

A REAL-TIME MANUFACTURING INFORMATION EXCHANGE APPLICATION
BETWEEN PROGRAMMABLE LOGIC CONTROLLERS OVER A FAULT
TOLERANT NETWORK

By

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ABSTRACT

An increase during the last fifteen years in seeking opportunities in data acquisition, reporting, and integrated control systems in automated factory floor environments has gained high priority for Enterprises Information Systems strategies. Improvements on manufacturing effectiveness through systems automation and integration have evolved to a higher step of complexity. The use of controllers and communications networking for the implementation of supervisory control and data acquisition without an adequate design in terms of faults could result in systems not able to alert on faults generation or recover from faults. Automated manufacturing equipment based on Programmable Logic Controllers and integrated through a fault tolerant Ethernet-based network is one of those challenging areas. Some manufacturing integrated systems have tools with their own graphical user interfaces but not necessarily showing operational information from other manufacturing tools in the same network.

This thesis presents a research on fault tolerant systems and the development of a fault tolerant communication network of programmable controllers with hybrid networking topologies to support operators in their manufacturing tasks of processing lot transactions and process monitoring. It describes the analysis process of tasks performed by operators, and describes the development of code logic for the controllers and configuration for the graphical user interface to achieve a fault tolerant network. It presents a usability test conducted to compare the performance and subjective satisfaction of the operators using the existing traditional method and the new information exchange application.

RESUMEN

Un aumento durante la última década del siglo veinte y principios del siglo veintiuno en la búsqueda de oportunidades en la adquisición y reporte de información, y sistemas de control integrados en ambientes automáticos de manufactura para las estrategias de los sistemas de información empresariales. Mejoras en la efectividad de manufactura a través de automatización e integración de sistemas han evolucionado a un nivel más alto de complejidad. La utilización de controladores y redes de comunicación en la implantación de sistemas para adquisición de datos y control supervisor sin un diseño adecuado en términos de fallas pudiese resultar en sistemas incapaces de alertar generación de fallas o de recuperación de fallas. Equipos automáticos de manufactura basados en controladores lógicos programables e integrados por una red Ethernet tolerante a fallas es un tema retante. Existen sistemas de manufactura integrados con sus interfaces gráficos por equipo pero cada interfase necesariamente no provee la información de otros equipos en el sistema.

Esta tesis presenta la búsqueda de sistemas tolerantes a fallas y el desarrollo de una red de controladores programables tolerante a fallas de comunicación, combinada de topologías, para disminuir el tiempo de completar las tareas de manufactura de operadores. Describe el análisis de las tareas, y el desarrollo del código de lógica de los controladores y la configuración de la interfase grafica con el usuario para lograr una red tolerante a fallas. También presenta la prueba de usabilidad conducida para comparar la ejecutoria y la satisfacción subjetiva de los operadores al utilizar el método tradicional existente y el nuevo método de intercambio de información.

TO

My wife, Teresa
My children, Carolina Teresa and Diego Armando
My parents, Alipio and Minerva

For their love, understanding, and for always being there for me.

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CHAPTER 1

Introduction

1.1 Factory Floor Automation

In recent years the importance of data collection, reporting, and integrated control systems in automated factory floor environments has gained high priority for Enterprises Information Systems strategies. The data collection and reporting vary among various subjects: production outputs counts, equipment functioning status, and material handling. Figure 1.1¹ shows the information flow in an automated factory floor where four levels have been defined: device, control, information, and enterprise.

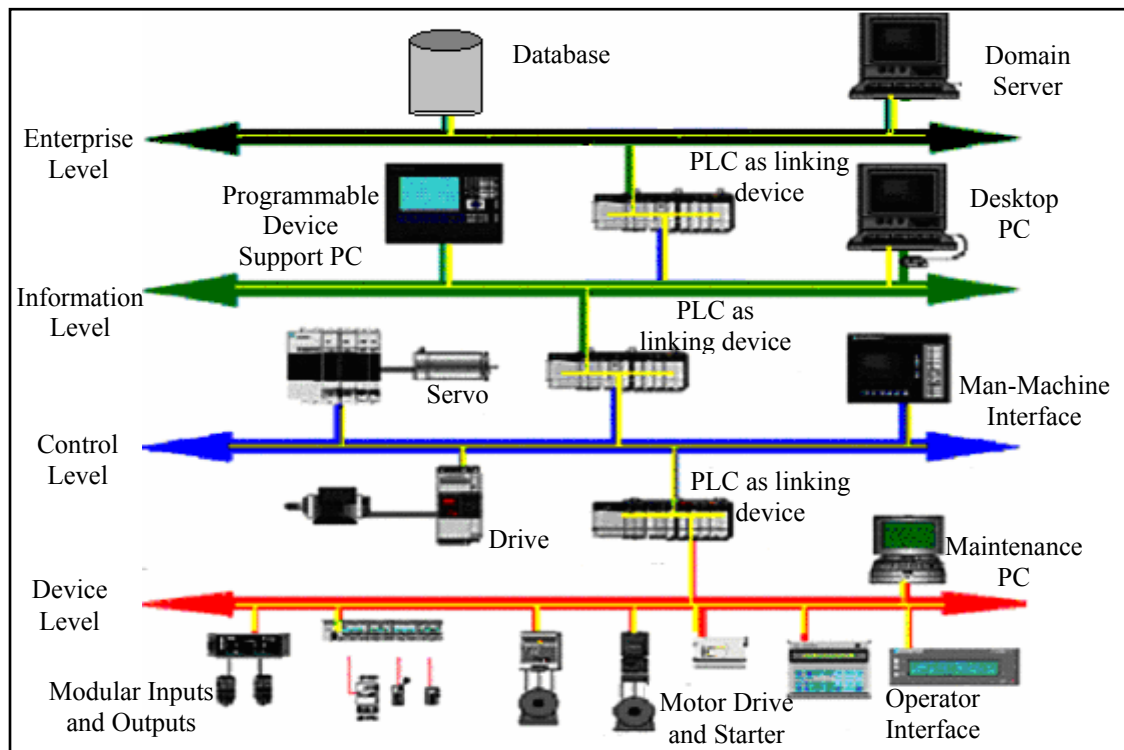


Figure 1.1 Typical Multi-level Data Collection Architecture

The integration of the four layers in figure 1.1 is given by the elements called PLC as linking device. These devices serve as gateways to allow the information

¹ Source: EtherNet/IP: Industrial Protocol White Paper; 2002, Rockwell Automation Internet

transmission from a communication network in layer to another communication layer in another layer. The flow of information on this architecture allows the understanding of the situation of an automated factory floor in order to assure overall plant productivity in a day-to-day basis [Manji00], and the decision making by corporate directives on what the needs are to better conduct businesses in order to improve revenues and profits [Callaway01].

This thesis presents the development of an application for the exchange of process and product information between programmable logic controllers (PLCs) of independent manufacturing lines based on networking fault tolerance (F-T) concepts to assure information integrity during information transmission. This application will allow the operators to execute production lot transactions both at accumulating devices, from now on called accumulators, and Packaging Tool #3 in a packaging area in order to improve speed on operators tasks performance. Manufacturing operators will be primary users of this application.

This thesis considers four factors for the application development. First, industrial environments have used PLCs over the last 30 years in process control because of their stability, reliability and simplicity [Smith03]. Second, network connections are critical components of control systems architecture because they provide the connectivity to transfer real-time process control information between shop floor controllers, and from shop floors to enterprise systems and vice versa [Byres00]. Third, fault tolerant systems employ a range of technologies that improve system integrity and reduce the likelihood of control systems failures [CSE02]. Fourth, near real-time monitoring systems are increasingly important in industrial environments in order to understand the process status, track product through the process and maximize support services [Asgari02].

The contribution of this thesis will try to show the possibility to apply fault tolerance capabilities (heartbeat, media redundancy, and reinstate to functional mode) to a real-time monitoring and control system composed of various different types of PLCs interconnected by a hybrid communication network.

1.2 Research Overview

The research describes how to apply each of the four factors considered, and present how to integrate some of them in certain applications. Reviewed literature presents that PLC based control systems, real-time monitoring systems, and fault tolerant systems are affordable and have been implemented in a variety of applications in areas such as general manufacturing, power generation, automotive, and electronics.

The research presents a study of the different tasks performed by the operating staff of a manufacturing center where the accumulators and Tool #3 are installed and functional. This study is based on the collection and analysis of information on how tasks are carried out to see if the implementation of real-time monitoring in PLC based systems networked with fault-tolerance could improved them. At this point the research presents a description of how the communication goes between PLCs in order to have high availability of data. An usability test compares the performance and subjective satisfaction of the operators using the traditional method where the accumulators information is not shown in Packaging Tool #3 and the information exchange application.

1.3 Outline of the Thesis

The thesis consists of seven chapters. Chapter two describes previous work related to real time monitoring, PLC based control, fault-tolerance networks, and networking applications development. Chapter three presents and discusses the results of a task analysis of the manufacturing process in the accumulator and Packaging Tool #3. Chapter four describes the integration of the accumulator controller and Packaging Tool #3 in the packaging area to allow remote transactions on production lots at the accumulator, the graphical user interface (GUI) that show the production information at the packaging area, and the tools used for its development and implementation. Chapter five describes the usability test performed with both methods of transactions and monitoring: the traditional method of physically moving to the accumulators screens and the information exchange application. Chapter six presents the usability test results and

the analysis of the data collected. Chapter seven establishes the conclusions and suggests future work.

CHAPTER 2

Previous Work

2.1 Introduction

The contents of some references which are the basis of previous work are next. PLCs have evolved in the last 30 years to incorporate technologies that permit their use for controlling manufacturing processes in real-time conditions. The technologies include massive network connectivity, processing speed, local storage, and programming flexibility [Smith03]. The volume and size of real-time (RT) distributed computing (DC) applications have grown in the last century in industrial environments [Kim01], based on wired and wireless networks, and with greater levels of complexity and scalability. The mixture of application tasks running on such systems is growing as well as the shared use of computing and communication resources for multiple applications including RT and non-RT applications is. An important consideration has been the cost-effectiveness of constructing RT DC systems, and it is to compose them in the form of networks of RT DC components, where computing nodes hosting RT DC components are expected to have resource managers that do not allow any component to monopolize certain node resources beyond predefined limits. Also, these systems are equipped with a configuration manager which maintains information on available computing nodes and interconnections and handles distribution of DC software components.

Fault-tolerance [Thybo98] is the ability of a system to detect, isolate and accommodate a fault in such a way that simple faults in a sub-system do not develop into failures at a system level. Fault tolerant systems employ a range of technologies that improve system integrity and reduce the likelihood of control systems failures. The fault tolerance in communication networks is achieved by implementing redundant networks with multiple, independent paths between devices on the network. Good redundant network design features communication cables running along different routes, minimizing the risk of network failure if one cable is accidentally damaged. In some cases, all available network bandwidth is used, with a failure of part of the network

increasing the traffic in the remaining parts of the network. In this case, the system needs to be designed so that some services are discontinued or slowed down to reduce traffic to match the available network bandwidth [CSE02]. A drawback when incorporating fault tolerance mechanisms into RT DC systems is the time overhead introduced. If the timing constraints of the applications are very rigorous, then the strategy on fault tolerance shall be of a small set of mechanisms, mostly relying on special hardware or extensive use of hardware redundancy. Similar situations exist for incorporating security enforcement mechanisms into RT DC systems.

The aforementioned factors become critical components of a real-time monitoring system in manufacturing environments when process or product data is transmitted from the production floor side to the corporate business side. In recent years Manufacturing Execution Systems (MES) have managed all activities and resources production processes in an effort to reduce cycle time, low inventory, and increase productivity [Byres02]. Faults auto-generated or infringed into the system would directly impact the production life cycle.

Some terminology need to be presented in an effort to make more understandable why this thesis considers the aforementioned four factors. Fault management is keyed when speaking about fault-tolerant systems; and typically, it is a process of five steps [Anderson01]:

- Detection: fault² found.
- Diagnosis: cause of fault is determined.
- Isolation: rest of the system protected from fault.
- Recovery: system is adjusted or re-started to proper functionality.
- Repair: faulty component of the system is replaced.

High Availability is associated to computer systems exhibiting almost no downtime, 99.9% or more uptime. The components of such a system are the following:

- Redundant hardware and software, including infrastructure such as networking

² A fault is the cause of a failure in a system and the failure occurs when the system has not delivered the service that the consumer expects with respect to a specification.

- Methods to store components information and relationships
- Methods for fault management (detection / recovery / repair)
- Methods for replacing and upgrading components with their stored information
- System dynamic reconfiguration

Availability cannot be confused with reliability³, since availability is the readiness for usage. There are applications that participate, control or operate within High Availability (HA) systems. Through a system management interface, the application can monitor operations and send status, heartbeat and checkpoint information. Also, the application may initiate a fail-over or due recovery action.

2.2 Data Collection and Control Applications

The following sections present some examples of applications that have been developed in areas such as general manufacturing, power generation, automotive, and electronics.

2.2.1 General Manufacturing

Real time access to manufacturing information enables cost savings and operational efficiency. [Bigam03] presents a shop floor data collection (SFDC) system using wireless communications methods, such as barcodes and radio frequency, to collect real time data automatically at the shop floor. The system integrates the captured shop floor data in a timely manner into the enterprise system resulting in accurate inventory information available up-to-the-minute. All these improve customer service.

[Hamilton99] presents a unified approach of detecting control and datapath faults, along with the identification of faults and reconfiguration of the controller. This relates to fault detection. The section of detecting control and datapath faults avoid the performance overhead due to error detection hardware on detecting faults. The section of

³ Reliability may be defined as the continuation of service in absence of failure.

reconfiguration isolates the identified faulty hardware and proceed with a rollback to restore a safe state.

2.2.2 Power Generation

[Klump02] presents an application that relates to a real time monitoring application for effective management of power generating systems, which require analysis of vast amounts of information. The techniques developed to visualize such large amounts of data are mainly three: animated flows, contouring, and 3-D visualization. These techniques have been integrated to real-time data sources to provide technical support personnel the data available and the understanding of the following: location of the transmission lines and direction of power distribution, location of lines overloads, the power market distribution and, consequently, price distribution. The addition of 3-D visualization shows the power magnitude along the distribution. However, the visualization technique has been integrated to data sources in an off-line environment; the integration to real-time data in control centers still remains an issue.

2.2.3 Automotive

[Ramanathan99] presents an application for automotive cruise control with an overload management technique due to components failures upon detection of a failure based on tasks prioritization as per their importance in the system. This relates to fault detection. It discards tasks which do not adversely affect the performance delivered by the application. When an overload occurs, a scheduling policy discards tasks instances to reduce system utilization, but assuring that the control law that said discard task invoked is modified.

2.2.4 Electronics

[Luoh02] presents a monitor and control solution based on a real-time computer system called Factory Automation Data Management (FADM). The main components of the FADM are the following: graphical user interface (GUI), data communication, digital inputs and outputs. The system records all operational and hardware parameters during the process, such as temperature, pressure, and gas flow rate. Single-wafer thermal process control is not an easy task because of its variability but it is very important to achieve product thickness uniformity; hence, an efficient manufacturing process.

[Preston00] presents a new MES with windows-based screens, which have been rationalized to speed up the learning process for new operators. Screens are organized in a sequence such that an operator performs his or her job with maximum efficiency by quick accessibility for the necessary process information. Also, there are some tasks related to information entry that are kept from unnecessary entry, maximizing operator's efficiency. For example, production lots have to be either released or put on hold; there are several steps necessary to follow through the screens in order to perform lot management.

[Fujimoto03] presents the design of an experimentation on a fault-tolerant configuration of distributed discrete controllers communicating over a network. This design uses an additional redundant controller over a User Datagram Protocol over Internet Protocol (UDP/IP). The experimentation was conducted with Personal Computers (PCs), each one emulating a PLC. UDP allows transmission of datagrams or streams of data; whereas it enables the receiving node to wait for datagrams that are out of order and reassemble those in the order they were sent. UDP is simpler than TCP with a header containing fewer bytes, and consuming less network overhead than TCP. TCP adds reliability, flow-control, and error-recovery functions to IP that UDP does not [Javvin04].

2.3 Summary

The use of PLCs for automated manufacturing systems monitoring and control in addition the implementation of monitoring systems with a fault-tolerant approach have gained extensive research, development and implementation specifically for critical applications. Reliability of PLC based control systems has been consistently proven over the last 30 years.

Also, several error detection and fault-tolerance methodologies have been developed and implemented, but to keep unaffected the systems efficiency has been always an objective. Therefore, the integration of both topics in one application solution goes a step beyond the quality and productivity assurance of manufacturing processes. The following chapter will present the operators tasks analysis for the traditional method and the information exchange application.

CHAPTER 3

Task Analysis of the Manufacturing Processes in the Accumulators and the Packaging Area

3.1 Introduction

This chapter presents the task analysis for the working environment which is described by the processing transactions at the accumulators and the packaging area, and its results. A task analysis involves the study of what an operator is required to do to achieve a system goal [Kirwan93]. In this analysis, the goal for each operator is to walk from the packaging area to the accumulators areas and perform hold and release operations to the production lots in the accumulators. Three different approaches to task analysis are the following: task decomposition, knowledge based techniques, and entity-relation based analysis [Dix93]. These are different ways of identifying tasks and their requirements in terms of the resources necessary for their successful accomplishment [Kirman93]. Task decomposition is the approach followed in this analysis because it tends to look at the observable behavior of users rather than their internal mental state as the other two approaches do. It is not the intend of this thesis to present a detailed comparison of the three approaches.

3.2 Task Analysis Decomposition

Task decomposition looks at the way to split a task into sub-tasks, and the sequence in which these are performed. The working environment was kept the same but the operators in the analysis were different. The objective of the execution of the task analysis is to identify how operators perform currently their tasks. This is a goals when automating with PLCs and User Interfaces (UI), interconnected via a network under a fault-tolerant platform.

Direct interviews with operators and live direct visual observation in the working environment were personally conducted to collect information about the process sequence (see Appendix A). Table 3.1 shows the resulting hierarchical task analysis

(HTA). The output of the HTA is a hierarchy of tasks and sub-tasks, and also the plans describing in what order and under what conditions sub-tasks are performed. Indentation is used to denote the levels in the task hierarchy, and the tasks are numbered to emphasize the hierarchy.

