To the Graduate Council:

I am submitting herewith a thesis written by Siva Kali Prasad Dasari entitled "Sensor Based PLC Programming for a Discrete Event Control System". I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Mechanical Engineering.

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(Original signatures are on file with official student records)

SENSOR BASED PLC
PROGRAMMING FOR A DISCRETE
EVENT CONTROL SYSTEM

A Thesis Presented for the

Master of Science

Degree

University of Tennessee, Knoxville

Siva Kali Prasad Dasari

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ABSTRACT

In the manufacturing industry, automation in material handling has increased the overall profitability of the product with an improvement in the quality and productivity of the system. This is primarily due to two reasons. First, automation reduces the total production cycle time, and second, it helps smooth flow of raw materials and finished products to their desired location with little or no human interference. But, such an implementation involves several problems. One significant problem is the location of sensors that perceive the system environment. A correct choice of sensors at precise locations enables the controller to collect the required information and take a suitable decision that makes the system more robust. Moreover, the sensor logic is vital to control the system.

This thesis addresses the sensor placement and control logic issues in an automated material handling system that was developed by The Providence Group, Applied Technology (TPGAT) at Knoxville, Tennessee. The proposed design prevents deadlock and controller jamming. This is achieved by a suitable control on the occurrence of events in the system. This solution also allows the controller to take decisions for the smooth movement of material. In addition, recommendations for an overall improvement in the structural aspects of the system are discussed. However, additional sensors need to be installed to implement this design. Although similar systems exist this thesis attempts a cost effective solution.

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CHAPTER ONE

INTRODUCTION

1.1 Background

Manufacturing deals with the conversion of raw materials to finished materials or products. The main components of manufacturing process are: business activities, product design, production planning, and production. Business activities deal with sales and marketing, product design concerns with the development of the product according to the specifications of the customer. Production planning and production control the generation of the product.

Automation has brought several drastic changes in manufacturing over the past century. These changes include increase in overall productivity and profitability of a manufacturing system. Development of electronics (transistors and micro chips) led to a jump in control technology and precision of various instruments. This laid a path for efficient and cost effective manufacturing processes. The definitions of automation given by various prominent persons are:

1) ‘Automation is the automatic handling of parts between progressive production methods from the stand-point that we must consider the effects of automatic handling on each and every phase of our manufacturing processes’ [1].

2) 'Any continuous and integrated operation of a production system that uses electronic or other equipment to regulate and coordinate the quantity and quality of production could be termed as automation' [2].

Automation of manufacturing systems requires integration of various fields such as mechanical, control and electronic systems, and computers as shown in Figure 1. Automation in various forms constitutes the backbone of most major industries. It has become a significant part of defense, medical, aerospace and automotive industries, materials processing and handling, manufacturing, and consumer products to meet the increasing demand for the production volume and product variety.

Material handling is an important part of production. Flow of materials in a production system effects the total time taken for producing the complete manufactured product. Different types of material handling systems exist for ease of movement of materials

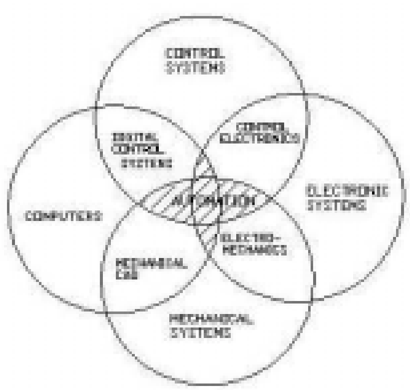

Figure 1. Conjunction of different systems.

on the shop floor. They are listed in Table 1.

Autonomous material handling system has both decision-making and reactive components. The architecture consists of three levels as shown in the Figure 2. At the lowest level the environment interacts with the system. Next level includes the proximity or optical sensors, to perceive the environment to give input to the next higher level and the different actuators that control the output. The role of the decision and execution level is to control the execution of the program in the memory of the central processing unit (CPU)

1.2 Problem statement and approach

When a material handling system is to be made autonomous there is a need for additional sensors and appropriate control logic to manage the discrete events. It should be also noted that an autonomous system does not differ much structurally from the existing system. This reduces the overall cost for the automation. Even before the system is built, modeling and simulation of the system gives not only a good perception of the dynamic

