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MODELING AND SIMULATION OF THE DISASSEMBLY OPERATIONS AND THE ASSOCIATED COMMUNICATIONS NETWORK

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ABSTRACT

Recently work has been done about simulation and analysis of manufacturing operations combined with the communications network it operates with. However no such methodology exists in disassembly line context. In this paper, we attempt to enhance their approach and apply it for a disassembly line. To this end, we look at a disassembly line system as a combination of physical processing (performed by machines) and information processing (performed by computer systems), and formulate a model to analyze the system behavior and to obtain an optimal or near optimal solution that would maximize the system performance by minimizing the risk of down time due to network capacity related problems. A case example is presented to demonstrate the feasibility of the model's implementation.

1. INTRODUCTION

Rapidly declining availability of landfill space and environmental hazards of trash is forcing governments to take regulatory actions in industrialized countries [1, 2]. Regulations in these countries are getting stricter every year. As a result of these regulations, companies are more responsible for recycling their products than ever. This situation increased the importance of recycling and disassembly techniques. Disassembly can improve the useful life span of a product and the purity of recycled materials.

Until recently, there hasn't been much interest to disassembly. It is applied mostly in used car industry in small scales. This was by large due to the fact that, parts to be disassembled usually aren't high on value. Additionally, nature of disassembly is such that critical variables affective on its success are mostly uncertain. These uncertainties are ...

- Number of product to be disassembled
- Model and brand of the product to be disassembled
- Remaining useful life in the product or its parts
- If the desired part in the product or not

These unknown variables render disassembly more challenging than assembly. Research showed that line approach is more profitable than cell approach in disassembly of most of the products (Cell approach makes sense only for small amounts of hazardous materials). Disassembly line should be structured to be flexible so that it can manage the uncertainties of the process.

One of the key aspects of flexible line is a network where all the stations and robots communicate with each other and a controller about flow of items on the line. This network enables all components to be aware of parts flowing on the line

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and have required information about the product, to be processed, be available on demand. Even though, information network plays a critical role at flexible disassembly lines, little research has been published regarding its effects on performance of the line, especially disassembly line.

Published work about this topic follows a two step approach. First simulate the physical plant and then simulate the communication network by using the statistical data of simulation of physical plant. This approach eliminated the opportunity to see the exact delay that would occur if the communication network were used. Our work combines physical and informational aspects of the disassembly line in the same simulation and gets the results accordingly.

2. DESIGN OF THE SIMULATION

2.1. Objective

The general objective of this paper is to investigate the affects of different communication network configurations on disassembly line performance. To this end we do the following.

- Prepared simulation model of a disassembly line and simulated it without communication network delay
- Integrated communication network into the simulation code and simulated to see the difference
- Features like message delay, total communication delay and network utilization have been analyzed for different packet transfer speeds

2.2. Simulation Methodology

SIMAN simulation program has been extensively used to simulate the disassembly line and information network. It is a wide spread used simulation tool that can simulate discrete, continuous, and combined systems. Simulation process is divided into three parts:

- Model development
- Experimental frame development
- Output analysis

Its structure is such that model and experimental frame behave as two distinct components of the simulations. Model is used to describe physical elements and their logical interactions with each other as well as with the entities moving in the system. Experimental frame is used to define experimental conditions (inter-arrival rate, service time, length of the conveyor, etc.). This separation enables to change the experimental specification by only modifying experimental frame. Once both sections have been completed they can be linked and executed by SIMAN or ARENA (visual version of SIMAN). Once the system is simulated output can be analyzed by using built in Output Analyzer of SIMAN [4, 6].

Following is a brief description of the modules used in the simulation.

Used TV module: This module supplies TVs to the line with statistical arrival rates and also determines if an arriving model is known or unknown to the disassembly plant.

Conveyor module: This module is responsible with transfer of TVs in right sequence of station, time delay that would occur during transfer, as well as deciding if the conveyor is full or not.

Station Module: This module introduces station operation delays and sequence of communication with controller.

Network Module: This module assures the correct transfer of communication packets on network and proper allocation of network resources.