Table 3.1 Hierarchical Task Analysis for Processing Transactions in the Accumulators and Packaging Areas

Tasks	Plan
0.0 Processing Transactions 0.1 Operator performs Release Lot transaction in the packaging area UI 0.2 Operator performs Hold Lot transaction in the packaging area UI 0.3 Operator performs Release Lot transactions in the accumulator UI 0.4 Operator performs Hold Lot transactions in the accumulator UI	Plan 0.0: Do 0.1- 0.2 and EXIT.
1.0 Operator performs Release Lot transaction in the packaging area 1.1 Walks to Tool #3 GUI 1.2 Select “Main Menu” button in GUI 1.3 Select “Release Lot” button in GUI 1.4 Select lot number from combo list 1.5 Select “Enter” button 1.6 Select “Back” button 1.7 Return to previous Tool for other tasks.	Plan 1.0: Do 1.1-1.7
2.0 Operator performs Hold Lot transaction in the packaging area 2.1 Walks to Tool #3 GUI 2.2 Select main menu button in GUI 2.3 Select “Hold Lot” button in GUI 2.4 Select lot number from combo list 2.5 Select “Enter” button 2.6 Select “Back” button 2.7 Return to previous Tool for other tasks.	Plan 2.0: Do 2.1-2.7

Table 3.1 Continuation

3.0 Operator performs Release Lot transaction in the accumulator area	Plan 3.0: Do 3.1-3.7
<ul style="list-style-type: none"> 3.1 Moves to Accumulator GUI 3.2 Select main menu button in GUI 3.3 Select “Release Lot” button in GUI 3.4 Select lot number from combo list 3.5 Select “Enter” button 3.6 Select “Back” button 3.7 Return to previous Tool for other tasks. 	
4.0 Operator performs Hold Lot transaction in the accumulator area	Plan 4.0: Do 4.1-4.7
<ul style="list-style-type: none"> 4.1 Moves to Accumulator GUI 4.2 Select main menu button in GUI 4.3 Select “Hold Lot” button in GUI 4.4 Select lot number from combo list 4.5 Select “Enter” button 4.6 Select “Back” button 4.7 Return to previous Tool for other tasks. 	

3.3 Operator Tasks

Operators are responsible for the transactions in the accumulators and packaging areas. Also, they are responsible for other related tasks. They handle finished product to staging areas, document non-conforming products and conditions affecting equipment uptime, handle material for packaging processes, receive instructions about production scheduling, clean equipment and working area, and pass information to the next shift operators.

3.4 Summary

The result of the task analysis identified tasks the operators performed, the main tasks being related to lot transactions. The transactions processing begins at the time the operator approaches the GUI of the accumulators and the packaging area. The transactions processing ends when a production lot is transported to the packaging area, then another lot is ready to be accumulated. Typically, the operators do additional tasks

related to the transactions processing such as splitting production lots, joining production lots, and deleting removed lots.

Currently, operators need to walk to the accumulators GUIs to process transactions, then move to continue working with production lots released from the accumulators to the packaging area. The following chapter will describe the development of the code logic of the accumulators and Tool #3 controllers for the information exchange application under a fault-tolerant communication network, and the GUI configuration improvements to show the process and product information of the accumulators in the Tool #3 GUI. This development will minimize the walking task by the operator.

CHAPTER 4

Exchange of Process and Product Information Application Development

4.1 Introduction

This chapter describes the development of the PLC logistics and the GUI coding for the exchange of process and production information between the accumulators and the Packaging area under a fault-tolerant environment. PLCs and corresponding coding exist to control processes at the accumulators and the packaging area. Production information is available at both locations but operators perform transactions to enter production lots to the packaging area at the accumulators GUIs. The PLCs at both locations are interconnected only by a legacy communication network, DataHighway+™[AB99]. Refer to figure 4.1 for a DataHighway+ topology diagram.

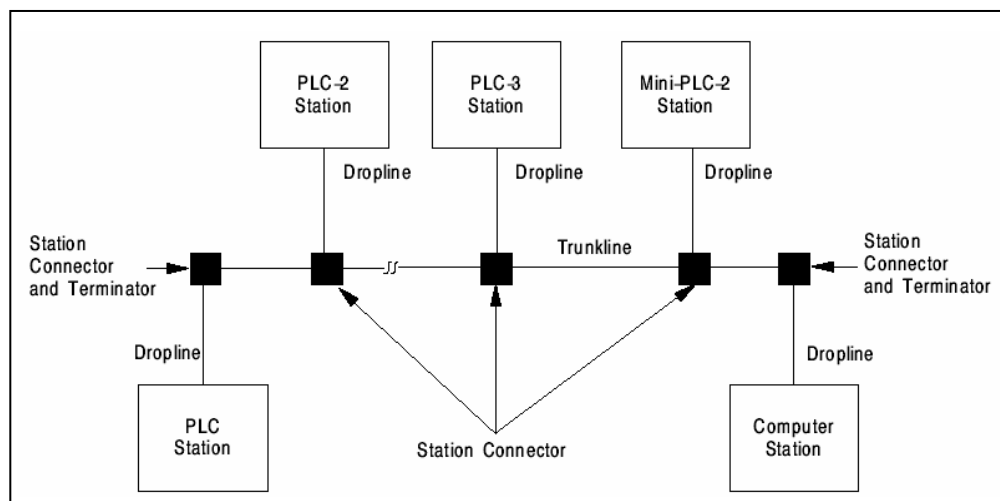


Figure 4.1 Typical DataHighway+ Topology

The approach of this work is different from the work presented by [Fujimoto03]. That application uses UDP/IP and PCs emulating PLCs. The application presented in this thesis was conducted with real PLCs over a mix of Transmission Control Protocol over Internet Protocol (TCP/IP) network and proprietary Data Highway+ (DH+) network, and no additional redundant controller.

4.2 Hardware Application Requirements

This section describes the actual manufacturing environment with its components and what hardware is needed to achieve the fault-tolerant networking of the controllers to exchange production information. The controllers in the accumulators, Allen-Bradley PLCs model ControlLogix®, have the sourcing data of the production lots to be either released or put on hold in order to deliver those to the packaging area. Each ControlLogix is connected to a Parker® GUI console, which shows the production lots in the accumulator, amount of units entering into the accumulator, amount of units exiting the accumulator and amount of units per production lot in the accumulator.

The controller in the Packaging area Tool #3, an Allen-Bradley PLC model SLC505®, is connected to another GUI where the operator is currently performing monitor and troubleshooting tasks for Tool #3. Besides, the operator will perform the transactions of releasing and holding lots in the accumulator from this GUI. Also, the operator will monitor the status of the accumulator in order for the operator to address operational conditions that impact the productivity.

In addition to the legacy DH+ network, an Ethernet network running at a maximum 10 Megabits per second will be laid to pursue the fault-tolerant networking environment. Refer to figure 4.2 for a typical Ethernet network in a manufacturing environment.

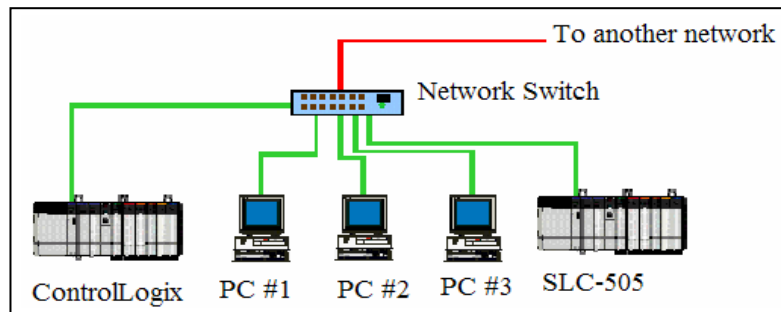


Figure 4.2 Typical Ethernet Network in a Manufacturing Environment

Figure 4.3 shows the networking layout for the information exchange between controllers in an effort to pursue a fault-tolerant networking environment. It only shows

the controllers in the application case with the DH+ and Ethernet connections between them.

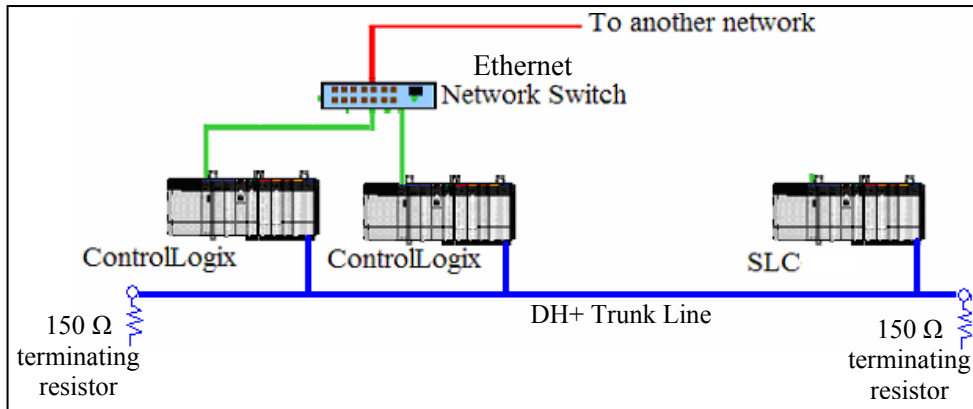


Figure 4.3 Application Networking Layout

4.3 Software Application Development Requirements

The software tools used for the application development are the following: Rockwell Software® RSLogix 5000, Rockwell Software RSLogix 500, and Allen-Bradley PanelBuilder32. The RSLogix family software and the PanelBuilder32 are Windows based software that runs in PCs on Windows 2000 platforms. This set of programming tools delivers a complete desktop development environment for creating applications and system components for PLC control code and GUI.

4.4 Functional Specifications

The functionality of the integration application focuses on delivering the production and process information through a fault-tolerant network to a GUI for operators to perform their duties in a faster way. Operators at Tool #3 in the packaging area will perform remotely releasing and holding transactions on production lots at the accumulator area, monitor accumulator operating conditions, and access information about lots in process. All this will be possible for the operators without leaving unattended the packaging area.

It takes advantage of existing PLCs code for process control in Tool #3 and the Accumulators to achieve transactions remotely from Tool #3; in addition to GUIs located at Tool #3 to allow display of the process and product information. The fault-tolerance of the network is based on redundancy of media, and the implementation of a heartbeat to monitor if the controllers are alive and ready to transmit the information from one to the other.

In essence, the Tool #3 PLC will generate a heartbeat signal every 100 milliseconds which is sent to both Accumulators controllers via a DH+ message. Each Accumulator PLC will response back to Tool #3 PLC with heartbeat signal via a DH+ message. Also, one Accumulator PLC will send a heartbeat signal to the second Accumulator PLC via an Ethernet message; then, this PLC will response back with a heartbeat signal to the previous Accumulator PLC. Each controller will monitor during a time window of 105 milliseconds for the reception of a heartbeat signal from the other controllers either via the applicable networks, DH+ and Ethernet, as shown in figure 4.3.

4.5 Detailed Interface Design

A GUI already existed in Tool #3 at Packaging area. Additional functionalities, such as command buttons, were added into it for the operators to perform actions related to lot transactions, accumulator operational status and lots information as observed in the execution of the task analysis in chapter 3. The additional GUI functionalities followed three Norman's principles of good design [Fleming98], which are discussed on the following subsections.

4.5.1 Norman's Principles

Three Norman's principles considered for the modified screens were the following: visibility, mapping, and feedback. Visibility refers to looking that the operators could tell the status of a lot in the accumulator, the status of the accumulator, and the alternatives for lot transactions. Good mapping refers to determine the relationships between actions and results, between the interaction controls and their

effects, and between production lots status and accumulator status, and what was visible in the GUI screen. Feedback was used so that the operator received full and continuous acknowledge about the results of GUI interactions.

4.5.2 Visual Hierarchies

Some visual hierarchies factors were considered to establish relationship between interface elements, paying attention to the relative size of the elements, their placement or position, and grouping or placing, and show the relationships between elements on the GUI. The relative size communicates information about the importance of one element over another. The more important elements on the screen are displayed in larger size to capture operators attention.

Placement or position of elements communicates their relative importance or sequence in which the operators should understand them. The use of a *Previous Screen* button is an example of a natural comfortable location to return one screen back. Grouping or placing elements in proximity are used to provide information about the logical relationships between screen elements. An example is the grouping at the bottom of the screen of command buttons for several tasks.

4.5.3 Interaction Techniques

The GUI of the integration application was based on a touch-tone screen application. Consequently, the GUI was designed for interaction techniques that let the operators touch with a finger and select elements that accomplish the desired tasks. There are several software interaction techniques [Grattan02]. Command buttons, and dialog boxes were some of the interaction techniques used for the application GUI to keep it simple in code design and ensure application usability. Buttons are individual and isolated regions within the display which can be selected by the operators to invoke specific operations. Clicking on the button invokes a command and its meaning is indicated by the button caption or button background color. Dialog boxes are

information windows used to capture the operators attention about some important information or giving feedback in the interaction. Refer to figure 4.4 for examples.

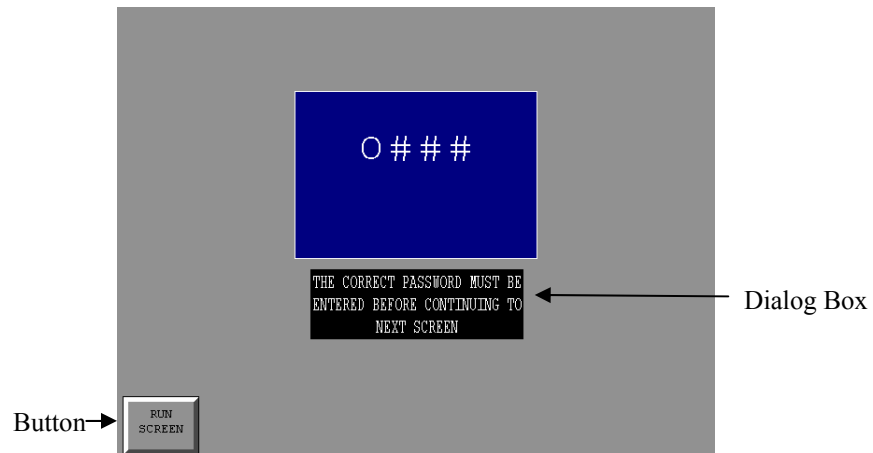


Figure 4.4 Examples of Buttons and Dialog Boxes

4.5.4 Graphical User Interface Main Components

The main objective of the GUI is to let the operators easily perform the production lot transactions, observe the accumulator operational status and the production data for the lots in the accumulator, running full screen locally in Tool #3. Table 4.1 describes the main GUI components and the software tools used in the development.

Table 4.1 GUI Main Components and Description

Components	Tools	Description
Login	PanelBuilder32	To create operators login security pad.
Main Screen	PanelBuilder32	To create the main menu dividing it in seven main categories: Data Screen, Auto/Manual, Product Changeover, TFM I/O status, Mimic Screens, Alarm History, Accumulator Status.
Accumulator Status	PanelBuilder32	To create the form to show production information for each accumulator.
Accumulator Summary	PanelBuilder32	To create the form to show each accumulator data for up to a maximum of 20 lots.

4.5.5 Application

The functionality of the information exchange application lets the operators to view the production lots numbers in the accumulator, released or on-hold status of the lots, operational status of the accumulator, send transactions of releasing or holding lots in the accumulator discretionally, and display all operational information of Tool #3. The application consists of the following five modified forms: Login Form, TFM RUN – MAIN Screen Form, Accumulator Status Screen Form, C3 Accumulator Summary Screen Form, C6 Accumulator Summary Screen Form. Each form displays command buttons and dialog boxes for selecting the transaction to perform on a production lot. The next section describes in details each form.

4.5.5.1 Login Screen Form

Login Screen Form is the login screen that creates a security access to the application. This is the first form displayed as soon as the application starts executing. The access is restricted to authorized operators. To start the login process the operator touches the rectangle captioned *Touch To Enter Password* on the center of the screen (see figure 4.5). Then, the operator enters a sequence of numbers from the GUI numeric keypad that matches a pre-determined password (see figure 4.6).

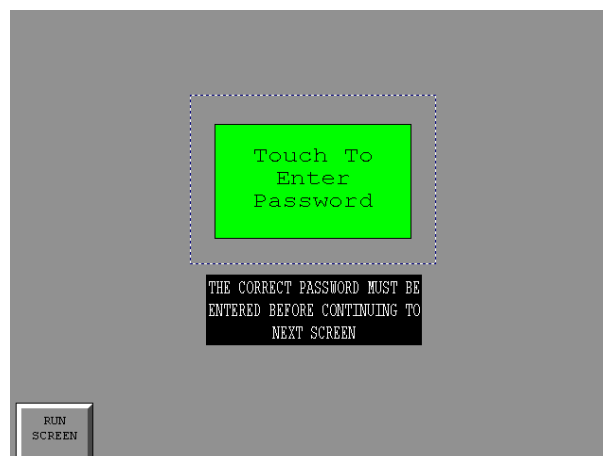


Figure 4.5 Login Screen Form



Figure 4.6 Numeric Password Entering Screen Form

4.5.5.2 TFM RUN - Main Screen Form

The main screen form is displayed as soon as the operator selects the *Run Screen* command button after entering the password with the numeric keypad, see figure 4.6. This form shown in figure 4.7 displays the options to access the screens with the accumulators information. The action of the operator selecting the *Accum. Status* command button will open the ACCUMULATOR STATUS screen form displaying production information of both accumulators.

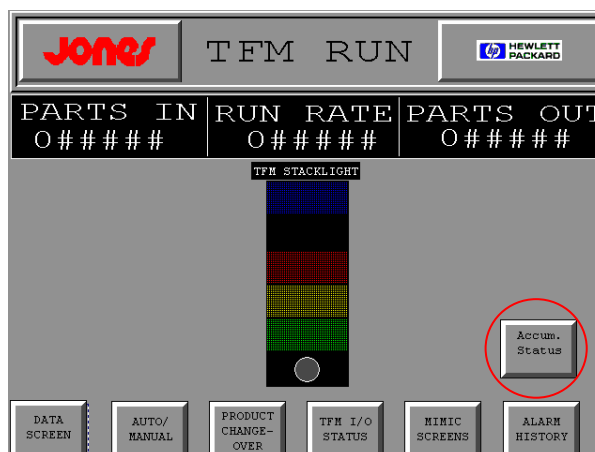


Figure 4.7 TFM RUN Main Screen Form

4.5.5.3 Accumulator Status Screen Form

The screenshot shows a dark blue screen with two columns of data. The left column is titled 'C3 ACCUMULATOR' and the right column is titled 'C6 ACCUMULATOR'. Each column contains four rows of data: 'Total Pens', 'Cur. Inp. Lot#', 'Qty. of Pens', and 'Cur. Out. Lot#'. The values for 'Total Pens' and 'Cur. Out. Lot#' are '#####'. The values for 'Cur. Inp. Lot#' are '#####'. The values for 'Qty. of Pens' are '###*' for C3 and '####*' for C6. At the bottom right, there is a button labeled 'PREVIOUS SCREEN'.

C3 ACCUMULATOR		C6 ACCUMULATOR	
Total Pens	#####	Total Pens	#####
Cur. Inp. Lot#	#####	Cur. Inp. Lot#	#####
Qty. of Pens	###*	Qty. of Pens	####*
Cur. Out. Lot#	#####	Cur. Out. Lot#	#####
Qty. of Pens	#####	Qty. of Pens	#####

Figure 4.8 Accumulator Status Screen Form

Figure 4.8 shows the form with production information for each accumulator. This form displays the following information: total quantity of units in the accumulator, current lot number and its amount of units inputting into the accumulator, and current lot number and its amount of units outputting from the accumulator. Each field of information is received by the controller of the packaging Tool #3 from the accumulators controllers. The packaging Tool #3 controller maps its variables to tags in the GUI in order to display the different screens with information to the operators. A command button captioned *PREVIOUS SCREEN* is available so that the operator may return to the Main Screen Form. The operator may access additional information related to status of each lot going into the accumulator when touching either the C3 Accumulator or the C6 Accumulator title bars, which actually are command buttons. This action opens the C3 Accumulator Summary Screen Form or the C6 Accumulator Summary Screen Form, respectively.