Table 1. Types of material handling systems

Load Type	Weight Range	Handling Type
Packages, Cartons, Plastic Bins	10Kgs-30Kgs	Flat/tilt belt or gravity roller, ball tables
Airport baggage and parcels	20Kgs-45Kgs	Close pitched rollers, conveyors, inclined carousel
Machine pallet and special pallet	More than 1500Kgs	Powered roller, twin stranded chains, walking beam chains, AGV, powered cars, stacker cranes and racking, lift trucks, cranes,

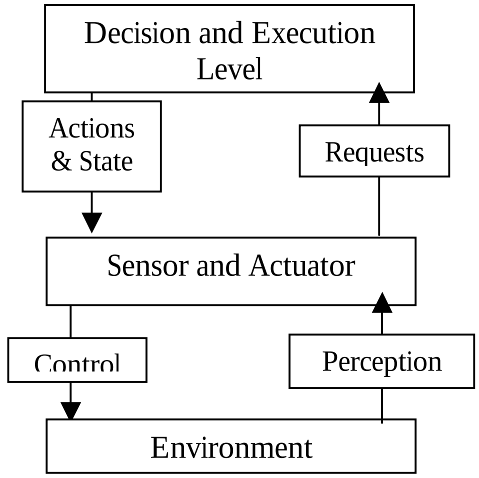

Figure 2. Autonomous system

operations, but also a method to verify the design. An autonomous material handling system can be modeled as discrete event system at a certain level of abstraction.

1.3 Discrete event system

A discrete- event system (DES) is a set of sequences of events that describe the behavior of a physical process. A change in the system's state of the process is precipitated by the occurrence of an action or event and is not time-driven. DES represents many important engineering systems such as: communication/computer networks, manufacturing systems, and transportation systems. State variables in such systems change their values only at discrete instants of time, and more importantly such changes are driven by occurrences of discrete-events or by executions of operation rules. For example, the number of users logging in to a particular computer network remains the same unless a user logs off or a new user logs on (which are random events). Another example is the execution of an ordered sequence of actions in a integrated circuit fabrication facility. Discrete event systems also arise naturally in supervisory-level control of complex systems where discrete decisions are made. Discrete event systems can be complex, stochastic, hierarchical, and nonlinear.

The control community increased their attention to discrete event systems in the late 1970s and early 1980s, when there was need to develop new methods to solve practical problems in a number of areas such as automated manufacturing systems, control of finite-state automata, and verification of logical designs. Surveys of the early developments can be found in research papers in [4]. DES's were soon recognized as a new breed of dynamic systems that are structurally different from the conventional models characterized by ordinary differential equations. Over the past two decades, the proliferation of computer technology, the needs for agile manufacturing, and the rapid growth of communication networks have fueled the research activities in this important field [5].

Ramadge and Wonham developed the framework for modeling the discrete-event systems [6]. Several works based upon the supervisory control theory address the control of discrete event systems [6] and various notions of state estimation under partial observations were first developed in [7]. Work has been done on all major branches of DES ranging from logical control to time-based analysis, from deterministic settings to stochastic frameworks, and from analytical methods to simulation based approaches. A discrete-event control problem arises when we want to restrict the system to perform a specified subset of overall system behavior. A solution to the discrete-event control problem exists when we construct an overseer (or supervisor) to achieve the desirable (or legal) behavior by either preventing some events from taking place (disabling an event) or allowing – but not forcing –others to occur (enabling an event) [8].

1.4 Outline

This work begins with the procedure for developing a machine design concept. It describes the various steps involved, to design an automated system and its components such as actuators, controllers, and sensors in Chapter 2. The following chapter gives a detailed illustration of the present working system and its design problem. Chapter 4 gives the detailed information regarding various design changes proposed and the methodology used to simulate the system. The results and summary are discussed in Chapters 5 & 6 respectively.

CHAPTER TWO

BASIC AUTOMATION DESIGN CONCEPT

2.1 Overview

The design and development of any product must have a predetermined path to achieve its desired objectives. The predetermined path for the design and development of the product is in no way applicable to all designs, but some general rules and guidelines are typically found in any design methodology. Although many authors have various well-documented design methodologies, no particular methodology is all-inclusive for all designs, but a typical design has the following steps:

Step 1: The designer requires product specifications, and technical information from the customer. Basic information required to develop a machine concept includes machine specifications, required performance, and customer unique specifications, such as in house standards, drawings of product assemblies and components, which the machine will have to handle, or otherwise interface/interact with.

Step 2: The process or machine requirements are to be defined on the basis of customer information.

