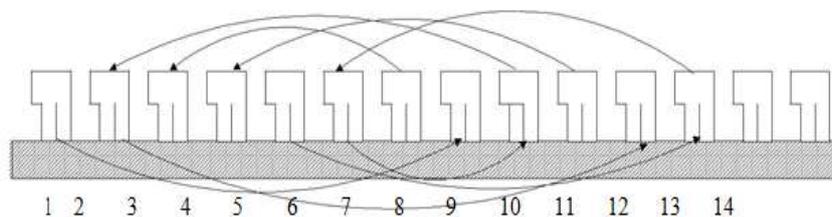The problem is to route AGVs along the bi-directional path layout, so that the distance traveled will be minimum.

Figure. 5. Bi-directional AGV flow path

The step-by-step procedure of the proposed algorithm for the problem stated in example 1 is given below.

Step 1. Loading is done at the respective station. Based on the positions of P/D jobs, the given set of jobs is classified into two disjoint subsets. Accordingly, AGVs are classified into two disjoint subsets. The two groups of AGV move in the opposite directions as shown in Figure 4.

$J^+ = \{(1,8), (2,11), (5,12), (6,9)\}$, and $J^- = \{(4,1), (12,6), (8,5), (9,2), (7,3), (10,4)\}$. Step 2. Since $J^+ < J^-$, all AGVs in V^- advance along lane L_1 from the *right* side to the *left* side, while AGVs in V^+ cross the bridge, reach their mirror-pickup stations, and advance along lane L_2 in opposite directions.

Step 3. When AGVs moving on lane L_1 reach their destinations, they immediately start unloading and stay in buffers after completion. However, AGVs on lane L_2 reach their mirror stations, cross the bridge to reach their drop-off stations; drop loads off and stay in buffers.

Step 4. Since $C_{AGV} \neq \varphi$, we have,

$C_{AGV} = \{3,11\}$, and $E_{AGV} = \{4,7\}$.

Accordingly, $C_{AGV}^+ = \{3,4\}$, and $C_{AGV}^- = \{11,7\}$.

Step 5. Route AGVs in W_{AGV}^+ set along lane L_1 from the *left* side to the right side, and AGVs in W_{AGV}^- set along lane L_1 from the *right* side to the *left* side. Once an AGV moves from a drop-off station to the nearest station (park), AGV will rest at that station until the scheduling for the next operation is done.
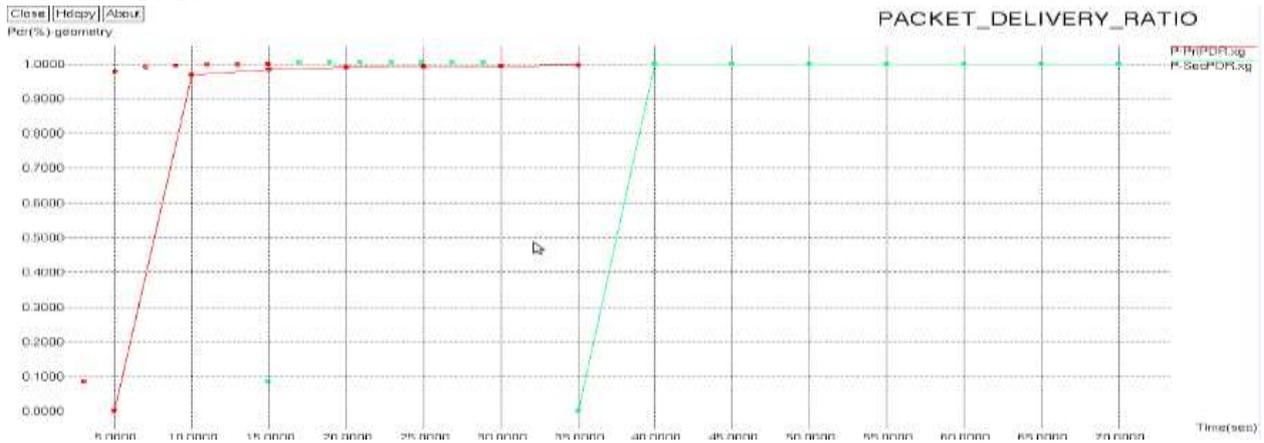
III. SIMULATION RESULTS