4.5.5.4 Accumulator Summary Screen Form

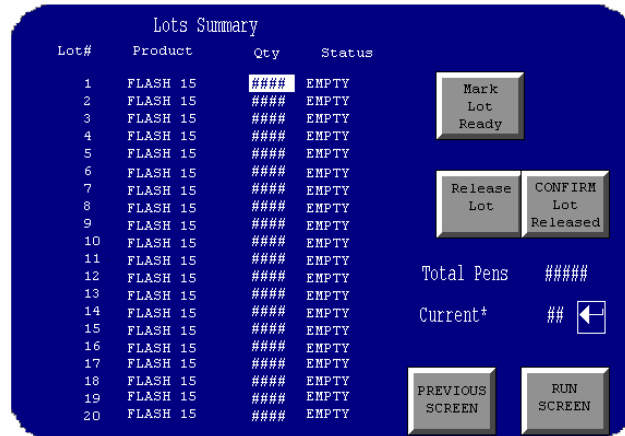


Figure 4.9 C3 Accumulator Summary Screen Form

Figure 4.9 and figure 4.10 show the Summary Screen Forms for C3 and C6 accumulators respectively. The data shown is for a maximum of twenty lots. Each form displays the following information: corresponding product part number, quantity of units, and the status for each lot. Also, the current lot number is displayed, and the total number of units in the accumulator. A collection of command buttons provides the following functionalities: *Mark Lot Ready* to perform the operation of holding the lot but ready for release at a later time; *Release Lot* to perform the operation of releasing a lot at the moment the operator is doing this; *CONFIRM Lot Released* to perform a confirmation to proceed with a lot release; *PREVIOUS SCREEN* command button to allow the operator to return the GUI to the Main Screen Form; *RUN SCREEN* to accept the changes performed. The operator can select a production lot number from the listing to the left of the screen by touching the screen on the spot on top of the lot number. An enter like key is available to acknowledge the selected lot number in order to perform the aforementioned functionalities on that lot number.

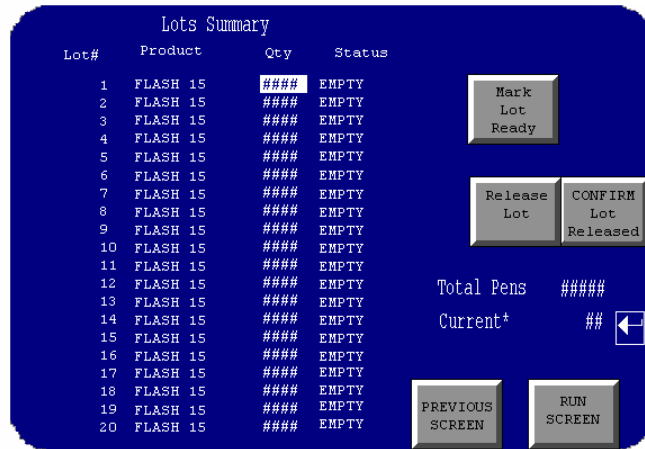


Figure 4.10 C6 Accumulator Summary Screen Form

4.6 Detailed Accumulators PLC Code Design

A general architecture of a PLC is shown in Figure 4.11a, where its main components are the CPU, the input and output image tables, and the physical input and output connection points [Bravenet04]. The CPU of a PLC is similar to the CPU of a personal computer. It is made of a microprocessor, where calculations and logic is performed; Random Access Memory (RAM), where user program is store; Read Only Memory (ROM), where the firmware or systems program is store; EPROM, where the user program is stored for backup or auto re-loading purposes when power is out.

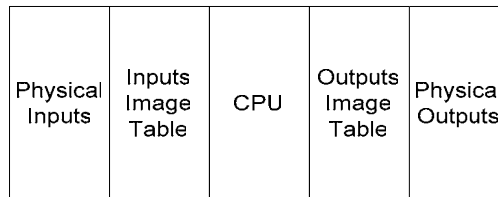
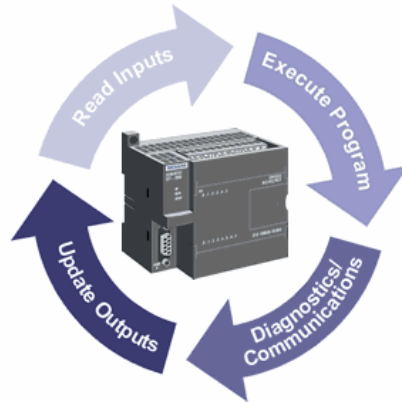


Figure 4.11a General PLC Architecture

The physical input and output (I/O) connection points is the hardware used in the PLC to interact with the external world; for example, sensors, valves, motors, and lights.

The input and output image tables are virtual connection points inside the PLC resembling the state of each point in the physical I/O. These virtual points are the memory locations in RAM that are read or written by the logic in the microprocessor.



Source: Basics of PLCs; 2004, Siemens Automation Internet

Figure 4.11b Representation of a PLC Scan Cycle

The scan cycle is the time during which the PLC central processing unit (CPU) hosts the events related to status of the inputs, execution of the application based on the logic, internal diagnostics and communication check, and the update of the outputs. Refer to figure 4.11b for the representation of the scan cycle, which varies from one PLC to another depending on various PLC attributes such as the CPU speed, memory size, amount of inputs and outputs, and application program size. The maximum scan time is the time elapsed in the longest program cycle of the controller. The average scan time indicates the time elapsed in the average program cycle of the processor, it is a running average. The watchdog time is the maximum time allowed to occur during a program cycle. None of the aforementioned parameters include I/O scan, processor overhead, and communication. The timing structure defined by the scan times, watchdog timers, and rates of tasks execution of the three PLCs is shown in table 4.2. The current average PLC scan cycle time is 10 milliseconds, with a maximum processing peak of 20 milliseconds. The current watchdog timer is set 100 milliseconds; therefore, the PLC can scan approximately 10 times before reaching the watchdog time out.

PLC code already existed in both accumulators to control the machine operation as well as information displayed in their corresponding GUIs related to process status and production lots status. Both Accumulators PLC code are identical to each other in order to keep coding standardization since the accumulators are alike in terms of mechanical and electrical construction, and physical appearance. Additional code was added on both PLCs for the data exchange with the controller of Tool #3.

Each accumulator PLC is sending a heartbeat signal to Tool #3 PLC every 100 milliseconds through both the DH+ and the Ethernet communication media, and Tool #3 PLC is sending back another heartbeat signal to each of the accumulators PLCs so that the three PLCs can detect when one of them is not communicating. The 100 milliseconds period has been determined based on the timing structure of the PLCs in the network. Some parameters related to the PLC timing structure are defined in the following paragraph to clarify the discussion about the heartbeat signals.

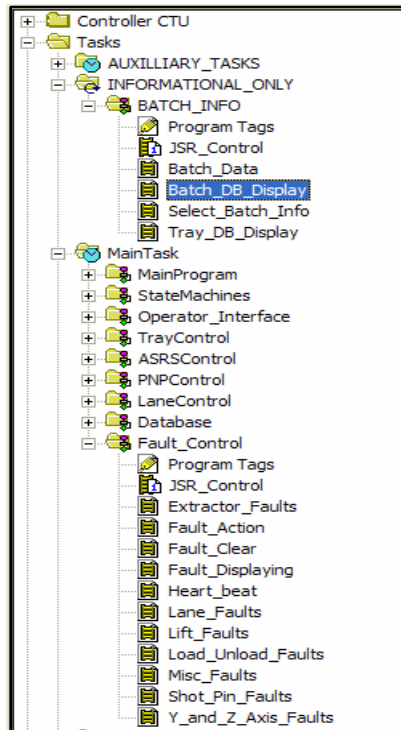
Table 4.2 PLC Processing Time Information

Scan Times{ms}	Tool #3 PLC	Accumulator C3 PLC	Accumulator C6 PLC
Maximum	20	20	20
Average	10	10	10
Watchdog	100	100	100

The following is an explanation of the routines structure of the accumulators PLC, refer to figure 4.12. First, the overall project is divided in tasks, each task has a priority assigned by the programmer in order to control its activation time. This control is similar to the interrupts handling routines in a PC. Each task has a one or more programs, and each program has one or more routines, and each routine has one or more rungs of code logic, also known as ladders.

How to read a PLC program? Start reading sequentially the rungs from top to bottom in order to understand the ladder logic listing in each subroutine. In its most basic definition, a rung is composed of one or more input instructions and one output instruction. The state of the first instruction to the left is examined for true or false; if it is true then the next instruction to the right is examined, and so on until all input instructions on the same sequential path are examined. If all instructions on the path are

true then the output is turned ‘on’. Branches are allowed in a rung, where two or more parallel paths of serial instructions are coded; the instructions are examined from left to right on each path then from top to bottom for every path. If all instructions in any of the parallel paths are true, then the instructions to the right of the branch are examined in the same sequential form, including the turn ‘on’ of the rung output if applicable. If, any instruction state is false then the examination of the rung is terminated. After a rung examination is finished, then the next rung below is examined; unless a ‘jump’ instruction or a call to a subroutine happens, where the sequential flow alters. Similar to computer compilers, CPU registers keep track of the next rung to examined so that the rules for non-sequential flows are met without affecting the logic coded. The related code logic in this thesis has been developed in the *Batch_DB_Display* routine of the *BATCH_INFO* program of the *INFORMATIONAL_ONLY* task, and in the *Fault_Displaying* and *Heart_beat* routines of the *Fault_Control* program of the *MainTask*, respectively.



Figures 4.12 Segment of Tasks, Programs, and Routines Structures For Accumulators PLC

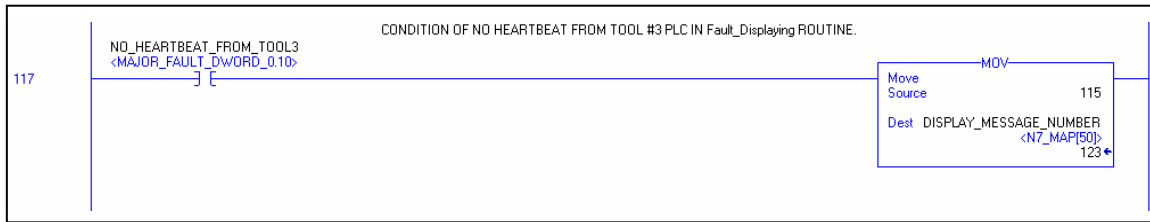


Figure 4.13 Code to Set The Condition of No Heartbeat From Tool #3

Figure 4.13 shows the logic to set the message that alert a condition of no heartbeat from Tool #3 PLC in the accumulator PLC. This code logic runs under the *Fault_Displaying* routine, which enables the alerts messages display for faults. Figure 4.14 shows the logic for controlling the heartbeat between the accumulators. If the regular communication with Tool #3 PLC stops then orderly stop the accumulator. Tool #3 heart beat is accomplished by the Tool #3 periodically clearing the *ext_Tool#3_Heartbeat* tag, while the accumulator PLC continuously sets this tag. If the tag is not cleared within the timer preset value, the fault message will be generated in the accumulator and Tool #3 GUI. The heartbeat is also monitored and reset on transitions. The code logic for only one accumulator is presented in figure 4.14 since both accumulators C3 and C6 have the same code logic. Variable array *N7_TFM,INT[100]* is a new buffer array that keeps the total units, product type, and lot status for each production lot at the accumulator. Data transfer occurs every ten seconds to the controller of Tool #3 by a message instruction, via the DH+ or legacy network.

4.7 Detailed Tool #3 PLC Code Design

PLC code already existed in Tool #3 at Packaging area to control the machine operation as well as information displayed in the GUI related to the packaging process. Tool #3 PLC receives two different heartbeat signals, one from each accumulator. The code logic for Tool #3 dedicated to the heartbeat signal processing is in subroutine 50. Rungs 0000 to 0003 control the reception of the heartbeat signal from C3 accumulator during the rising edge of the signal, and the transmission of the heartbeat of Tool #3 to the C3 accumulator. Rungs 0004 to 0007 control the reception of the heartbeat signal from C6 accumulator, the transmission of the heartbeat of Tool #3 to the C6 accumulator.

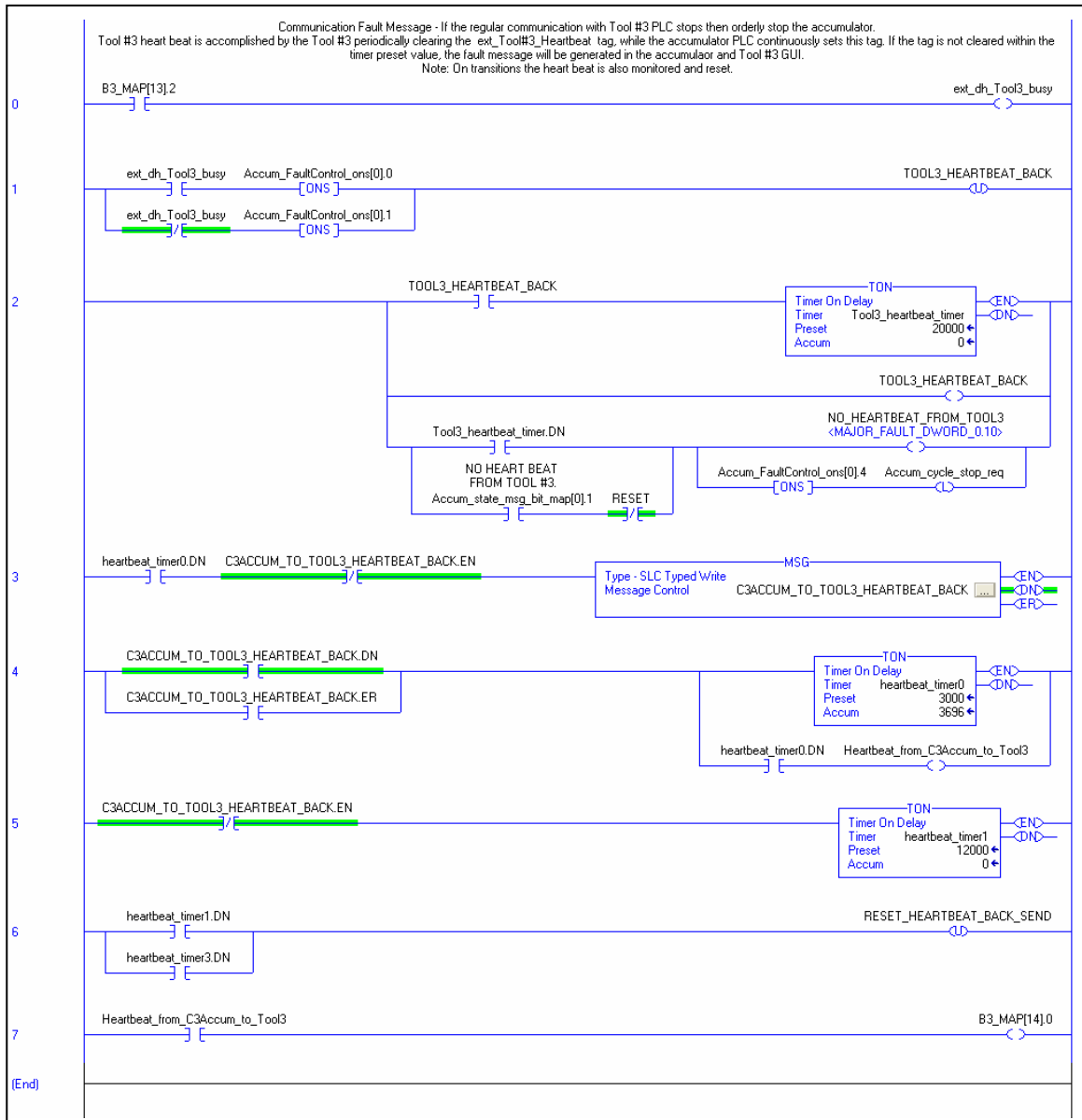


Figure 4.14 Code to Set Heartbeat Functionality Between Accumulators and Tool #3

The logic is the same in both set of rungs: signal from accumulator is received; if it is not received then a timeout occurs and an alert message is enabled. The heartbeat of Tool #3 is sent to the accumulator via a message instruction. DH+ is the media for the reception and transmission of the heartbeat signals for Tool #3. Figure 4.15 and figure 4.16 show the logic for controlling the heartbeat in Tool #3.