Collision Management Module: This module checks for possible data packet collisions and if one happens, it applies the recovery procedure.

A schematic representation of the simulation model and its modules is shown in figure 1

Following assumptions have been incorporated in the simulation model:

- Operation times of the stations are normally distributed
- There is always TVs to disassemble at the unloading deck
- Message processing times are negligible comparing to network delivery times
- ID reading errors don't occur
- 60% of the TVs coming in the line are new to the system so they have to be identified [7]

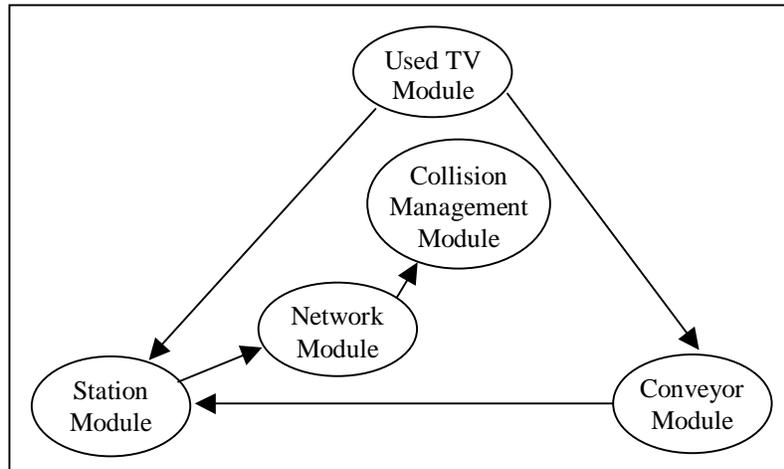


Figure 1: Schematic representation of the simulation model

2.3. Disassembly Line

The disassembly line being simulated here is based on the line mentioned in Hirasawa E.'s paper [3], which is a home appliance disassembly line. It can disassemble TVs, refrigerators and washing machines. This work focuses on the TV disassembly line only and assumes that plant is formed out of two parallel lines with same capacity.

All the items are placed on pallets before entering the line. They stay on the pallets till they leave the line. Design of the line is such that teaching stations take the item and its pallet off the main line, since all the items don't have to stop at those stations. Other stations, which all the items have to stop at, operate on the item while it is still on the line. Conveyor stops neither for an item to enter to buffer of a teaching station, nor to be serviced, while it is on the main line. Item and pallet elevates one inch up the pallet and gets serviced and then drops back on the conveyor. If another pallet arrives to a busy station, it elevates up the conveyor as well and stops to wait the station to be available.

Flow of the TVs on the line is as follows. TVs enter the facility from loading area and get manually loaded on to the disassembly line. Once on the conveyor, they stop at the *Identification Station* first. All the TVs gets identified and assigned a unique identification number (ID) at this station. IDs are recorded to magnetic sections of the pallets carrying the TVs. Purpose of this station is to be able to decide if the item has been processed before or not. If it has been processed on the line previously, it means that there is information about the size, type, cutting and claw coordinates at the database. This also means that item won't have to go to teaching stations, where information is uploaded to the database.

After Identification station, unknown type TVs go to *Cut Line Identification Station* (First of two teaching stations). Once a TV arrives to any station except Identification station, first operation done at that station is to read its ID. After that, depending on the station, either a message is sent to controller to get information about the item or information is sent to the controller to be saved to the database (Teaching stations). In this station a worker records the rear cover cutting coordinates with a coordinate measuring machine (CMM) and sends the data to the controller along with TV's

ID. Controller, which is connected to the database, gets the message over the Local Area Network (LAN) and writes it in the database.

Next on the conveyor is *Rear Cover Cutting* station. Station reads the ID and sends an inquiry to the controller for the rear cover cutting coordinates of the TV. Once it receives the coordinates it starts cutting.

After the rear cover is cut, it gets removed at *Rear Cover Removal* station. Station asks for the claw coordinates to the Controller and waits for the coordinates. Rear cover is mostly ply wood, so it is sent to a different facility for recycling.