Step 3: Identify alternative methods to mechanize process operations identified above. Before looking for an alternative design the designer has to have complete understanding of the requirements of the present systems in order to incorporate the best of the alternative designs into one.

Step 4: Synthesize system concept(s) to fulfill process requirements with identified mechanizations, using designer creativity and experience with similar kinds of systems. Steps 1-3 of the concept design process have resulted in identifying the system elements with which we have to work.

Step 5: With proven technology, available components and designer experience, evaluate alternative machine concepts technically. Modeling, simulation and value analysis of the system could help the designer to evaluate his conceptual design.

Step 6: The design has to be finalized on the basis of customer budget and requirements along with consistency, maintenance, and availability of spare parts.

Step 7: Detailed Design consists of:

- Prepare individual detail drawings for all fabricated machine parts.
- Perform tolerance study to assure proper machine references, alignments, and clearances.
- Calculate stresses in machine members, holding brackets, pressure vessels, etc., and select material and size members.
- Write control programs (algorithms) if computer controlled.
- Document of operational procedures and troubleshooting of machine

Step 8: Procurement of the materials as per the design specifications and to build the system with the assembly of various parts. Lots of interaction with the customer has to take place between detailed design and this step.

Step 9: Test the system. First the system is tested to meet the structural requirements and then a functionality test is performed to verify whether system meets the requirements of the customer.

2.2 Breakdown of the design into components

2.2.1 Actuators and drive systems

Actuators are the means by which parts are moved. They act like muscles giving power to the system. Actuators are classified as hydraulic, pneumatic and electrical according to the type of energy they use to drive the system. Hydraulic and pneumatic are fluid actuators where power is carried by oil or by air respectively. They different types of actuators, their advantages and disadvantages are listed in Table 2.

2.2.1.1 Pneumatic cylinders

These are popular actuators for use in automatic machinery applications. As industrial facilities have easily available compressed air at pressures 80-100 psi, while low-pressure air can be exhausted to environment without posing any safety or environmental hazard. The fundamental application of a cylinder is to exert a linear force through a distance known as the cylinder stroke. A pneumatic cylinder exerts a non-uniform force over the extent of its stroke. This is due to the compressibility of air. The criteria for selecting

Table 2. Types of actuators

Type	Description	Advantages	Disadvantages
Hydraulic	Motion generated by liquid present in the system. Liquid is typically oil or water based.	High power to weight ratio, high acceleration can be realized.	Leakage problems and expensive. The working fluid usually organic compound possesses safety problems (such as inflammability) in hazardous locations.
Pneumatic	Motion generated by compressed gas, usually air.	Lower cost, good for open-close applications, that is for discrete control.	Analog control of position is difficult.
Electric	Motion generated by electrical power with magnetic flux interacting with electrical current flow.	Good speed control reliable, and readily available power source.	These are more expensive than pneumatic actuators but lower in cost compared to hydraulic actuators. Easier to maintain.

a pneumatic cylinder for machine application are: force, stroke, speed, cylinder configuration, and mounting.

2.2.1.2 Cylinder force requirements

Having defined the force requirements from the conceptual design the minimum cylinder diameter can be selected by:

$$D = \sqrt{\frac{4F}{\pi P}}$$

where, D= Diameter capable of providing required force

F= Maximum force required to be exerted by actuator, including the force to overcome the start the load in motion.

P= Pressure of the air supplied to the cylinder

2.2.2 Controller systems

The controller system will ultimately control the mechanical device and has a great impact upon the overall performance and reliability of the machine. In fact the controller can “make or break” a design.

The types of controller systems are listed in Table 3.

2.2.2.1 Basic structure of programmable controller system

The general structure of a programmable controller system is illustrated in Figure 3. These functions communicate with each other and with the signals of the machine/process to be controlled.

Table 3. Types of controller systems

Type of Controller System	Principle and Characteristics	Advantages	Disadvantages
Relay Control	Control relays are used to implement sequential machine control.	Very cheap and simple in logic for small tasks like building lighting or alarm systems	Cannot perform complex tasks and not flexible. Wiring is expensive.
Programmable Logic Controller (PLC)	The PLC environment allows for I/O cards, motion control cards, etc.	They are very well established for industrial applications.	Multiple controllers are required for controlling different systems.
Industrial Microcomputer (PC Based)	Primary function would be motion control and secondary function as logic controller. The architecture includes ISA, EISA, and PCI standard PC bus structures.	Highly versatile, easy to implement.	The software can be overly complex.
Integrated Industrial Modules (Bus or LAN architecture)	They architecture is modular. The back plane of the bus architecture has a very high data transfer rate, which is suited for high data transferal applications. In LAN the communication is done through ethernet or fiber optic.	These are extremely versatile. They minimize the computation requirements due to modular in structure, thus reducing the cost.	User has to integrate the system. Thus user needs to have a good knowledge of the modules. The module cards are expensive.