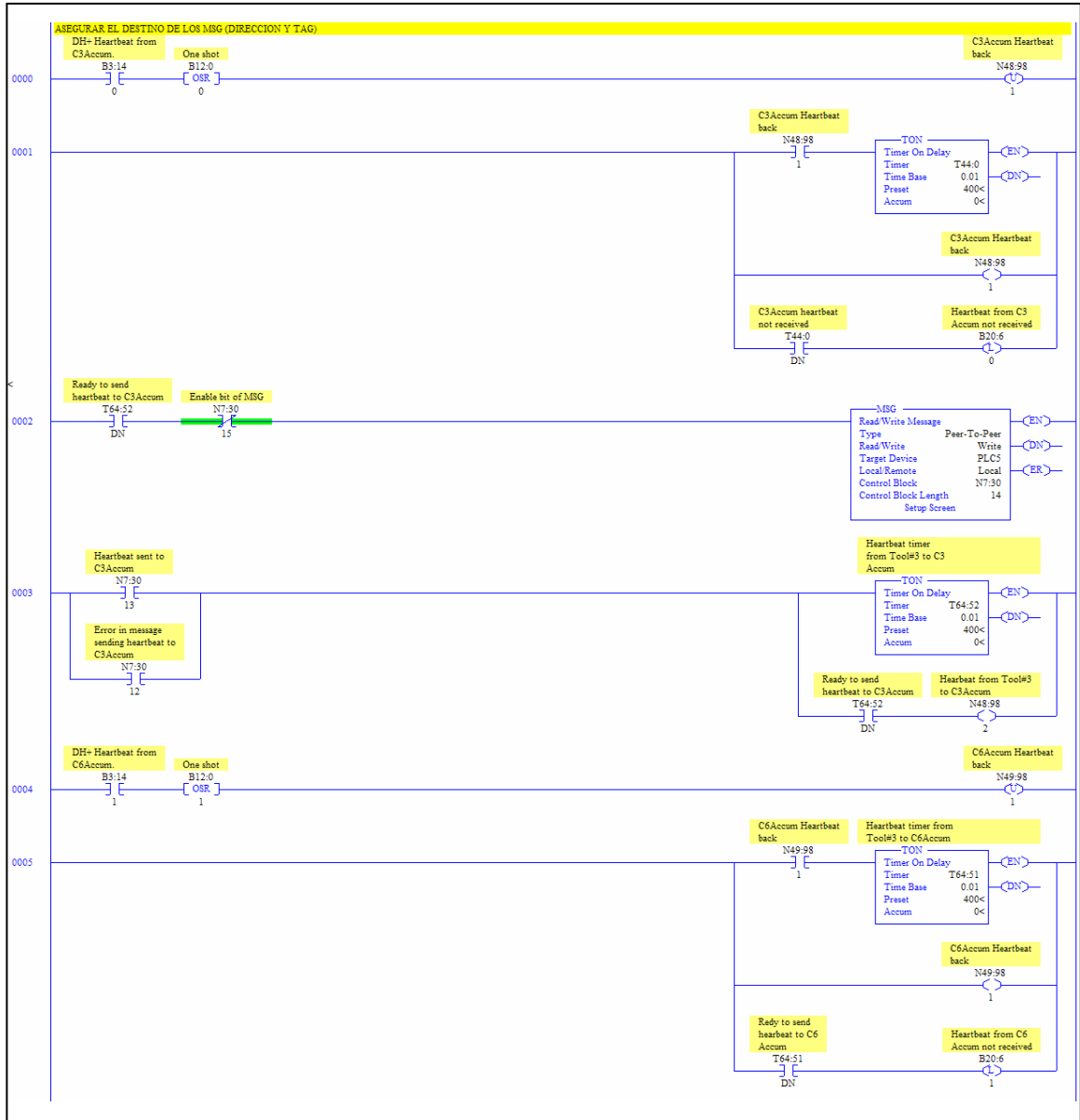


Figure 4.15 Logic for Controlling the Heartbeat in Tool #3

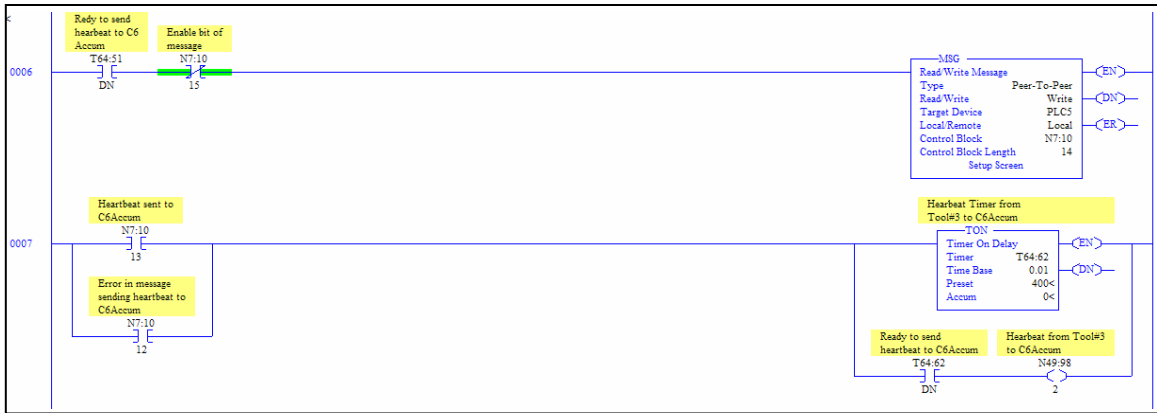


Figure 4.16 Continue Logic For Controlling The Heartbeat in Tool #3

4.7.1 Accumulators Data Display in Tool #3 GUI

Tool #3 PLC contains a number of ladder logic rungs that are executed sequentially once when the routine is called. The routine *P.V. COMM* contains the PLC code to display the additional data from the accumulators. Rungs 0000 through 0005 control the message secure access to screens in the GUI. Rung 006 activates bits 5, 7, 8 and 9 of integer words N48:95 and N49:95 for the transactions of mark (hold) and release lot on C3 and C6 accumulators, respectively. Each lot transaction through the GUI has a confirmation action that the operator has to select to acknowledge the transaction. Refer to figures 4.17a, 4.17b and 4.17c.

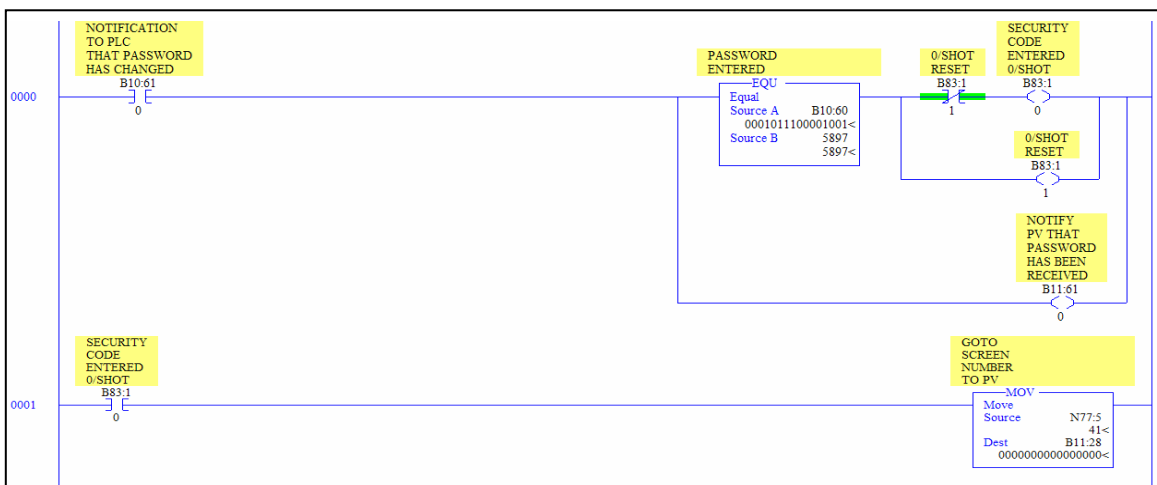


Figure 4.17a Code to Set Lot Transactions Status Including Confirmation

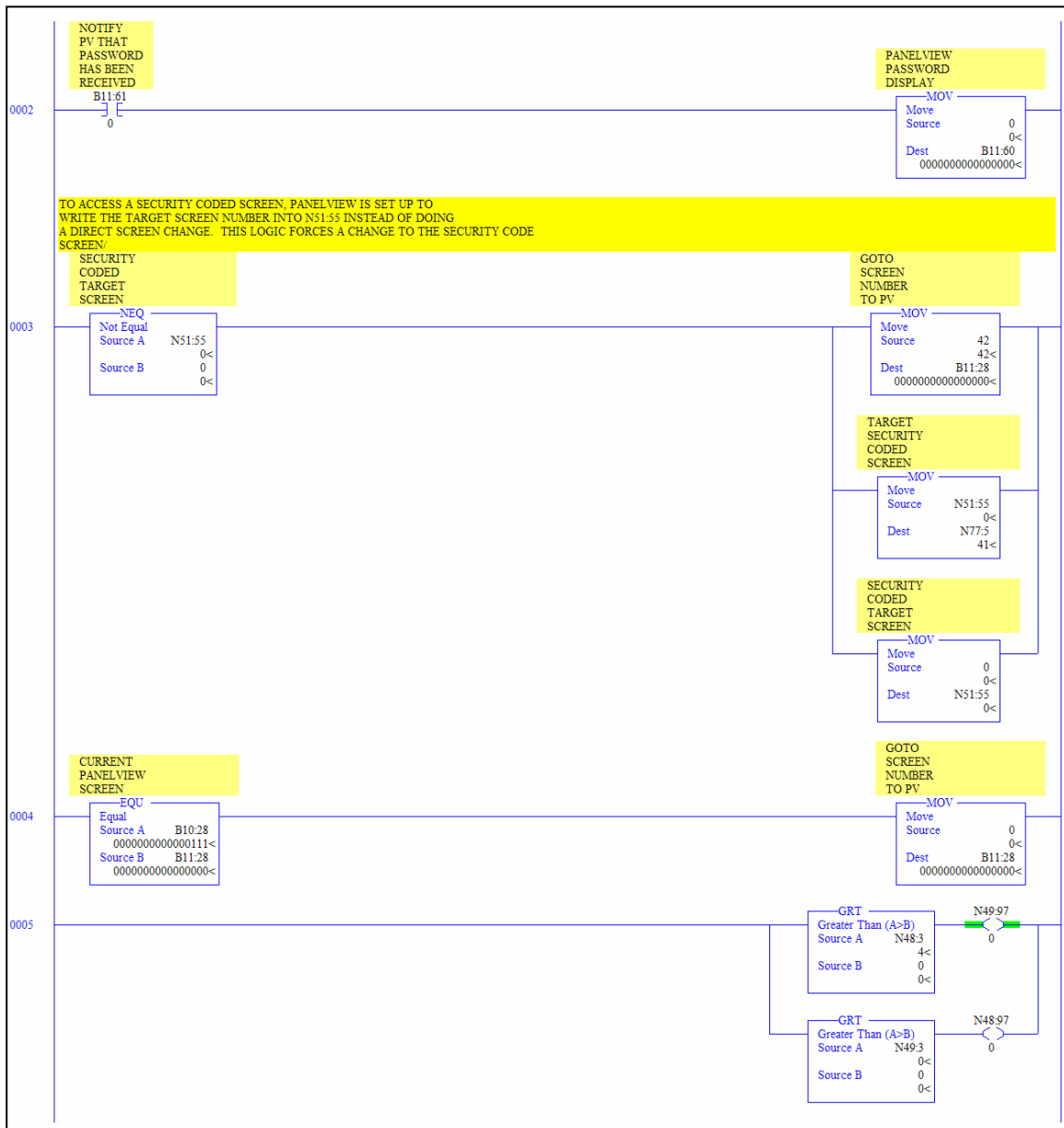


Figure 4.17b Continue Code to Set Lot Transactions Status Including Confirmation

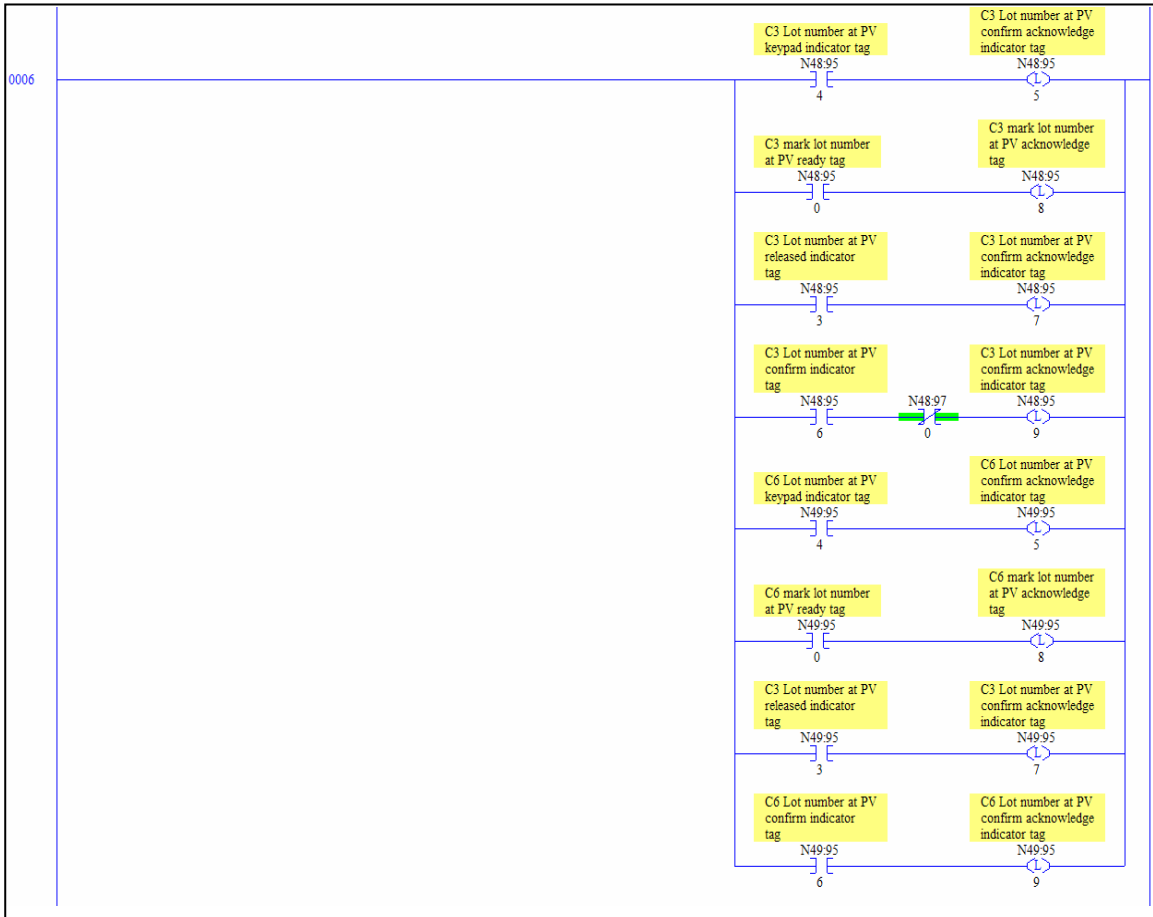


Figure 4.17c Continue Code to Set Lot Transactions Status Including Confirmation

4.7.2 Data Exchange Between Accumulators and Tool #3 Controllers

PLC code already existed in each accumulator controller to control the machine operation to move and accumulate the parts, perform the marking and releasing of production lots, and information display in the GUI related to the accumulation and release of parts. Additional code was added in each accumulator controller for the data exchange with the Tool #3 controller sending or receiving messages via the DH+, legacy communication platform, and Ethernet, added communication platform. C3 Accumulator PLC code will be discussed since both accumulator controllers are identical in terms of software. Additional code logic was added in Tool #3 PLC to stop the functioning of the tool and enable the alert messages in its GUI when the heartbeat signal of either C3

accumulator or C6 accumulator is not received on time in Tool #3. Refer to figure 4.18 for the code to stop functioning.

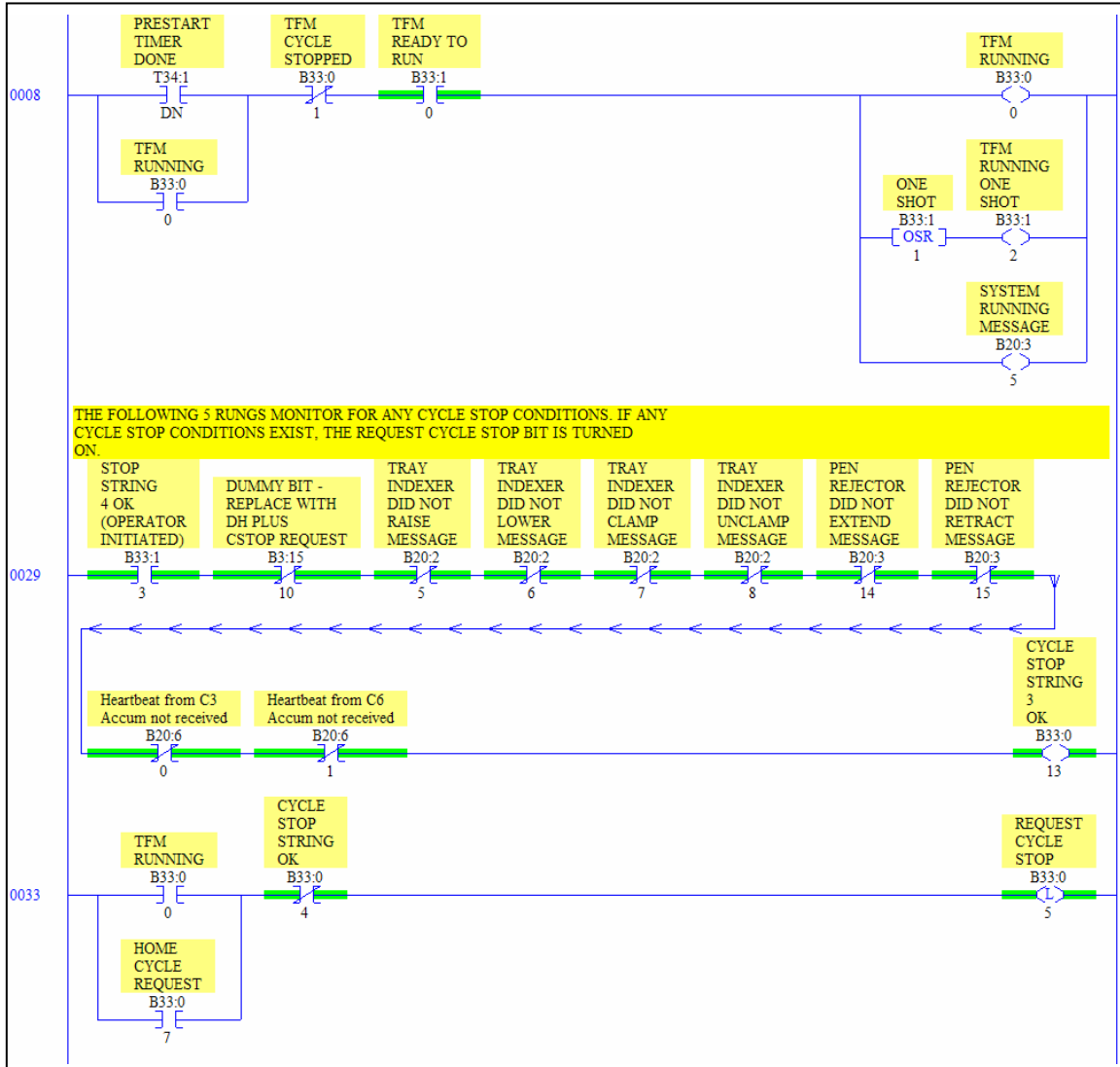


Figure 4.18. Code to Stop Functioning of Tool #3 Because No Heartbeat Received

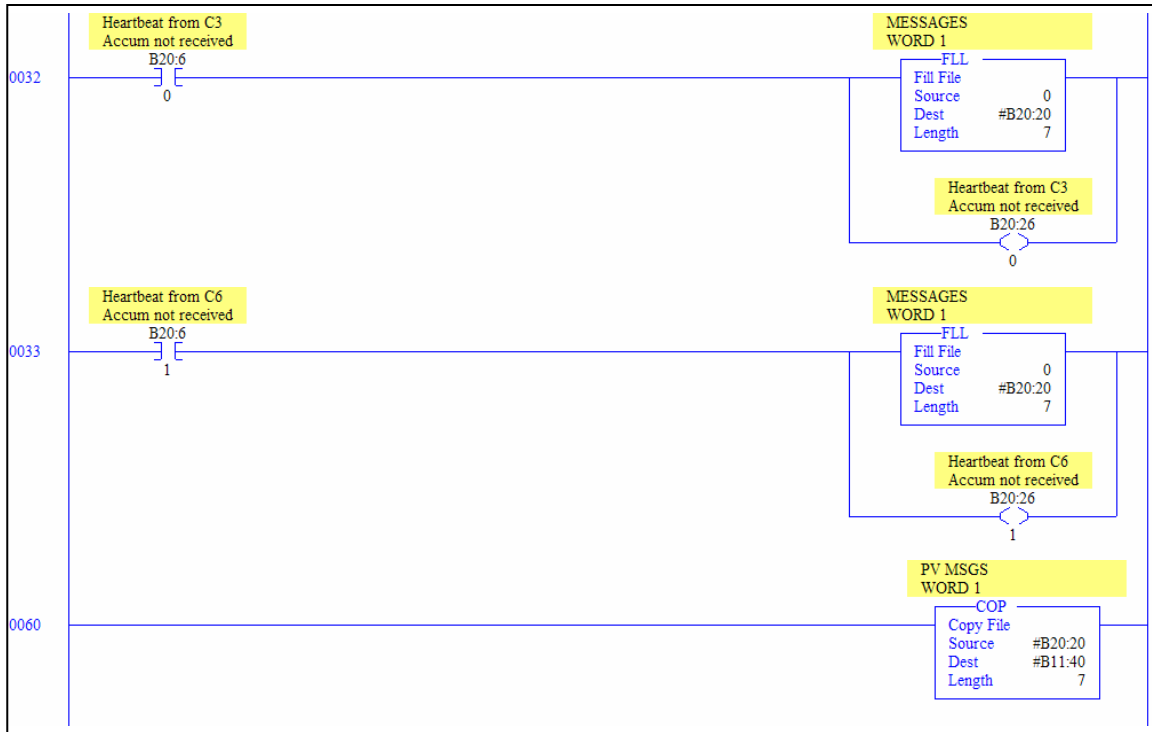


Figure 4.19. Code to Enable Alert Messages in Tool #3 GUI

Refer to figure 4.19 for the PLC code to enable the display of alert messages in Tool #3 GUI due to no heartbeat received. The bits for heartbeat not received like other control bits in Tool #3 are mapped into another arrays of bits, these are B11:40, B11:41, B11:42, B11:43, B11:44, B11:45, and B11:46. Some of these new bits at the PLC code are the enablers of the alert messages in the GUI. In other words, these bits are the outputs of the PLC that enable the inputs in the GUI to display alert messages. Hence, bits 0 and 1 of B11:46 are the corresponding bits 0 and 1 of array B20:26 for the conditions of no heartbeat received.