Following station is *Cleaning*. This station doesn't need any communication, since it is basically a big box and high pressure air jets. It blows air to make the dust airborne and then sucks it by a vacuum, which is at the top of the box.

Next is manual disassembly section, which has three identical *Manual Disassembly* stations. Workers separate parts, which have material value and/or needs to be taken away to increase purity of other materials at recycling.

Once the PCBs and such parts are separated, CRT is ready to be taken away. If the item is an unknown model, it stops at *CRT Mounting Screw Identification* station (Second teaching station). A worker with coordinate measurement machine records the locations of the screws and sends it to the Controller.

If the TV is a known model, then it goes to *CRT Mounting Screw & Electron Gun Removal* station. In this station the screws are removed and electron gun is destroyed by a fast vibrating metal rod.

CRT and Front panel gets removed at the next station. This station also needs the CRT and Front Panel holding coordinates from Controller. Front panel is mostly ply wood and it is sent to a different facility for recycling.

CRT goes to CRT disassembly plant and TV disassembly line ends here. Figure 2 shows the schema of the disassembly line and processing times of stations can be seen at table 1.

2.4. Communication Network

Communicating parts on disassembly line are Ethernet cards (nodes), workstation (Controller), database, CMM (Coordinate Measuring Machines), magnetic readers, vision systems, displays, basic processors and robots for various tasks. Each line has 11 stations but 10 of them need communication. Cleaning station's procedure is same for all types of TVs, so it isn't necessary for that station to know which type of TV is in the station. All ten stations and controller have network nodes to communicate over the LAN. A schematic of the communication network can be seen at figure 3.

2.5. Local Area Network (LAN) communication Protocol

A LAN is one of the most economic ways to connect communication nodes together. In this setting, any of the nodes can communicate with any other node on the LAN. Main elements of the LAN are one main cable, connector cables and nodes. Main cable is used for all the communications between nodes. In other words, any message that needs to be communicated to another node has to be carried by main cable. Since there is only one cable at any given time there can only be one message being transferred on the cable. This is the main drawback of a LAN. However, there are protocols (set of rules) created to overcome this drawback. There are two main types of protocols governing the communication on a LAN. These are Carrier Sense Multiple Access (CSMA) and Token Ring.

CSMA is the more widely used one of these two. Therefore, this study focuses on the last version of this protocol [5].