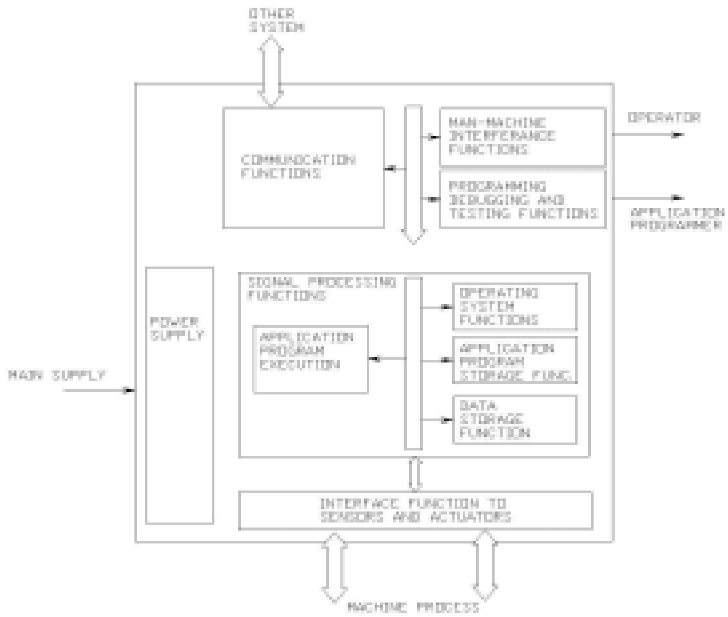

Figure 3. Basic functional structure of PLC

2.2.2.2 Programming of PLC

All controllers have to be programmed to meet the functions of the system. A control program is made up of:

<u>Functions</u>: Standard functions such as ADD (addition), ABS (absolute value), SQRT, SIN (sine), COS (cosine) and Boolean functions like NOT, AND, OR and combinations of Boolean functions are universal in nature. User defined functions, once defined, can be used repeatedly.

Function Blocks, FBs: Function Blocks are the equivalent to Integrated Circuits, ICs, representing a specialized control function. They contain data as well as the algorithm, so they can keep track of the past (which is one of the differences with respect to functions). They have a well-defined interfaces and hidden internal logic, like an IC or black box such as temperature loop control, and PID control. Once defined, it can be used repeatedly, in the same program, different programs, or even different projects. This makes them highly usable. Function blocks can be written in any of the International Electro technical Commission (IEC) languages (ladder logic, instruction list, functional block diagram, structured text), and in most cases even in “C”.

Sequential flow-charts (SFC): SFC describes graphically the sequential behavior of a control program. It is derived form Petri Nets and IEC 848 Grafcet, with the changes necessary to convert the representation from documentation standard to a set of execution control elements. SFC consists of Steps, Linked with Action Blocks and Transitions. Each step represents a condition, which, when true, causes the step before the transition to be deactivated, and the next step to be activated. Steps are linked to action blocks, performing a certain control action. Each element can be programmed in any of the IEC languages, including SFC itself. One can use alternative sequences and even parallel sequences, such as commonly required in batch applications.

Programming Languages: IEC has defined four programming languages. This means that their syntax and semantics have been defined, leaving no room for dialects. The languages consists of two textual and two graphical version:

Textual languages are instruction list and structured text.

1) Instruction List (IL): Instruction List is a textual language. It resembles assembler.
2) Structured Text (ST): It is a powerful high-level language with its roots in Ada, Pascal and "C". It contains all the essential elements of a modern programming language, including selection branches (IF-THEN-ELSE and CASE OF) and iteration loops (FOR, WHILE and REPEAT). These elements can also be nested. It can be used excellently for the definition of complex function blocks, which can be used within any of the other languages.

Graphical languages are ladder diagram and functional block diagram.