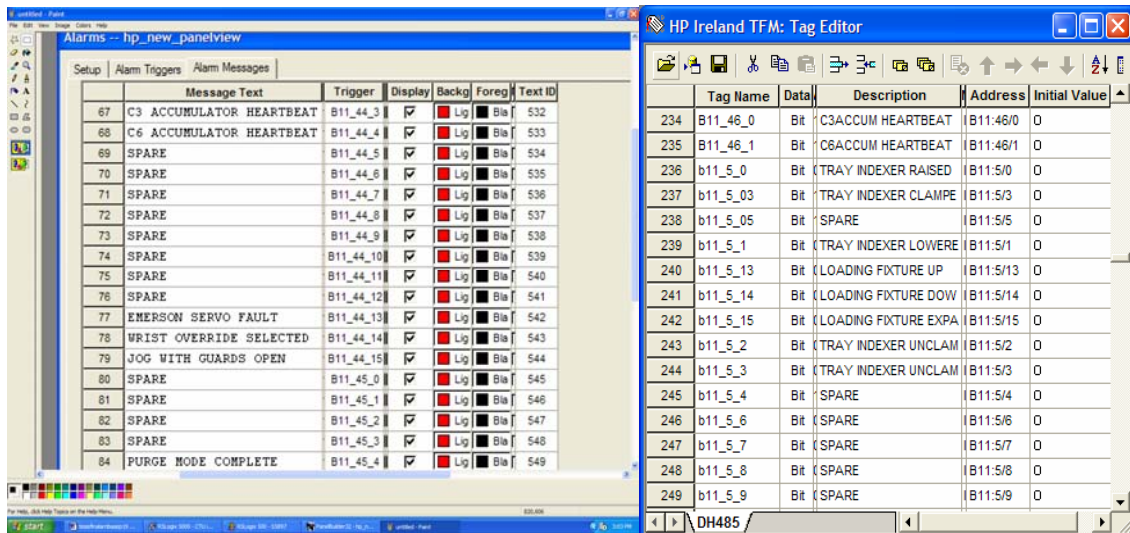


Figure 4.20. Tool #3 GUI Alert Messages Configuration for No Heartbeat Received

Refer to figure 4.20 for Tool #3 GUI alert messages configuration for no heartbeat received. More code was added to the existing logic to store the processor status of Tool #3 PLC into array N122. This allows engineering resource to understand the cause of an error that cause the heartbeat signals not to be received. Also, the additional code copies a good working processor status previously stored in array N121 into array S2. Figure 4.21 shows the Tool #3 PLC code for the heartbeat signal from C3 accumulator. Refer to figure 4.22 for the Tool #3 PLC code for the heartbeat signal from C3 accumulator.

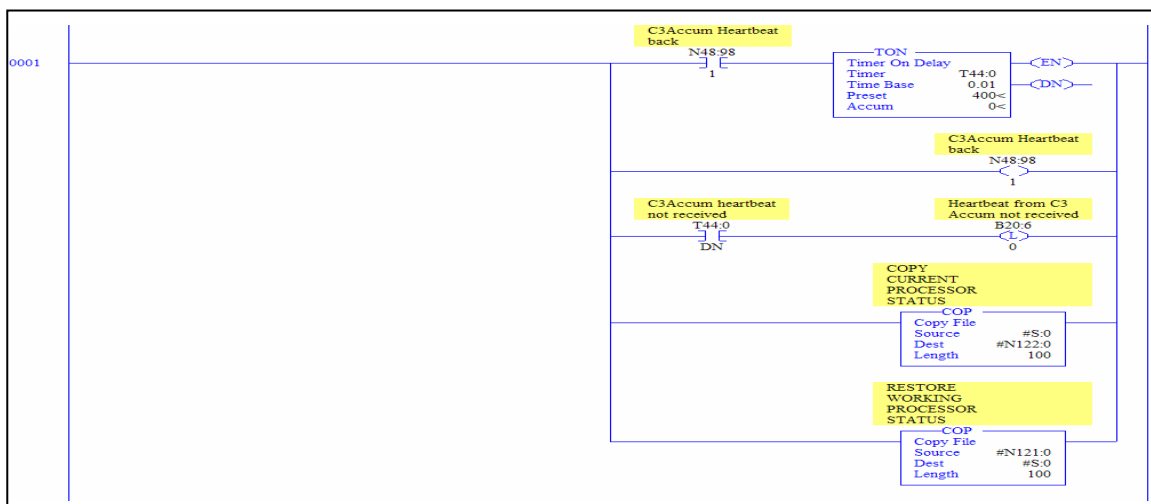


Figure 4.21. Tool #3 PLC Processor Status Copy and Restore for C3 Accumulator

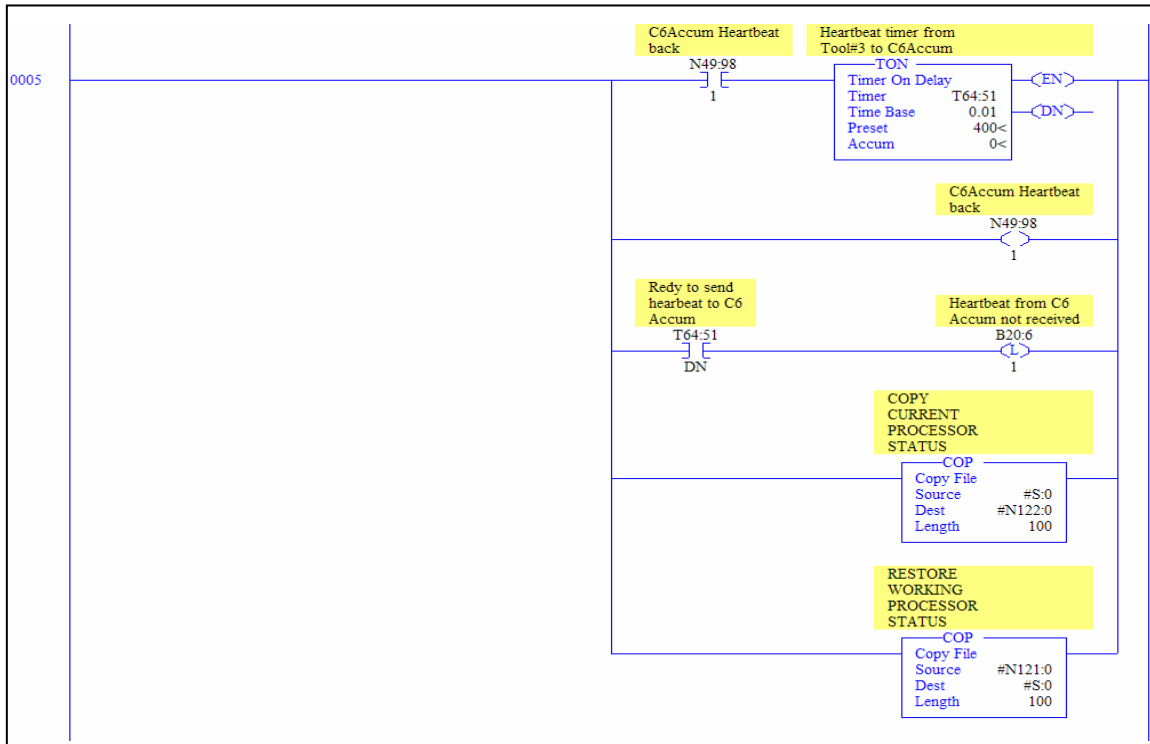


Figure 4.22. Tool #3 PLC Processor Status Copy and Restore for C6 Accumulator

4.8 Summary

The application for the integration of the C3 and C6 accumulators with Tool #3 at the packaging area to exchange information is an implementation that alert and announce operators about downtime issues at the accumulator. The hardware requirements are the following: Datahighway+ (DH+) and Ethernet with wired connectivity, and color screen features in the GUI. After a fault generation the system stores the current processors status and restore a pre-defined good communication configuration.

The GUI of the application follows the Norman's principle: visibility showing the operators the status of the production lots, operational status of the accumulator, and the alternatives for transactions, good relationship between the presentation of the lot and operational status and operator tasks, and continuous feedback to the users of the results of transactions using color and message features. The following chapter will describe the usability test plan conducted on the information exchange application to compare user interaction in both methods.

CHAPTER 5

Test Plan for Information Exchange Application

5.1 Introduction

This chapter describes the usability test plan conducted on the information exchange application to compare user interaction with the information exchange application between the accumulators and Tool #3 at the packaging area. The information exchange application should provide consistently production information of each accumulator to the operators. Therefore, operators can make transactions and look at operational status of the accumulators from Tool #3 GUI. Also, they can follow the traditional method of walking to the accumulator GUI for making transactions and monitoring the accumulator operation. The usability test consisted of collecting data while observing representative users performing typical tasks. The users were operators with work experience at the packaging area. During the usability test, connectivity between PLCs was tested by disabling the connection of one or more PLCs from the network while observing how the system triggers alarms of the disabled points, sends messages to the users interfaces, and stop production if necessary.

5.2 Purpose

The purpose of the usability test was to compare the performance and subjective satisfaction of the operators performing transactions and monitoring accumulator operational status using both the information exchange application and the traditional method. It measured the time taken by operators to complete tasks, the amount of tasks completed, and user satisfaction with some tasks.

The purpose of the connectivity test was to measure the effectiveness of the information exchange application to detect connectivity failures, and to trigger alarms and send messages to the user interfaces in the accumulators and Tool #3 as soon as it detected information was not exchanged when it had to. It measured the amount of connectivity failures for each point in the network, and the amount of messages the

system sent to the user interfaces alerting the system has not exchange information. Then, those measurements are compared to the amount of planned connectivity failures with their corresponding alert messages.

5.3 Problem Statement

The specific questions that need to be answered were:

- 1) How effective are operators performing typical tasks with the information exchange application in comparison with the traditional method?
- 2) How satisfied are operators performing typical tasks with the information exchange application in comparison with the traditional pen method?
- 3) What amount of planned connectivity failures are actually detected by the information exchange application.
- 4) What amount of messages are sent to the user interfaces that match the planned connectivity failures.

5.4 User Profile

A group of 12 participants participated in the study. The participants had experience as operators working in the packaging area as well as in the accumulator area. Hence, they previously used the GUI of the accumulators and Tool #3. Participation of experienced operators helped to keep constant the variable of experience in order to understand the effect of the fault tolerance features and the remote data monitoring and control through information exchange application.

5.5 Methodology

The participants were asked to perform six tasks with two methods: physically moving to the accumulator GUI for making transactions and monitoring the accumulator operation, and making transactions and monitoring the accumulators performance from

the GUI in Tool #3 through the information exchange application. Each participant executed the same six tasks with each of the methods while the test monitor challenge the fault tolerance features of the system during the execution of the tasks.

All participants received a five minutes training session on the new features in the GUI of Tool #3. Each participant was asked to answer a user satisfaction questionnaire after completing the tasks with the two methods. The amount of 12 participants is sufficient for analysis purposes, and the participation of more operators for the test was totally dependent on their availability; a situation out of control for the test monitor. The following subsections describe the most important aspects of the test process.

5.5.1 Background Questionnaire

The participants were personally greeted by the test monitor, and asked to feel comfortable and relaxed. The participants were asked to fill out a questionnaire that gathered basic background information (see Appendix B).

5.5.2 Orientation

They received a short verbal introduction and orientation to the test, explaining the purpose of the test, and additional information about what was expected from them, refer to the orientation script on Appendix B. They were assured and reminded that the information exchange application was the center of the evaluation, not them. They were reminded that they should perform in the way that was typical and comfortable to them. The participants were informed that they were going to be observed by the test monitor.

5.5.3 Performance Test

The performance test consisted of a series of tasks that the participants were asked to perform while being observed using both methods: physically moving to the accumulator GUI for making transactions and monitoring the accumulator operation, and

making transactions and monitoring the accumulators performance from the GUI in Tool #3 through the information exchange application. The participants were observed to see how they accomplish the tasks, and the data collection form was completed for each participant, refer to Appendix B. The participants were encouraged to work without guidance.

The tasks performed by each participant were the same for both methods. The only difference between them were the details of their execution: the operators needed to physically move to the GUIs of each machine in order to obtain the corresponding production information using the traditional method. The operators were physically located near Tool #3 when asked to start with the first task. The tasks were ordered and executed from the easiest (task 1) to the most complex (task 6). Task details are presented as follows: requirements for the task (REQT), task completed successfully (COMP), and maximum time defined to complete the task (MAXT). The description of each task executed with the traditional method is presented in table 5.1

Table 5.1 Task Description for Usability Test of Traditional Method.

Task Number	Task Description	Task Details
1	Read the general production information for an accumulator	REQT: Read general production information in the Accumulator Status Screen. COMP: Move physically to the GUI of C3 Accumulator, click on the <i>Accum. Status</i> button from Main Screen, wait for the Accumulator Status Screen to show, and read the amount of Total Units, the current input lot number and its quantity of units, and the current output lot number and its quantity of units. MAXT: 40 seconds
2	Read the summary information for a production lot in an accumulator.	REQT: Read the summary for lot #10 in C3 accumulator. COMP: Click on C3 Accumulator bar from Accumulator Status Screen and wait for the C3 Accumulator Summary Screen to show. Read from left to right the product code, quantity of units and the status information for lot #10. Then read the field that says Current Output MAXT: 15 seconds
3	Execute transactions on a production lot in an accumulator.	REQT: Mark lot ready and release lot in C3 accumulator. COMP: Press the arrow key on the GUI keypad. Enter lot #10 in keypad shown in the screen. Click on Mark Lot Ready button, then click Release Lot button. Read the quantity on the field Current Output. MAXT: 10 seconds

Table 5.1 Continuation of Task Description for Usability Test of Traditional Method

4	Read the general production information for an accumulator.	REQT: Read general production information in the Accumulator Status Screen. COMP: Move physically to the GUI of C6 Accumulator, click on the <i>Accum. Status</i> button from Main Screen, and wait for the C6 Accumulator Summary Screen to show, and read the amount of Total Units, the current input lot number and its quantity of units, and the current output lot number and its quantity of units. MAXT: 40 seconds
5	Read the summary information for a production lot in an accumulator.	REQT: Read the summary for lot #11 in C6 accumulator. COMP: Click on C6 Accumulator bar from Accumulator Status Screen and wait for the C6 Accumulator Summary Screen to show. Read from left to right the product code, quantity of units and the status information for lot #11. Then read the field that says Current Output MAXT: 15 seconds
6	Execute transactions on a production lot in an accumulator.	REQT: Mark lot ready and release lot in C6 accumulator. COMP: Press the arrow key on the GUI keypad. Enter lot #11 in keypad shown in the screen. Click on Mark Lot Ready button, then click Release Lot button. Read the quantity on the field Current Output. Return to Tool #3. MAXT: 40 seconds

5.5.4 Connectivity Test

The connectivity test consisted of challenging the communication fault tolerance features of the information exchange application by the generation of faults in its communication links during the execution of the tasks by the participants. The test monitor observed the impact of said features in the satisfaction of the participants performing the tasks measuring the amount of planned connectivity failures actually detected by the information exchange application and the amount of messages sent to the user interfaces that match the planned connectivity failures. The faults generated were the following: disconnect the DataHighway+ (DH+) link of C3 Accumulator, disconnect the DH+ link of C6 Accumulator, disconnect the Ethernet link of C3 Accumulator, disconnect the Ethernet link of C3 Accumulator, and disconnect the DH+ link of Tool #3.

Table 5.2 describes when each connectivity test was performed during the sequence of tasks executed by the operator for the information exchange application. Task details present what fault is generated generation (FGEN) during the task execution.