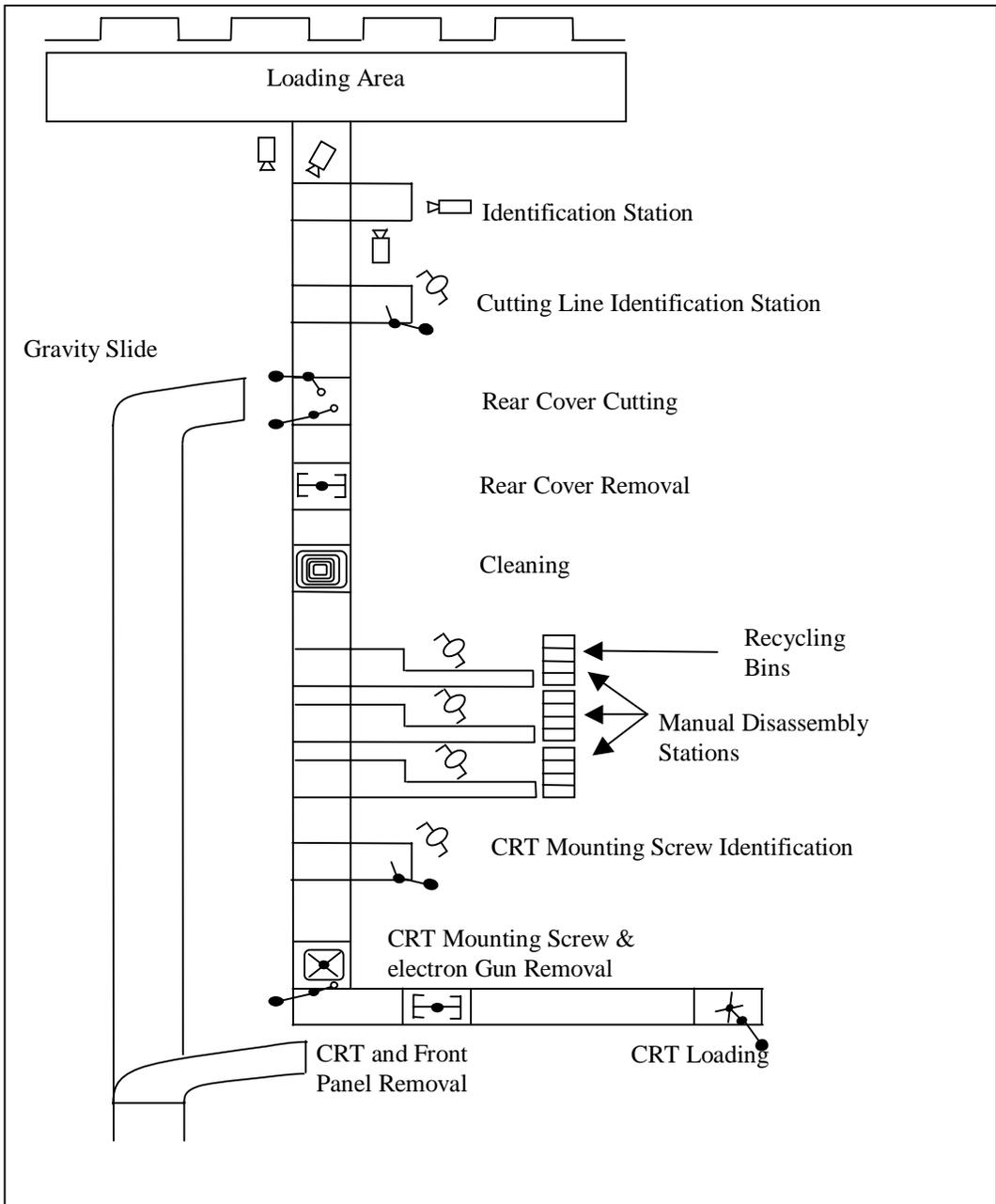


Figure 2: Schematic of one of two parallel TV Disassembly Lines

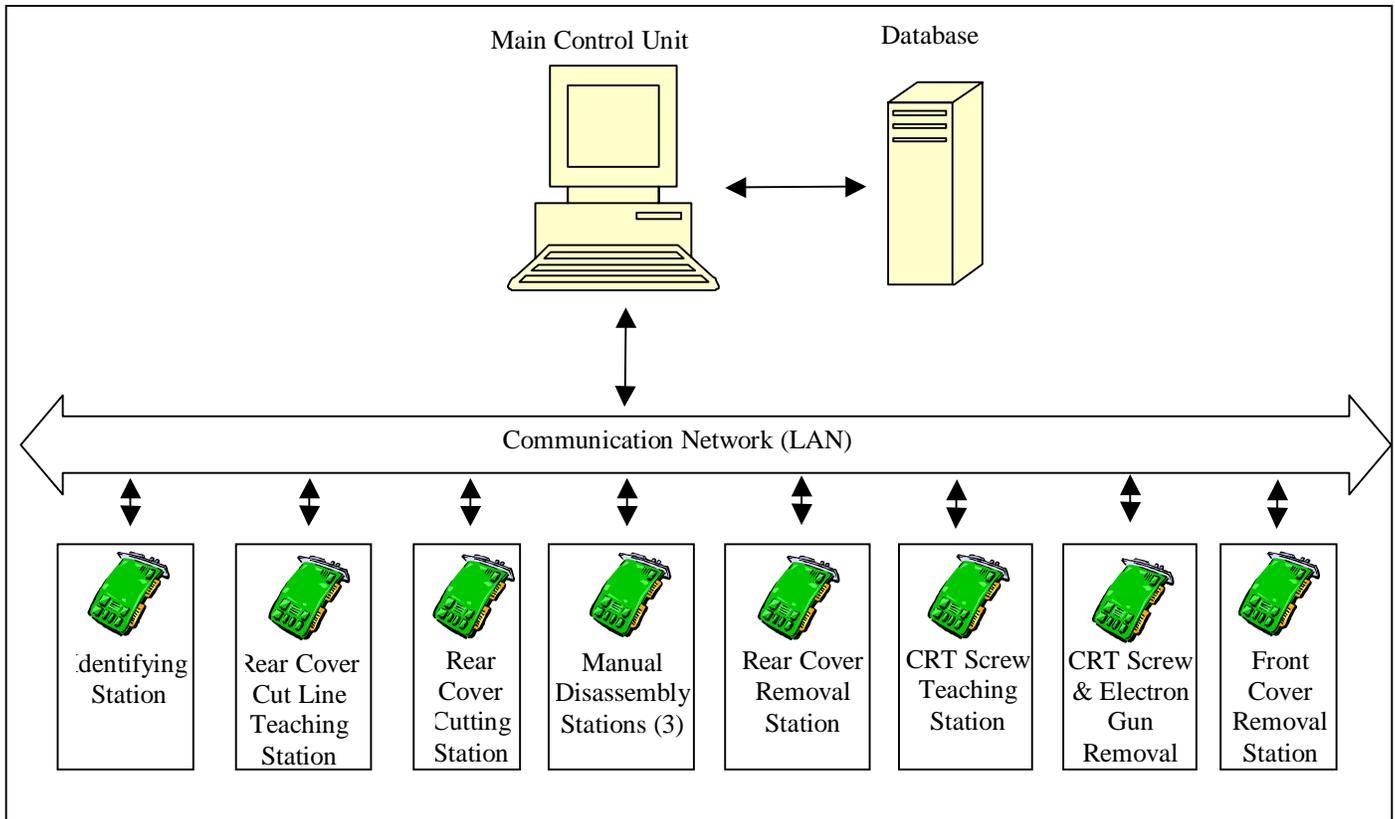


Figure 3: Communication System

2.6. Challenges of Carrier Sense Multiple Access technique:

Communication on a LAN is done by transportation of information packages formed of bits (0 or 1 signal) and there is no authority to control this transportation on the LAN. Therefore, individual nodes have to be able to make sure that their packages have arrived to the destination without any damage. One important tool that nodes have is the capability of sending package and listening to the line at the same time. This gives nodes the ability to identify, if some other node is sending a package at the same time.

If two nodes send packets on the line at the same time, this causes the information to be unreadable (lost). This is called as a *collision* in the literature. Collision happens due to very small time interval that occurs for signal to travel from one node to another. This delay occurs because of the time it takes electrons to travel on the medium. A basic scenario for a collision would be as follows. Once one node finishes sending the packet, two or more nodes with packet(s) ready to send, read the line as idle and start sending their packets to the line. Time passes before those nodes realize that there are packets being sent on the line and stop sending its packet.

Since there is no authority to manage the line there is always possibility that a collision will occur. The goal of this protocol is to recover from a collision rather than trying to avoid one.

Schematic of a communication packet can be seen at figure 4. Section called "Data Packet Size" is where the data to be communicated is stored, first five sections and the last section are for delivery purposes (Detailed explanation of different sections of the packet can be found at IEEE Std 802.3 [5]). It can be seen from the figure 4 that size of the data being sent can change from 1 bit to 1500 Bytes. If the data to be sent is less than 38 Bytes it gets filled with a padding to

be able to satisfy the minimum packet length rule. Changing size of the packets affects the performance of the network. Increasing the packet size can decrease the time spent for waiting for inter frame gap time after sending each message but on the other hand it might increase the message delay time, since each node will be waiting longer for another node to send its message. Additional to that, possibility of collision will increase, since more nodes will be waiting to send by the time one node finishes sending.