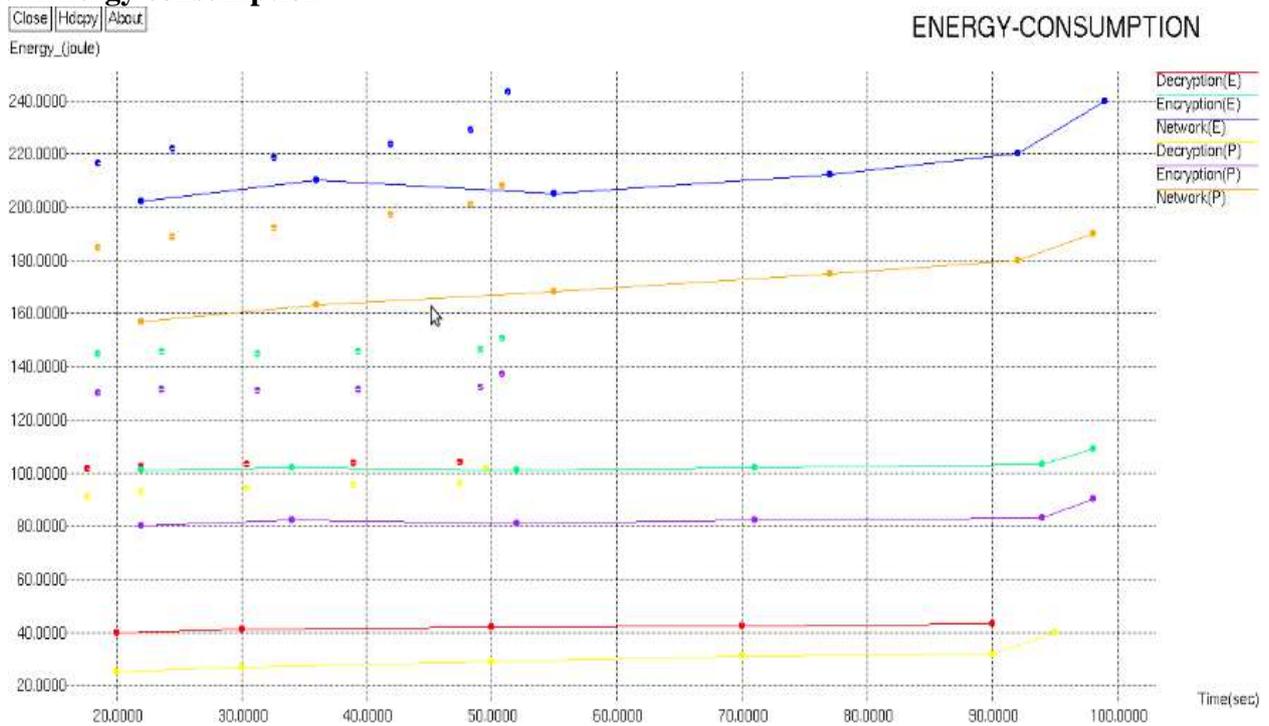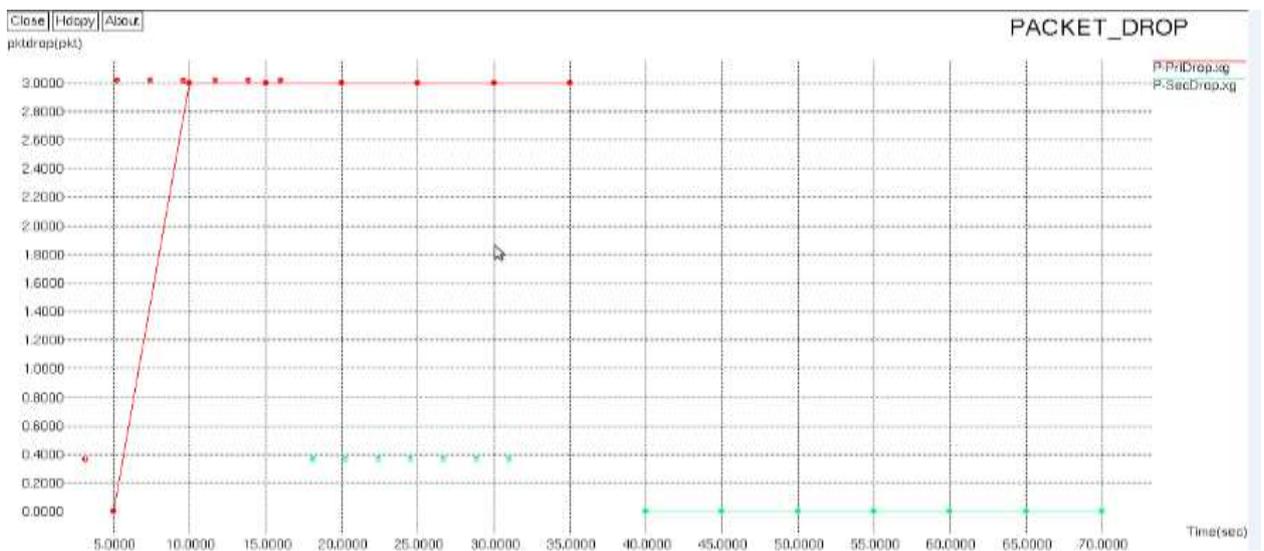### 1. delay
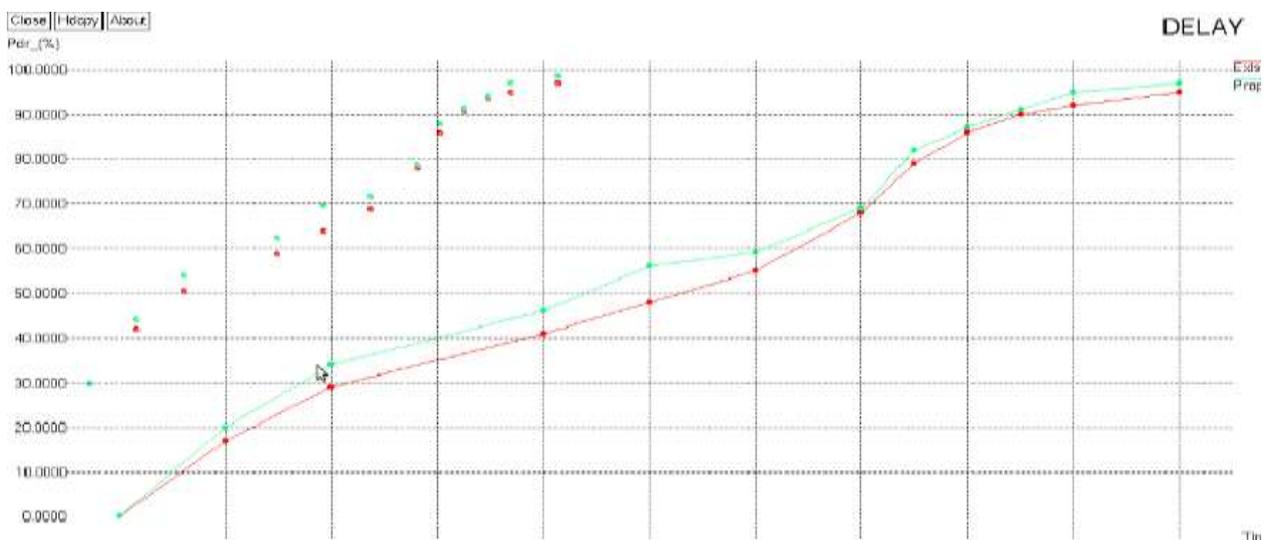
2. Energy
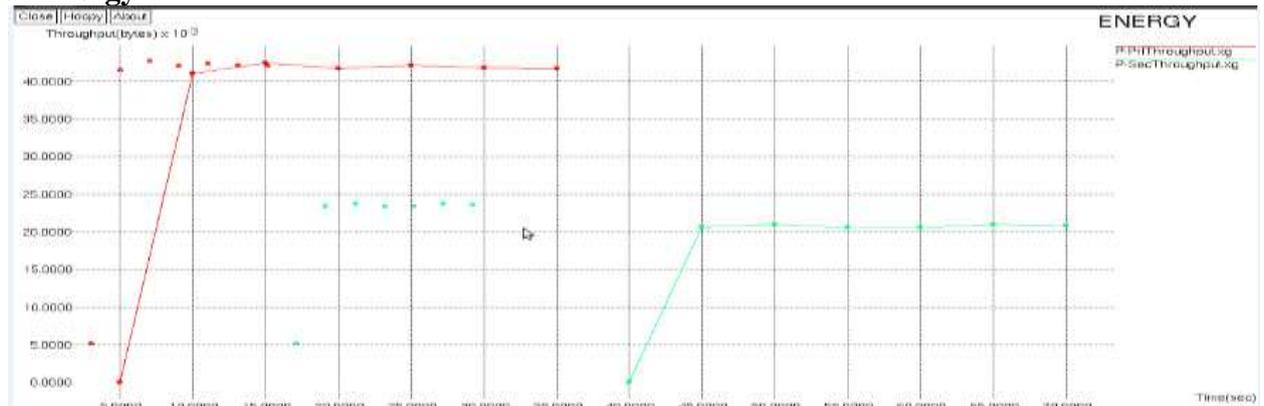
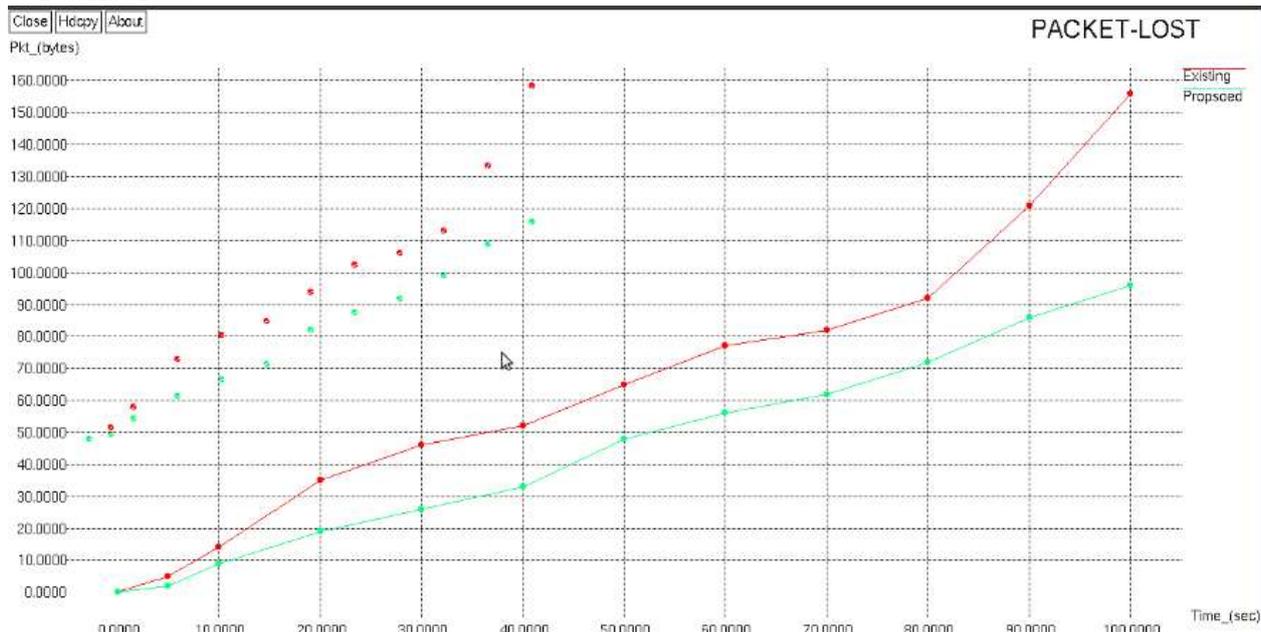### 3. Packet ratio

4. Energy consumption

5. Packet drop

6. Packet loss

III. CONCLUSION

The aim of this research is to achieve higher transportation efficiencies, thereby driving the logistics cost down. The AGV routing and network design is a key factor in the optimization of material transportation in a container terminal. This thesis has proposed a mathematical model for conflict-free routing of AGVs in a bi-directional path layout. The model offers a trade-off between the network optimization and efficient routing. The path layout and routing algorithm for a specific path topology are presented to route AGVs within the shortest possible time. The time required for the loading and unloading process creates no conflict, because these operations are carried out either at the beginning or at the end of operation. As AGVs are placed at each workstation, the AGV travel time is reduced, and the system throughput is increased. The advantage of the model is best realized when the ideal situation (all the vehicles move along lane L_1 and only one vehicle moves to the nearest workstation after drop-off operation) occurs, and the number of P/D task increases. The model shows that the inclusion of park at the respective stations leads to a large reduction in the travel distance, and ultimately reduces the logistics cost. The proposed model may be regarded as a framework suitable for extension and application to a container terminal.

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