Table 5.2 Task Description for Usability Test of Information Exchange Application Method

Task Number	Task Description	Task Details
1	Read the general production information for an accumulator	<p>REQT: Read general production information in the Accumulator Status Screen.</p> <p>COMP: Click on the <i>Accum. Status</i> button from Main Screen at Tool #3 GUI, wait for the Accumulator Status Screen to show, and read the amount of Total Units, the current input lot number and its quantity of units, and the current output lot number and its quantity of units.</p> <p>FGEN: Disconnect DH+ link of Tool #3.</p> <p>MAXT: 15 seconds</p>
2	Read the summary information for a production lot in an accumulator.	<p>REQT: Read the summary for lot #10 in C3 accumulator.</p> <p>COMP: Click on C3 Accumulator bar from Accumulator Status Screen and wait for the C3 Accumulator Summary Screen to show. Read from left to right the product code, quantity of units and the status information for lot #10. Then read the field that says Current Output.</p> <p>FGEN: Disconnect DH+ link of C6 Accumulator.</p> <p>MAXT: 10 seconds</p>
3	Execute transactions on a production lot in an accumulator.	<p>REQT: Mark lot ready and release lot in C3 accumulator.</p> <p>COMP: Press the arrow key on the GUI keypad. Enter lot #10 in keypad shown in the screen. Click on Mark Lot Ready button, then click Release Lot button. Read the quantity on the field Current Output.</p> <p>FGEN: Disconnect Ethernet link of C6 Accumulator.</p> <p>MAXT: 20 seconds</p>
4	Read the general production information for an accumulator.	<p>REQT: Read general production information in the Accumulator Status Screen.</p> <p>COMP: Click on the <i>Previous Screen</i> button from C3 Accumulator Summary Screen, and wait for the C6 Accumulator Summary Screen to show, and read the amount of Total Units, the current input lot number and its quantity of units, and the current output lot number and its quantity of units.</p> <p>FGEN: Disconnect DH+ link of C3 Accumulator.</p> <p>MAXT: 15 seconds</p>
5	Read the summary information for a production lot in an accumulator.	<p>REQT: Read the summary for lot #11 in C6 accumulator.</p> <p>COMP: Click on C6 Accumulator bar from Accumulator Status Screen and wait for the C6 Accumulator Summary Screen to show. Read from left to right the product code, quantity of units and the status information for lot #11. Then read the field that says Current Output.</p> <p>FGEN: Disconnect Ethernet link of C3 Accumulator.</p> <p>MAXT: 15 seconds</p>
6	Execute transactions on a production lot in an accumulator.	<p>REQT: Mark lot ready and release lot in C6 accumulator.</p> <p>COMP: Press the arrow key on the GUI keypad. Enter lot #11 in keypad shown in the screen. Click on Mark Lot Ready button, then click Release Lot button. Read the quantity on the field Current Output.</p> <p>MAXT: 20 seconds</p>

5.5.5 Participant Debriefing

Each participant was debriefed by the test monitor after the tasks sequence was completed or the time expires. The participants were thanked for their effort and released after the debriefing session. The debriefing included the following:

- Filling out a brief preference questionnaires pertaining to subjective perceptions of usability for each method, see figure 5.1. This questionnaire allowed the operators to judge each one of the preferences criteria with a specific statement of perceptions, corresponding to a measure of agreement or disagreement with the statement. For example, a score of 3 to the left side for the simplicity criterion means that the method is considered very simple to use, otherwise a score of 3 to the right side means that it is very complex to use. The preferences criteria were classified as: simplicity, technology impact, reliability, easy to use, friendliness, professionalism, security, resilience, attractiveness, quality, easy to learn and likeliness.

Preference Questionnaire

Using the following rating sheet, please circle the number nearest the term that most closely matches your feeling about the methods:			
	<input type="checkbox"/> Traditional		<input type="checkbox"/> Information Exchange Application
Complex	3 2 1 0 1 2 3		Simple
Lo tech	3 2 1 0 1 2 3		High tech
Unreliable	3 2 1 0 1 2 3		Reliable
Complex to use	3 2 1 0 1 2 3		Easy to use
Unfriendly	3 2 1 0 1 2 3		Friendly
Unprofessional	3 2 1 0 1 2 3		Professional
Unsafe	3 2 1 0 1 2 3		Safe
Fragile	3 2 1 0 1 2 3		Durable
Unattractive	3 2 1 0 1 2 3		Attractive
Lo Quality	3 2 1 0 1 2 3		High Quality
Complex to learn	3 2 1 0 1 2 3		Easy to learn
I dislike	3 2 1 0 1 2 3		I like

Figure 5.1 Preference Questionnaire Pertaining to Subjective Perceptions of Usability

- Participant’s overall comments about his or her performance.

- Discussion between the participant and the test monitor about specific errors or problems during the test.

5.6 Test Environment and Equipment Requirements

The test environment was the actual manufacturing environment, the equipment used for the test were the GUI of Tool #3 and the GUI of each accumulator.

5.7 Test Monitor Role

The test monitor conducted the test and recorded timing, errors, and observations. The test monitor did not help any of the participants unless they had a question about the test procedures.

5.8 Statistical Analysis

The analysis focused on the relationship between both methods, the probability distribution that the information exchange application follows, what are the significant variables that affect the response time when using the information exchange application, and the measurement of the user satisfaction information exchange application over the traditional method. The dependent variables of the study were time to complete the tasks by operator; some demographics for each operator such as age, gender, and education and computer experience; number of tasks completed; number of errors, number of faults generated and number of messages generated.

A linear regression analysis was used to establish the relationship between the methods. A Kolmogorov-Smirnov test was used to find the appropriate probability distribution function, or goodness of fit test. A correlation analysis was used to determine relationships between overall satisfaction and each satisfaction category.

5.9 Summary

This chapter presented the usability test conducted to compare the performance and subjective satisfaction of the operators for making lot transactions, and monitoring accumulator status and lot conditions using two methods: physically moving to the accumulator GUI for making transactions and monitoring the accumulator operation, and making transactions and monitoring the accumulators performance from the GUI in Tool #3 through the information exchange application.

The communication fault tolerance features of the information exchange application were challenged by the generation of faults in its communication links during the execution of the tasks by the participants. The main steps to conduct the usability test were the following: preparing the test plan, preparing for testing, following the testing plan, doing debriefing and assembling the data. The following chapter will describe results and analysis of the usability test and the connectivity test.

CHAPTER 6

Test Results and Analysis

6.1 Introduction

This chapter presents the results and analysis of the usability test, and the connectivity tests between controllers. The results are analyzed focusing on the comparison of both methods performed by the operators: traditional physical movement to the accumulator GUI, and the information exchange application.

6.2 User profile

User sample for the usability test consisted of a total of 12 participants. They were not required to have any computer experience or typing skills. Table 6.1 presents the results of the pre-test questionnaire administered (see Appendix B). It shows the demographical information of the participants. The numbered one (1) mark which category each operator falls in.

Table 6.1 Pre-test Questionnaire Results

	Computer Experience													
	Age {years}				Sex		Education		Years	Hours/day			Type of Exp.	
	18-25	26-35	36-50	51+	M	F	Col.	Grad.		1-2	2-4	4-8	RTDC	Design
O-1	1				1		1		3		1			1
O-2	1					1	1		4		1			1
O-3		1			1		1		3			1	1	
O-4	1				1			1	6			1	1	
O-5			1		1		1		3	1			1	
O-6		1				1	1		4			1	1	
O-7		1			1		1		3			1	1	
O-8	1				1		1		3			1	1	
O-9				1	1		1		1	1			1	
O-10		1				1	1		3			1	1	
O-11			1		1		1		1			1	1	
O-12			1		1		1		1			1	1	
%	33	33	25	8	75	25	92	8		17	17	67	83	17

The first column refers to the twelve operators. The next four columns shows the range of ages each operator falls in; with a 33 percent falling in 18 to 25 years range, 33 percent falling in 26 to 35 years range, 25 percent falling in 36 to 50 years range., and eight percent (1 operator) with over 50 years old. The following two columns show the gender of the operator, with a 75 percent of males and 25 percent of females. Ninety-two percent of the operators have college education while eight percent (1 operator) has graduate studies. Finally, all operators have computer experience, varying in the daily amount of time using computers with 83 percent of them using computers more than two hours per day.

6.3 Statistical Analysis

This section presents the results of the analysis to compare the information exchange application (IEA) with the traditional method or approach (TA) in terms of time requirements. The amount of 12 participants is sufficient for analysis purposes, and the participation of more operators for the test was totally dependent on their availability, a situation out of control for the test monitor. Goodness for fit tests are used to determine the appropriate probability distribution for the total and the individual task durations.

The initial test performed compared the total duration for the information exchange application (IEA) versus the traditional method or approach (TA). Since each operator used both methods, a paired-t test was performed using $H_0: \mu_{IEA} - \mu_{TA} = 0$. Figure 6.1 shows the results obtained in Minitab. The significant reduction in time when using IEA is easily observed on next page in Figure 6.2, which demonstrates how far away from zero do the IEA-TA values reside.

	N	Mean	StDev	SE Mean
IEA	12	85.167	12.626	3.645
TA	12	107.417	11.008	3.178
Difference	12	-22.2500	5.8016	1.6748

95% CI for mean difference: (-25.9362, -18.5638)
T-Test of mean difference = 0 (vs not = 0):
T-Value = -13.29 P-Value = 0.000

Figure 6.1 Paired T-Test and Confidence Interval: IEA - TA

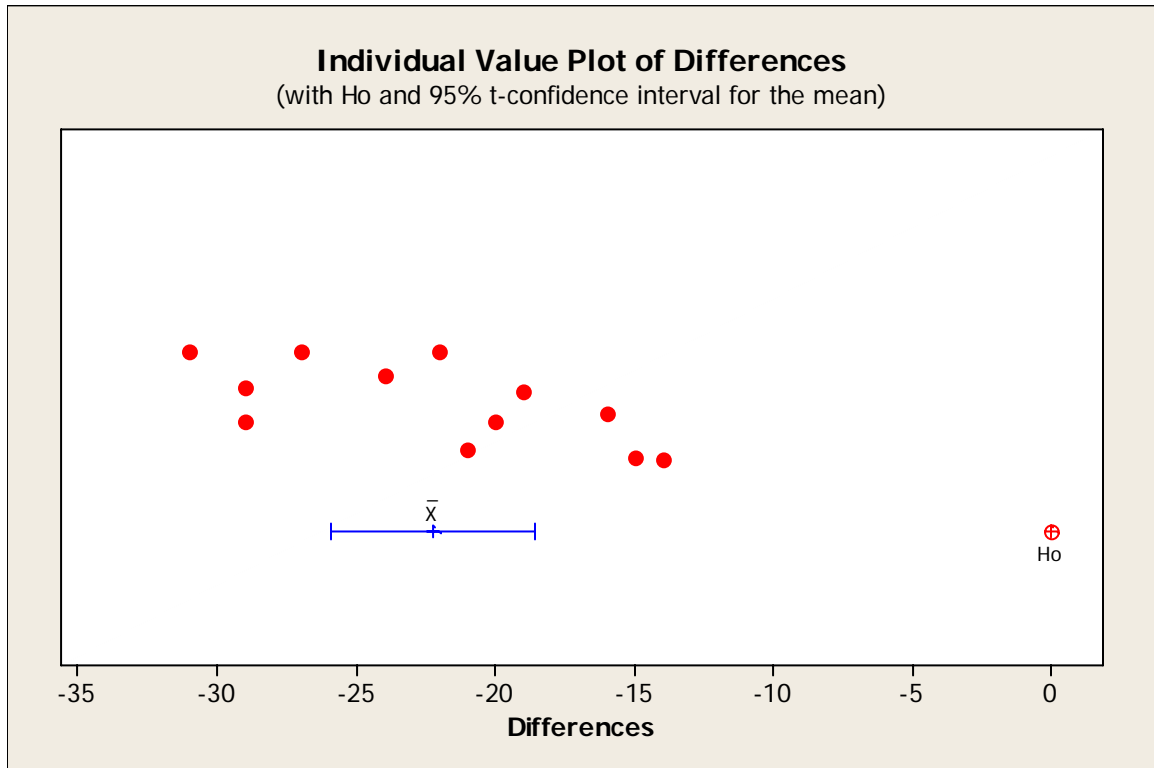


Figure 6.2 IEA–TA Values for the Twelve Operators

The possible relationship between the IEA and TA values was analyzed by means of a linear regression model. A simple straight line ($y=b_0+b_1*x$) model was tested using TA as the independent variable and IEA as the response or dependent variable. The results of this analysis are presented in Figure 6.3a. The R-sq. value (78.9%), known as the coefficient of determination, is defined as the percentage of the variability explained by the model. The correlation between IEA and TA is obtained from the square root of R-sq. and equals 0.888, which is highly significant. The linear model described by the regression equation in Figure 6.3a is easily observed in Figure 6.3b.

The observed time reduction to execute the tasks using IEA vs. TA can be related to improvements in productivity. To increase productivity means to produce more with less. In factories and corporations, productivity is a measure of the ability to create goods

and services from a given amount of labor, capital, materials, land, resources, knowledge, time, or any combination of those [Mintzer92]. In this case, time reduction to execute tasks is directly proportional to an increase in productivity. If the number of lots per 24 hours per day is assumed to be twelve (12), each one needing the series of tasks assigned to the operators. Based on Figure 6.1 the mean time for tasks execution using IEA is 85.2 seconds and using TA is 107.4 seconds; therefore, the corresponding total time consumed per day for each method is 1022 and 1289 seconds, respectively. The total number of transactions time in a year of fifty (50) weeks of five (5) working days each results approximately in 71 and 90 hours, a difference of 19 hours. If this scenario for one production line is replicated to eight (8) production lines then the total transaction time difference is 152 hours; which means 76 lots of capacity increase. If the cost of a lot is \$10,000 then there is approximately \$760,000 of additional income for the company.

The adequacy of the straight line model was evaluated with the analysis of the residual values, which should be normal and identically distributed with mean of zero and constant variance. Figure 6.4 on next pages presents a residual analysis provided by Minitab which checks the normality and constant variance assumptions. These graphs do not reveal any deviation from the required assumptions.

The regression equation is					
IEA = - 24.3 + 1.02 TA					
Predictor	Coef	SE Coef	T	P	
Constant	-24.28	17.98	-1.35	0.207	
TA	1.0189	0.1666	6.12	0.000	
S = 6.08089		R-Sq = 78.9%		R-Sq(adj) = 76.8%	
Analysis of Variance					
Source	DF	SS	MS	F	P
Regression	1	1383.9	1383.9	37.43	0.000
Residual Error	10	369.8	37.0		
Total	11	1753.7			

Figure 6.3a Regression Analysis: IEA versus TA

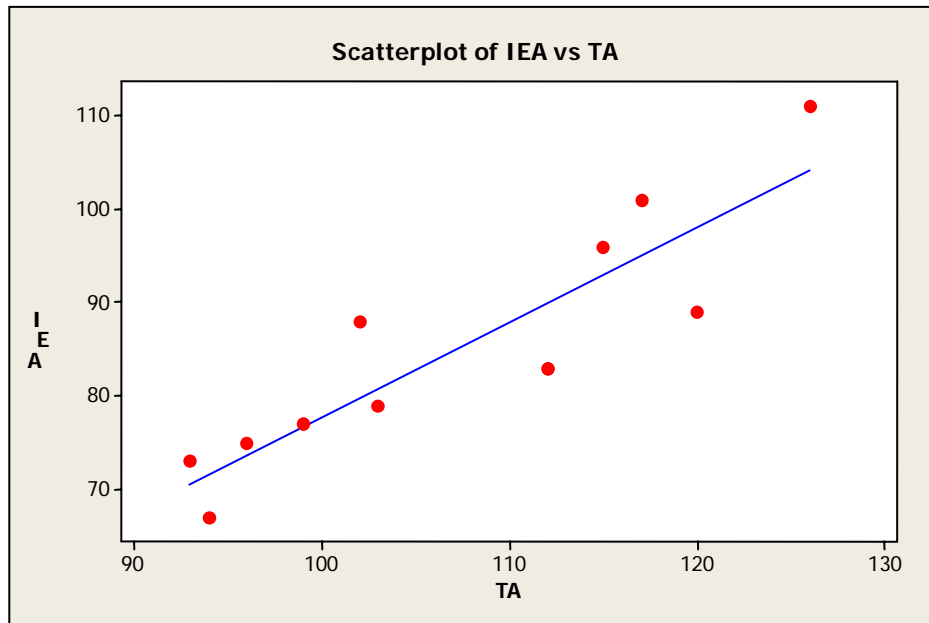


Figure 6.3b Graph of the Regression Analysis: IEA versus TA

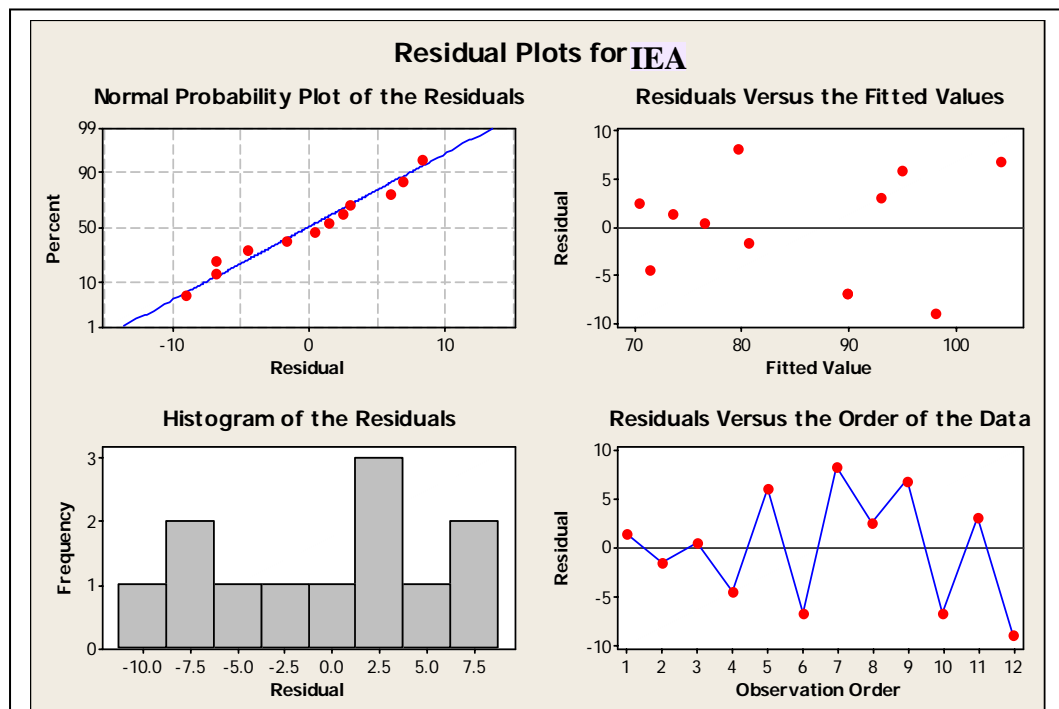


Figure 6.4 Regression Model Residual Analysis

An analysis was performed to determine if the normal distribution can be used to model the IEA values, which result from the sum of six tasks. The Kolmogorov-Smirnov

(K-S) goodness-of-fit test was used given that only twelve data points are available. Figure 6.5 presents the twelve data points in a normal probability plot. The resulting K-S statistic value is 0.131 with a p-value greater than 0.15. This implies that the null hypothesis of normality in the twelve data points cannot be rejected. Similar analyses were performed for tasks 1 through 6; the only task that failed normality was the first one, which had a K-S statistic value of 0.257 with a p-value of 0.036. Given a significance value of 0.05, the obtained p-value lies below this threshold. These results are presented in Figures 6.6 through 6.11.