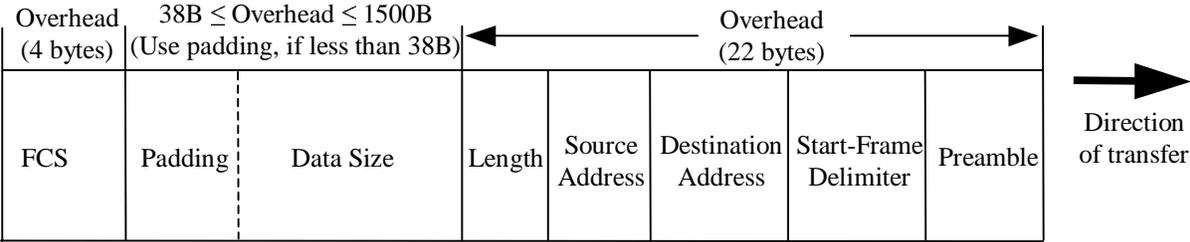


Figure 4: IEEE 802.3 Ethernet frame format

2.7. Specific model description

In this section, we present the specific model studied in this paper. The relevant data is as follows:

- Arrival rate of the TVs to the line is normally distributed with a mean of 25 seconds and standard deviation of 2 seconds.
- There are 10 stations at each line.
- Speed of the conveyor is 30 feet per minute. Each pallet takes up 3 feet length of the conveyor. There has to be minimum 1 feet distance between two pallets on the conveyor.
- Operation times of the stations are given at Table 1
- Amount of the data each station sends is given at Table 2

Table 1: Operation times of stations

Stations	Operation Time		
	Distribution	Mean	Std Dev
Identification	Normal	25 sec	4 sec
Cut Line Teach	Normal	36 sec	4 sec
Cut Rear Cover	Normal	36 sec	5 sec
Remove Rear Cover	Normal	18 sec	2 sec
Clean	Normal	29 sec	2 sec
Manual Disassembly	Normal	68 sec	7 sec
CRT Screw Teach	Normal	37 sec	4 sec
CRT Screw & Electron Gun Removal	Normal	36 sec	4 sec
CRT & Front Cover Removal	Normal	23 sec	4 sec
CRT Load	Normal	15 sec	2 sec

Table 2: Amount of Data each station needs to transfer

Station	Data
Identification	234 KB
Cut Line Teach	2.41 KB
Cut Rear Cover	2.3 KB
Remove Rear Cover	2.3 KB
Clean	-
Manual Disassembly	8.15 MB
CRT Screw Teach	2.31 KB
CRT Screw & Electron Gun Removal	2.31 KB
CRT & Front Cover Removal	2.3 KB
CRT Load	-

3. RESULTS AND ANALYSIS

This work is focused on three main kinds of network speeds, which are widely used in the industry. They are 10 Mega bit per second (Mbps), 100 Mbps & 1 Gbps. Figure 5 illustrates the delay caused by the communication system in the model. If the model has been simulated without the communication delay, result wouldn't represent these delays.

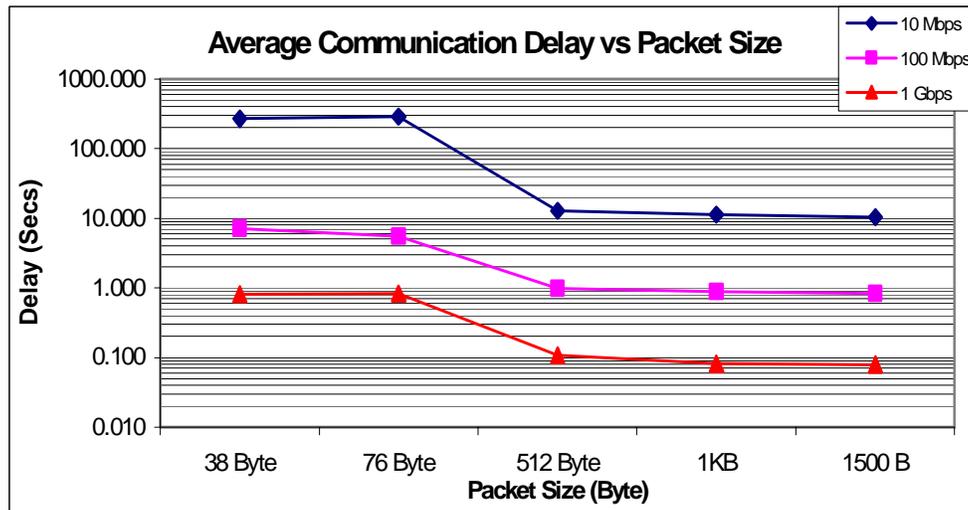


Figure 5: Average Communication Delay vs. Message Sizes for three different transmission rates