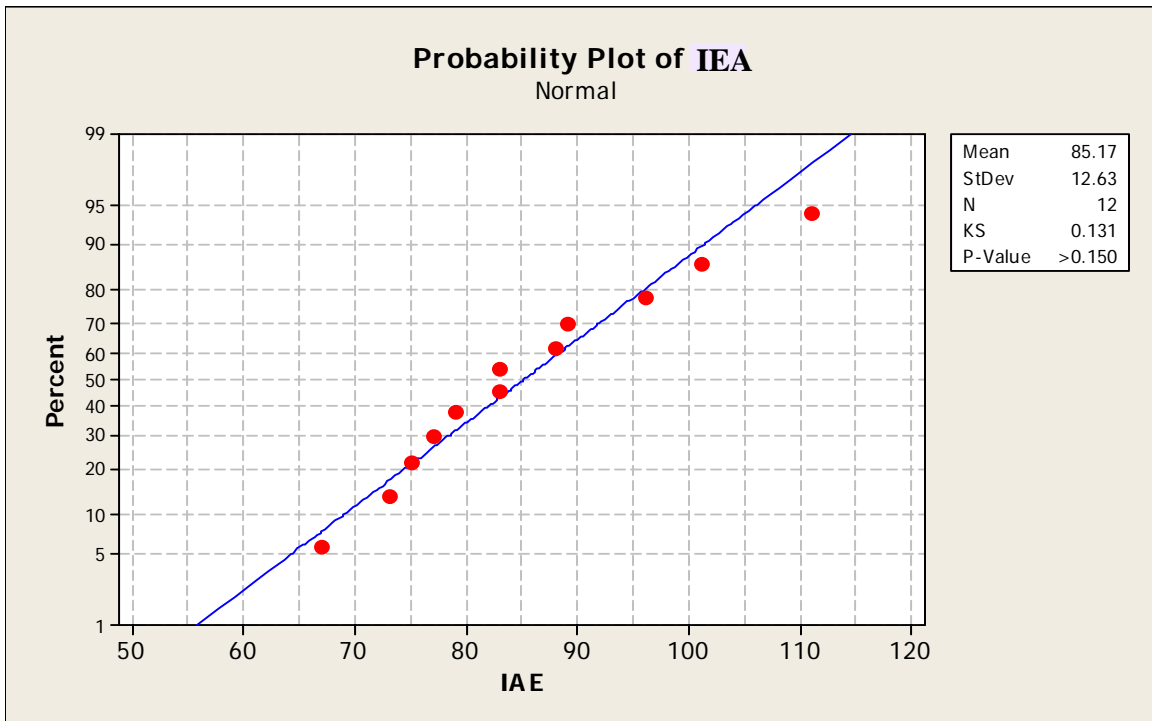


Figure 6.5 Normality Analysis for IEA Values

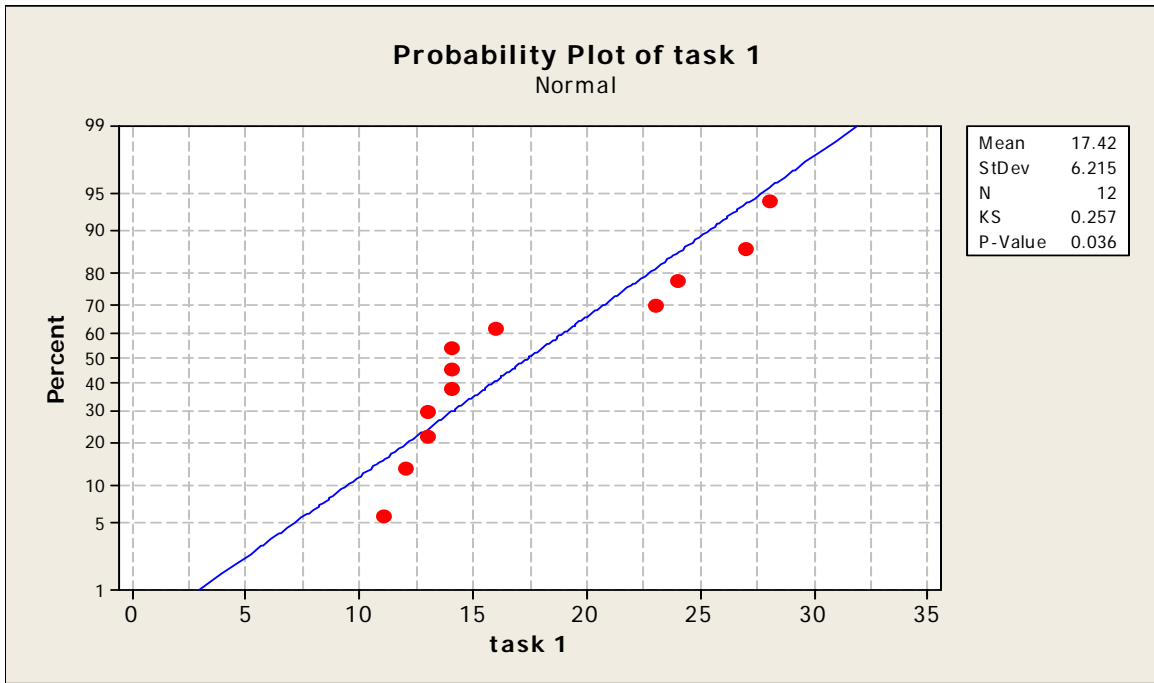


Figure 6.6 Normality Analysis for Task 1

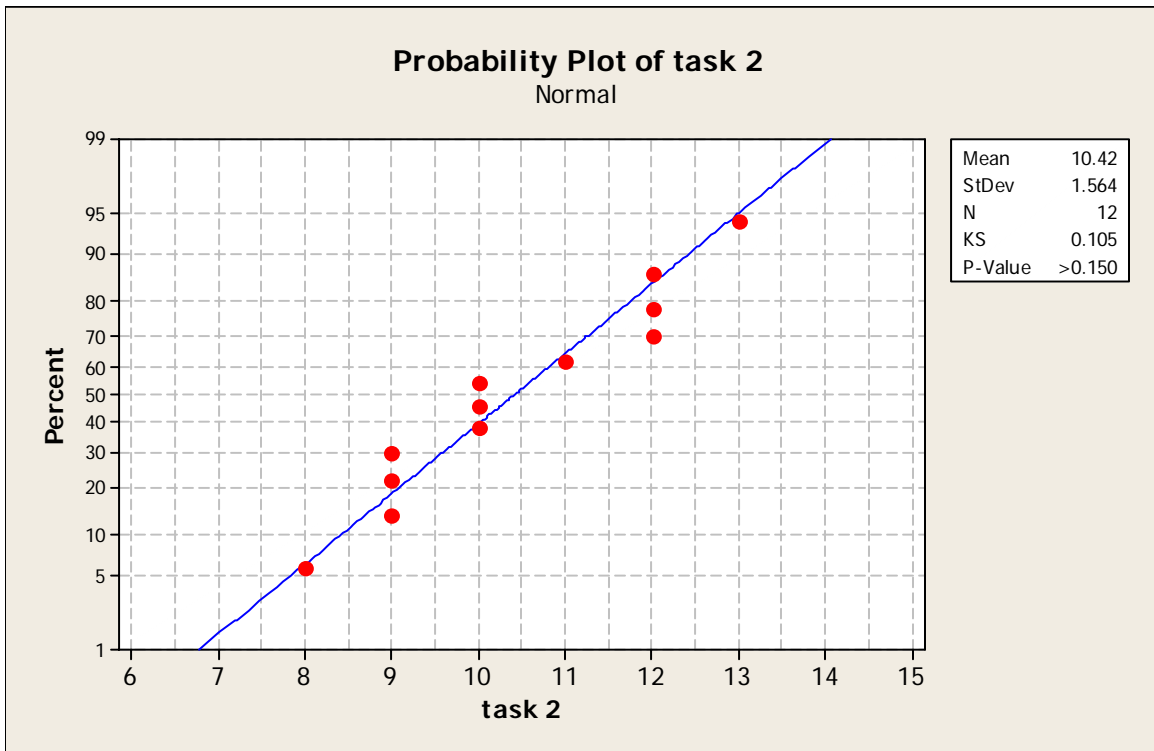


Figure 6.7 Normality Analysis for Task 2

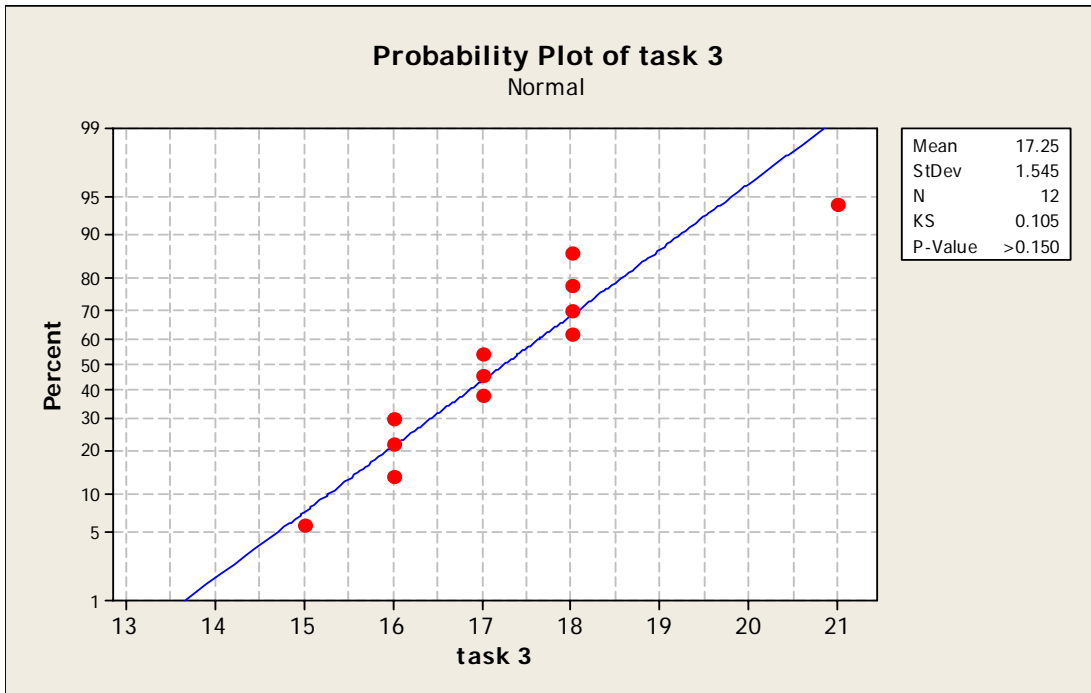


Figure 6.8 Normality Analysis for Task 3

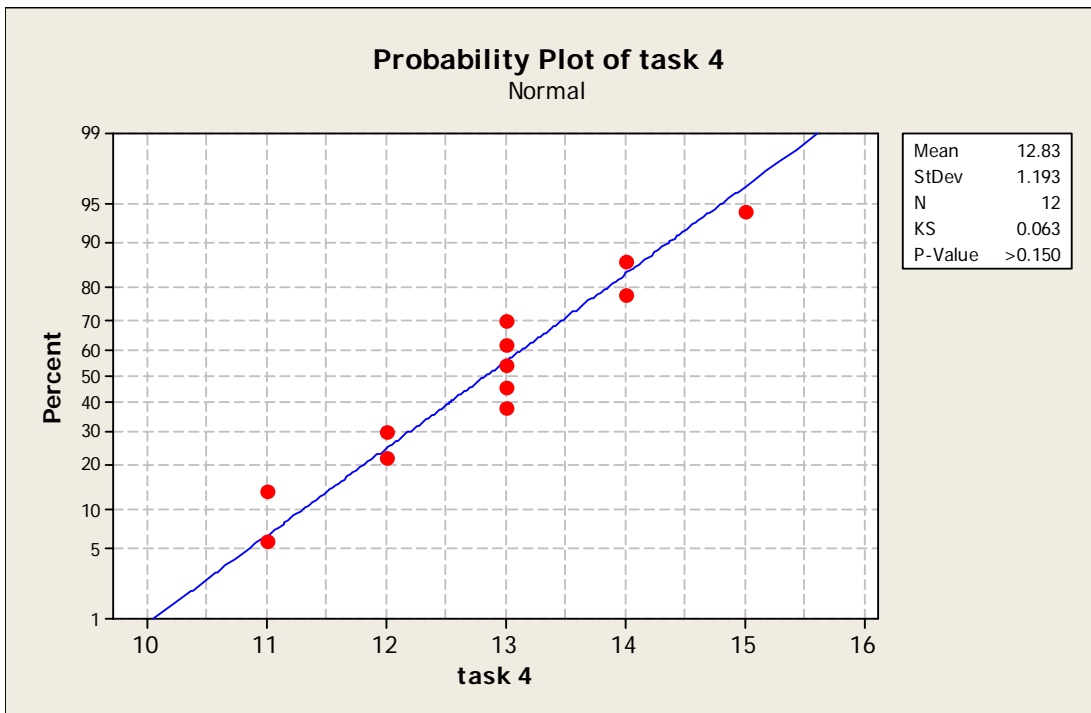


Figure 6.9 Normality Analysis for Task 4

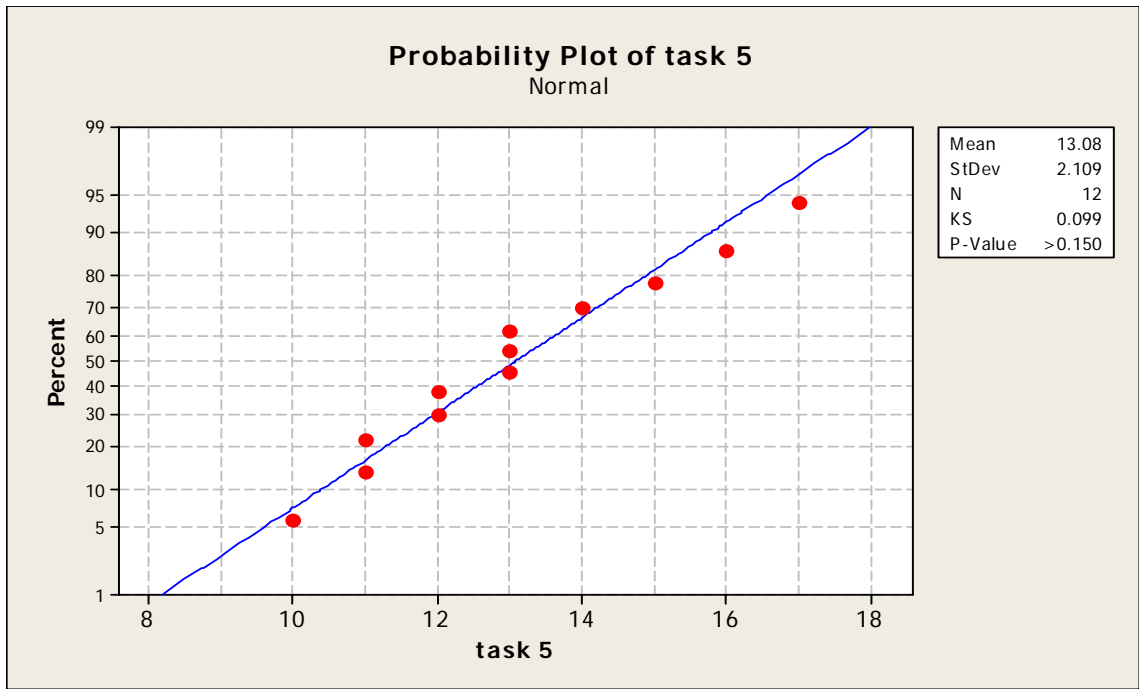


Figure 6.10 Normality Analysis for Task 5

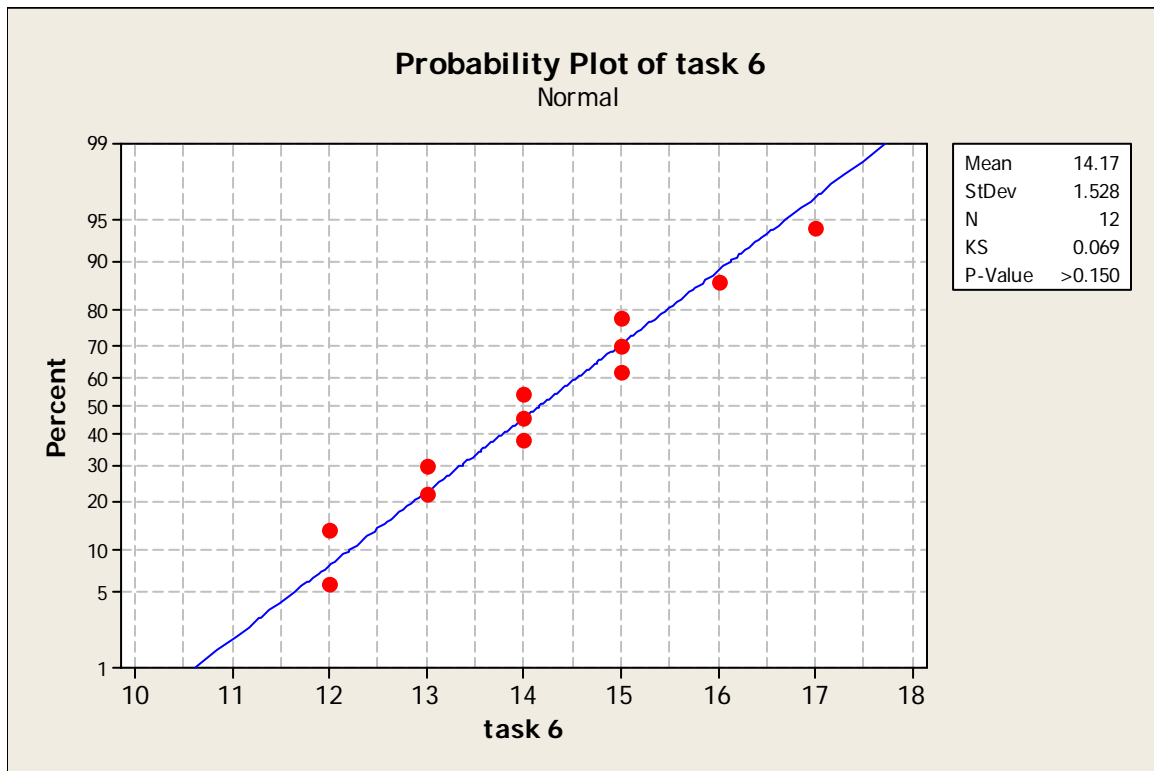


Figure 6.11 Normality Analysis for Task 6

Two final analyses performed relate to age and gender. As explained above, four age classes were defined: 18-25, 26-35, 35-50 and >50. The results from this test, presented in Figures 6.12 and 6.13, reveal that age is a significant factor in predicting task duration in the IEA scenario. The analysis of variance (Figure 6.12) presents confidence intervals for each age range, which move to the right as age increases. The individual value plot (Figure 13) shows the dispersion by age category and also illustrates the increase in IEA as age increases. The analysis performed for gender and its relationship to IEA included nine males and three females. The results, presented in Figures 6.14 and 6.15 reveal much higher variability in male IEA results but no difference in average values.

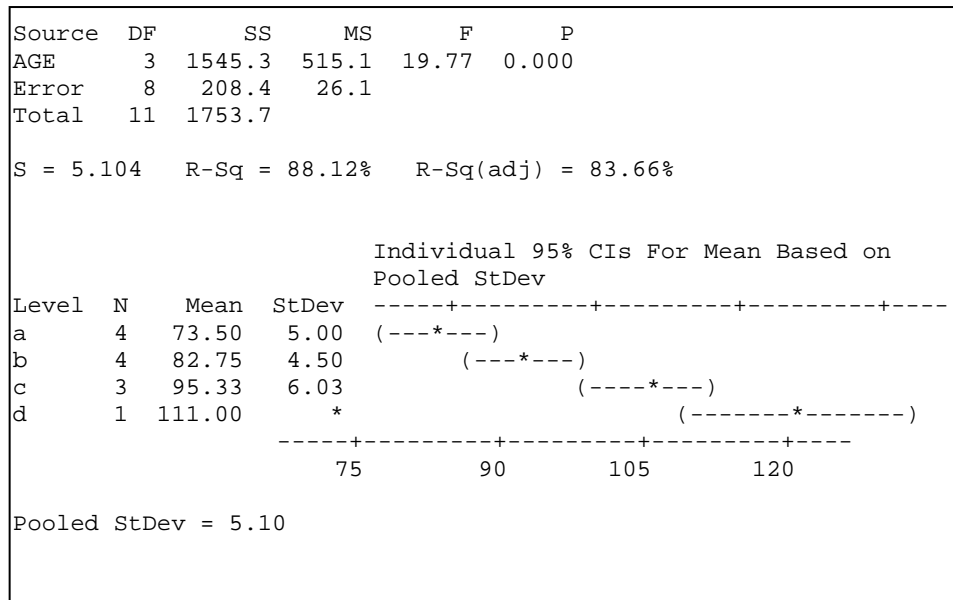


Figure 6.12 One-way ANOVA: IEA versus AGE

The analysis of variance (Figure 6.12) presents confidence intervals for each age range, which move to the right as age increases. The individual value plot (Figure 6.13) shows the dispersion by age category and also illustrates the increase in IEA as age

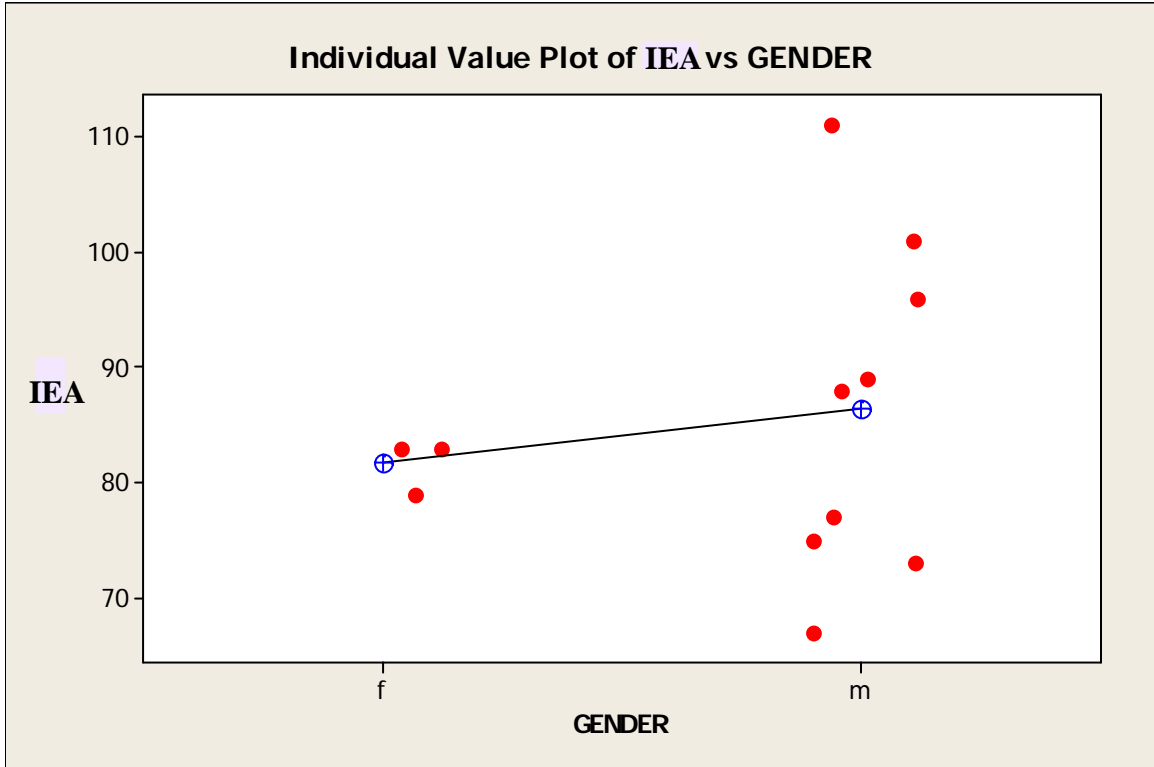


Figure 6.15 Individual Value Plot of IEA vs GENDER

The preference questionnaire results for each method are shown in tables 6.2 and 6.3 on next page. For the analysis purposes the scale of the questionnaire was translated to a -3, -2,-1, 0, 1, 2, 3 scale (refer to Figure 5.1). Table 6.2 shows the preference measures scores when the operators were using the IEA method. Letters a through l are the categories measuring the operator satisfaction. Each operator submits answers, with the row at the bottom showing the average score of each category. Table 6.3 shows the preference measures scores when the operators were using the TA method.

Table 6.2 Preference Measures Scores Using IEA.

Operator opinion about IEA												
Oper.	a	b	c	d	e	f	g	h	i	j	k	l
O-1	2	3	3	3	3	3	3	3	3	3	2	3
O-2	2	3	3	2	3	3	3	3	2	3	2	3
O-3	2	3	3	2	2	3	3	3	2	3	2	2
O-4	2	3	3	3	3	3	3	3	3	3	2	3
O-5	3	3	3	3	3	3	3	3	3	3	3	3
O-6	2	3	3	2	3	3	3	3	2	3	2	3
O-7	3	3	3	3	3	3	3	3	3	3	3	3
O-8	2	3	3	3	3	3	3	3	3	3	2	3
O-9	3	3	3	3	3	3	3	3	3	3	3	3
O-10	2	3	3	2	3	3	3	3	2	3	2	3
O-11	3	3	3	3	3	3	3	3	3	3	3	3
O-12	3	3	3	3	3	3	3	3	3	3	3	3
AVG	2.4	3	3	2.7	2.9	3	3	3	2.7	3	2.4	2.9

Table 6.3 Preference Measures Scores Using TA.

Operator opinion about TA												
Oper.	a	b	c	d	e	f	g	h	i	j	k	l
O-1	3	2	1	2	2	2	2	3	2	2	3	2
O-2	3	2	1	2	2	1	2	3	2	2	3	2
O-3	3	3	2	2	1	1	2	3	2	2	3	2
O-4	3	2	1	2	1	2	2	3	3	2	3	2
O-5	3	3	2	3	2	2	2	3	3	2	3	1
O-6	3	3	3	2	1	2	2	3	2	2	3	2
O-7	3	3	2	3	1	2	2	3	3	2	3	2
O-8	3	2	1	2	1	2	2	3	3	2	3	2
O-9	3	3	2	3	1	1	2	3	3	2	3	2
O-10	3	3	2	2	1	1	2	3	1	2	3	1
O-11	3	3	2	3	1	2	2	3	3	2	3	2
O-12	3	3	2	3	1	2	2	3	3	2	3	2
AVG	3	2.7	1.8	2.4	1.3	2	2	3	2.5	2	3	1.8

A difference in users satisfaction is evident with all items of the post-test user satisfaction questionnaire except items 1 and 11, simplicity and easy of learn criteria, respectively. For the other items the participants were more satisfied with the IEA method than with the TA method. Figure 6.16 illustrates the differences in user satisfaction for the two methods.

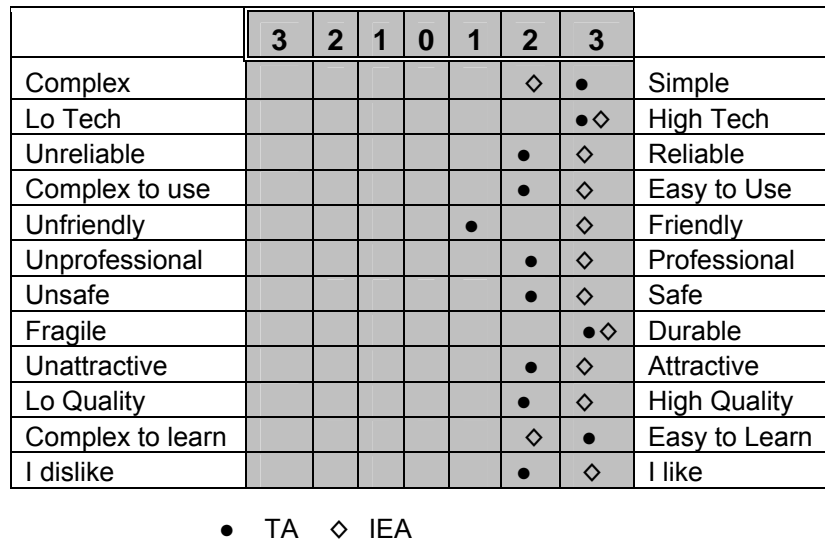


Figure 6.16 Subjective User Measures for TA versus IEA Methods

Each connectivity test was performed during the sequence of tasks executed by the operator for the information exchange application (refer to Table 5.2 for faults generated [FGEN] during the tasks execution). For Tasks 1 through 5 an alert message was generated showing on the Tool #3 GUI, giving the operator the cause of the problem. The test was not performed during the traditional method since the code logic for the alerting communication faults between the controllers in the network was not available. However, if the connectivity test would had been performed for the traditional method, then the response time would have been significantly higher than the response times for the information exchange application; there were no messages active that could alert of the communication fault.

6.4 Summary

This chapter presented the results of the statistical analysis of the tests performed on the traditional application and the information exchange application. The initial test performed compared the total duration for the information exchange application (IEA) versus the traditional method or approach (TA). The significant reduction in time when using IEA was easily observed, which represents a productivity increase for the factory. IEA and TA were related by means of a straight line model. IEA values followed a normal probability distribution function. Age was the most significant demographic factor for the IEA model such that smaller values of IEA were obtained for the lower range of age, from 18 to 25 years old. The operators were more satisfied with the IEA method than with the TA method. The following chapter will present the conclusions of this thesis and future work that could be developed.

CHAPTER 7

Conclusions and Future Work

7.1 Conclusions

Based on the results from the execution of an usability test to compare the information exchange application and the traditional method of physically moving to the accumulators screens, the conclusions are the following:

- The usability test revealed that the information exchange application is usable for processing lot transactions at the accumulators being the operator at Tool #3 of the packaging area, matching 100 % of tasks completed with the traditional method of physically moving to the accumulators screens. In other words, operators can perform the tasks for processing lot transactions with both the information exchange application and the traditional method.
- The usability test revealed that the information exchange application resulted more effective in terms of a faster completion of tasks when compared to the traditional method during the usability test, with 94.44% of tasks successfully completed in less time than expected.
- The operators were highly satisfied with the information exchange application on processing lot transactions and monitoring accumulators status because they considered it simple, reliable, friendly, professional, safe, attractive, high quality, high technological impact, easy to learn, and easy to use. Their experience using the accumulators screens helped them to accomplish the tasks using modified screens at Tool #3 GUI for the first time. The GUI design resulted familiar to them in terms of language and lot processing cycle.
- The development of the information exchange application considered four factors: use of PLC due to stability, reliability and simplicity; network connections such as 10.0 MBauds per second Ethernet and 57.6Kbauds per second Datahighway+, to provide the connectivity between system components; fault tolerant concept employed to reduce the downtime of the

systems due to failures; near real-time monitoring systems to present process status, and track product through the process.

The contribution of this thesis is that it is possible to apply fault tolerance capabilities (heartbeat, media redundancy, and reinstate to functional mode) to a real-time monitoring and control system composed of various different types of PLCs interconnected by a hybrid communication network. Applying such capabilities helps to improve operators speed in task performance in a manufacturing environment therefore their efficiencies, and ultimately the productivity of the factory. After assuming a two hours period for a transaction lot with a price of \$10,000 per lot, the productivity increase would result in additional income for the amount of \$760,000.

7.2 Future Work

The application of fault-tolerance in a hybrid network of PLCs is a contribution to a better implementation of PLC networks to reduce system downtime and improve operators satisfaction. The following are some areas that show opportunities for future research of this thesis: reduction of the time elapsed between the message triggered for the generation of the fault and the reaction of the operator to the problem; benchmark analysis of other communication platforms, like Modbus or wireless, in order to determine which is the best choice for the implementation of the information exchange application; the use of wireless communication could be tested to detect any wireless interference from other devices such as PDAs, scanners for radio frequency identification, motors, frequency drivers, and PCs that are used in manufacturing facilities.

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Appendix A

Task Analysis Instruments

This appendix presents the instruments used in the task analysis for processing transactions at the accumulators and the packaging area.

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A.1 Task Analysis Questionnaire

The following questionnaire, in Spanish, was administrated to operators and supervisors at the manufacturing areas where Tool #3 and Accumulators are located to evaluate the processing of transactions at said manufacturing areas.

Cuestionario

Análisis de tarea – Procesar Transacciones en Acumuladores.

Ambiente

Area de manufactura:

Tool#3 Acumulador #3 Acumulador #6 Otro _____

Persona entrevistada:

Supervisor(a) Operador(a) Otro _____

Edad promedio:

18 - 25 26 – 35 36 - 50 51 o más

Destrezas en el uso de computadoras en general:

- ninguna
- básicas (prender, apagar)
- moderadas (uso de Windows, Internet, aplicaciones como Word, etc.)
- avanzadas (programación de la computadora y sistemas operativos entre otros)

Preguntas

1. Indique las tareas que realiza, favor indicar el orden en que las ejecuta. Si no lleva a cabo alguna de ellas entonces indique N/A en la segunda columna. Puede insertar tareas u observaciones en la tercera columna. Si alguna tarea usted la ejecuta de alguna forma en específico favor de indicarlo, por ejemplo, el mecánico ejecuta la reparación de la máquina.

Tarea	Si/No	Observaciones
Recibir orden para hacer transacción en acumuladores		
Moverse físicamente a pantalla GUI del acumulador C3		
Verificar en la pantalla GUI el status del lote a) Status del lote b) Cantidad de piezas en el lote.		
Marcar transacción "Mark Lot Ready"		
Confirmar transacción "Mark Lot Ready"		
Hacer transacción "Release Lot"		
Confirmar transacción "Release Lot"		
Moverse físicamente a pantalla GUI del acumulador C6		
Verificar en la pantalla GUI el status del lote c) Status del lote d) Cantidad de piezas en el lote.		
Marcar transacción "Mark Lot Ready"		
Confirmar transacción "Mark Lot Ready"		
Hacer transacción "Release Lot"		
Confirmar transacción "Release Lot"		
Moverse físicamente al area de empaque, Tool #3		

A.2 Direct Visual Observation Questions

The following instrument was used to collect data during direct visual observation to operators during working hours at Tool #3 and Accumulators. The focus point was to study transactions processing, specifically moving physically to the GUI screens to find the information required.

Análisis del método tradicional de moverse físicamente para verificar la información de producción.

1. ¿Cómo identifica el lote para hacerle transacción? _____
2. ¿Cómo identifica la información del lote en el GUI? _____

3. ¿Siempre ejecutas ambos “Mark Lot Ready” y “Release Lot”, o uno o el otro? _____
4. ¿Qué otras tareas dejas de hacer para moverte físicamente al GUI de los acumuladores? _____

Análisis del método para intercambio de información

1. ¿Cómo accesa el sistema? Password, etc. _____
2. ¿Que secuencia de menus presenta? _____
3. ¿Cómo sabe que proceso aplica al lote? _____
4. ¿Cómo cambia de menus? _____
5. ¿Cómo cancela una transaccion? _____
6. ¿Cómo sabe si la transacción de “Mark Lot Ready” fue exitosa? _____
7. ¿Cómo sabe si la transacción de “Release Lot” fue exitosa? _____
8. ¿Cómo sabe si hay problemas en el sistema? _____
9. Otras oservaciones:

Appendix B

Usability Test Instruments

This appendix presents the instruments used for the usability test.

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B.1 Background Questionnaire

Participant Background Questionnaire

Job Title: _____

Please answer the questions below in order to understand your background and experience:

Personal

Age:

18-25 26 – 35 36 – 50 Over 50

Sex: Male Female

Education

Please choose the highest level achieved in education and the total years, if applicable.

<input type="checkbox"/> No School	Years
<input type="checkbox"/> High School	
<input type="checkbox"/> College	1 2 3 4 more
<input type="checkbox"/> Graduate	1 2 3 4
<input type="checkbox"/> Post Graduate	

Computer Experience

1. What is the total of time you have been using GUI devices? _____ years

2. On a typical day, how long do you use a GUI to perform your job?

- 1 – 2 hours per day
- 2 – 4 hours per day
- 4 – 8 hours per day

3. Please select the type of GUI you have used:

- VB Forms
- Real-Time Data Collectors (i.e. Factory Link, Wonderware)
- Design (i.e. Multisim, Labview, ..)
- Internet

B.2 Orientation Script

Orientation Script

Buenos dias. Soy Alipio Cabán y con su ayuda estaré llevando a cabo una prueba de usabilidad a una aplicación en la pantalla del Tool #3 que mostrará los siguientes elementos: información de los lotes en los acumuladores, además del status funcional de los acumuladores, y permitirá hacer transacciones de lotes. Para esto necesitare comparar con el método tradicional de físicamente moverse al GUI de cada acumulador para los elementos mencionados anteriormente.

Mi función es observar, escribir notas y tomar el tiempo que tarden en realizar seis tareas específicas relacionadas a obtener información de los acumuladores y hacer transacciones con lotes tanto con el método tradicional como con la aplicación. Agradeceré que se sientan cómodos y si fuera necesario me indiquen en el momento que tengamos que pausar.

Como parte de la prueba no podré solucionar problemas que se encuentren al correr la aplicación. Si así fuera, continuamos a ver si encuentran una forma de solucionarlo sin mi intervención.

Comenzaremos con el método _____ y luego haremos el método _____.

Comenzare a contar el tiempo tan pronto iteraciones sobre la pantalla, y terminare cuando regreses a la pantalla principal.

Tan pronto terminemos con un método pasaremos al otro.

B3. Data Collection Form

Date / Time: _____ / _____

Participant #: _____

Page ____ of ____

<u>Task #</u>	<u>Elapsed Time</u>	<u>Task completed (Yes/No)</u>	<u>Comments and Notes</u>
A1			
A2			
A3			
A4			
A5			
A6			
B1			
B2			
B3			
B4			
B5			
B6			