3.1. LAN Utilization (%)

LAN utilization is one of the most important measurements used to analyze the network performance. LAN utilization is the ratio of time LAN was used to total simulation time. According to practical experience and published reports utilization should be around 5 – 10 % of maximum loading [7]. This will decrease the variations of delay time to acceptable levels.

There are three main factors which effects LAN utilization. One factor is the size of packets used in transmission. It has been mentioned in section 2.6 that each packet can carry between 1 and 1500 bytes of data. In this work we used 38, 76,

256, 512, 1000 and 1500 Byte size packets to be able to analyze the effects of the packet size. Using different packet sizes resulted at LAN utilization between 69.97% and 33.47% for 10 Mbps transfer rate, between 13.36% and 3.31% for 100 Mbps transfer rate and between 1.43% and 0.33% for 1 Gbps transfer rate.

Other factor is the transmission rate of the LAN. In this work three speeds have been considered. Simulation resulted with LAN utilization of 69.97% to 1.43% for 38 byte packet size, 68.6% to 0.8% for 76 byte packet size, 38.18% to 0.38% for 512 byte packet size, 34.89% to 0.34% for 1KB packet size, 33.44% to 0.33% for 1500 byte packet size. Figure 6 shows that increase in either packet size or speed of the network causes a decrease at LAN utilization. This can also be seen in figure 5 as well. In this logarithmic chart it can be observed that for this particular system increasing the packet size from 38 bytes to 1500 bytes decreases the average delay due to communication around ten times for three different speeds.

Last factor is the amount of data that needs to be transferred over the LAN. Scope of this study doesn't cover the study of this factor on the performance of LAN. Therefore, amount of data that each station will communicate is same for all simulation runs. On the other hand, amount of data each station will communicate is set for that particular station and might be different than other stations. Table 2 shows amount of data that each station needs to send.

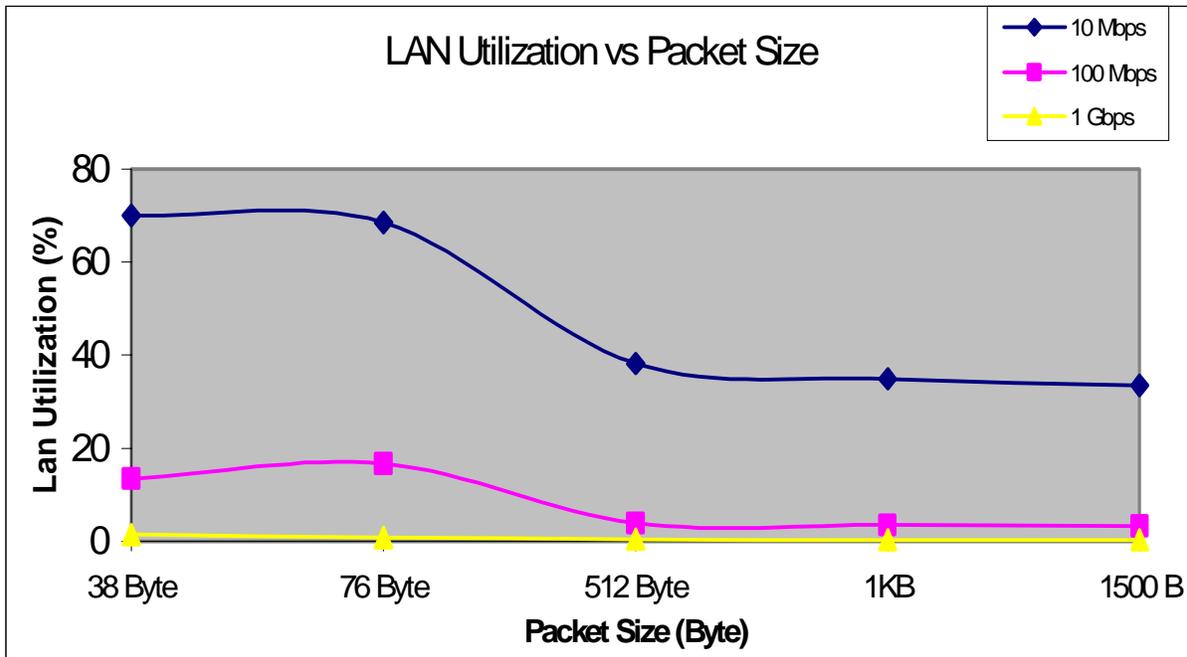


Figure 6: LAN Utilization vs. Message Sizes for three different transmission rates

Network speed is a hardware oriented problem and in most cases physical modifications will be necessary to be able to change it. On the other hand packet size is a software setting and can be altered by system administrator in relatively shorter time.

For this particular case, figure 6 tells us that if we have a 100 Mbps LAN and use 76 byte packet size LAN Utilization will be around 20% which would be considered as high. There are two ways this can be pulled down; install expensive equipment and increase the speed to 1Gbps or instead of using 76 byte packet size adjust the system to use 1500 Byte packets. Equipment to install a 100 Mbps LAN for this plant would cost around \$260 whereas a 1 Gbps LAN would cost around \$2000. As a result using 1500 Byte packets would be the appropriate solution for this particular system.

On the other hand, there is a trade off for increasing the packet size. Higher packet size means once a node starts sending data it will be using the network longer than a smaller packet. Therefore, if another node wants to send a message, it will wait longer for LAN to be available. Figure 7 shows the effect of this. However, analysis show that average message delay is not as critical value as overall station communication delay or LAN utilization for this particular application.

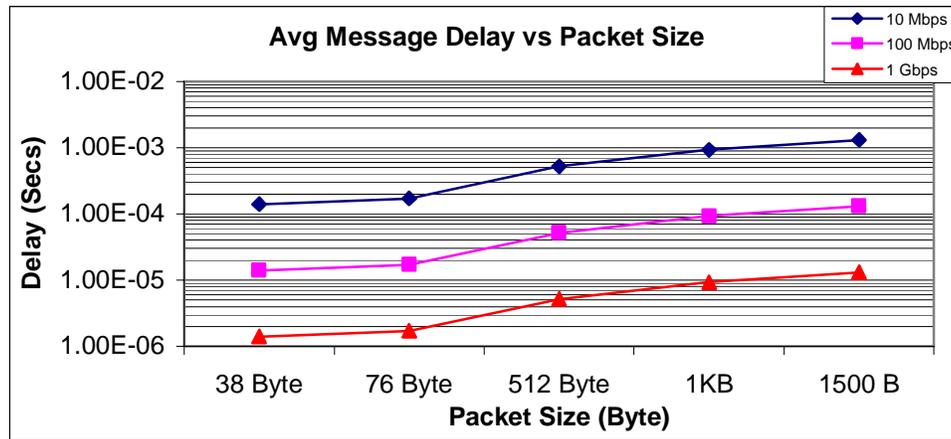


Figure 7: Average Message Delay vs. Message Sizes for three different transmission rates

4. CONCLUSION AND FUTURE RESEARCH

This paper proposes that network performance of a Disassembly system should be considered, while determining the overall system performance. To support this, model of a TV disassembly plant has been created and its network system has been integrated for accurate results. The model has been simulated with and with out the network to be able to observe the difference.

Paper included study of effects of different network speeds and packet sizes on the overall system performance. This technique of integrating both aspects in one model has higher accuracy at providing performance prediction. Such technique can be applied to any disassembly system as well as assembly system.

For future study, effects of different data sizes on the system performance can be researched. Additionally, this research didn't include the less popular "token ring" Ethernet protocol; performance of this protocol can be investigated for different network speeds, packet sizes and data sizes.

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