1) Ladder Diagram (LD): It is based on the graphical presentation of relay ladder logic. The symbols are similar to electrical circuit.
2) Function Block Diagram (FBD): Function Block Diagram is very common to the process industry. It expresses the behavior of functions, function blocks and programs, as a set of interconnected graphical blocks, like electronic circuit diagrams. It looks at a system in terms of the flow of signals between processing elements [9].

2.2.3 Sensors

Sensors are devices through which a system is able to perceive its environment. They are an important component of an automated system. They are of different types, classified according to their application or according to the approach of measuring data from the working environment. There are different technologies employed in sensing schemes- contact closure, magnetic, piezoelectric, capacitive, photoelectric, magneto resistive, piezoresistive, ultrasonic, acoustic.

Types of sensors or sensing equipment according to the approach of measuring data from the working environment:

1) Contact Sensors- These sensors interact with the surroundings at the work place or with the job being performed to make their measurements or to get data about the job. The following are the types of sensors that are usually used as contact sensors:

    i) Micro switch. This is the simplest form of contact sensors. Micro switch provides with a simple binary output (0 or 1) representing the presence or absence of an object. The control of applied forces and accurate positioning of switch is difficult due to the inertia of moving parts; but they can be used for supervising static states like door or valve positions, start/stop positions.

    ii) Tactile Array sensors. These sensors are mostly used in mobile robots and automated guided vehicles (AGVs) to provide a last resort indication of collisions with surrounding obstructions.

2) Non-Contact Sensors. These sensors are preferred over contact sensors when sensors cannot be in physical contact with the job. This can be due to various engineering considerations, like blocking of the process

of job execution (especially in continuously flowing process) or the nature of the sensor is that it does not need contact at all. The following are frequently used non-contact sensors:

i) Acoustic sensors. These are used to sense over long ranges for various objects. The principle is similar to the hearing phenomenon in bats.

ii) Proximity sensors. These sensors detect an object when it is at a certain distance. Table 4 gives the common types of proximity sensors.

iii) Optical sensors. They work on the principle, interrupt a light beam by a work piece or machine element or reflect a light beam back by the work piece or machine element passing in front of the projected beam. The reflection can be direct scan, reflective scan, and retro reflective scan. For example, photoelectric sensors, optical time-of-flight sensors, vision sensors, and rotary position encoders.

Sensors can also be classified on the basis of application or on the basis of the physical property they sense or measure. For example: temperature sensor, pressure sensor, flow monitors, level sensors, densitometer, range sensors, speed, orientation, and position. Sensors measure the property using one or more principles mentioned above.

Table 4. Types of proximity sensors

Type of proximity sensor	Description
Inductive	They are designed to operate by generating an electromagnetic field and detecting the eddy current losses generated when ferrous and nonferrous metal target objects enter the field. The sensor consists of a coil on a ferrite core, an oscillator, a trigger-signal level detector and an output circuit. As the metallic object advances into the field, eddy currents are induced in the target. The detector circuit then recognizes the decrease in the amplitude and generates a signal. Care should be taken that vibration the objects is less than the hysteresis band/differential travel to avoid chattering of the sensor.
Ultrasonic	They operate by emitting and receiving bursts of high-frequency sound waves. They are usually in the order of 200kHz. There are two basic modes of operation: opposed mode and diffuse (echo) mode. These have inherent blind zone located in the sensing face. They cannot detect the object if it is in the blind zone.
Capacitive	These are designed to operate by generating an electrostatic field and then detect the changes in this field when target approaches the sensing face. It consists of a capacitive probe, an oscillator, a signal rectifier, a filter circuit and an output circuit. The approach of the target raises the capacitance of the probe. When the capacitance reaches the threshold, oscillator is activated, which triggers the output

CHAPTER THREE

EXISTING DESIGN AND ANALYSIS

3.1 Introduction

General Electric Co. has a manufacturing facility in Maryville, Tennessee. The blank cutting machine is a critical component of the whole facility. It provides the sheet metal for the appliances developed by the plant. As a part of the undergoing automation, The Providence Group (TPG), Applied Technology was awarded the contract to develop an automated material-handling system (shown in Figure 4.) for offloading the loaded pallets (weighing about 6000lbs when fully loaded) arriving from the blank cutting machine. The material handling system should finally send the emptied pallets to the blank cutting machine after being unloaded by a forklift.

Figure 4. Complete material handling system

The whole system was developed, tested and delivered by TPG. The system is mainly comprised of four tables, two optical sensors, and a proximity sensor on each of the four tables. The primary set up of the system is shown in Figure 5. The Figure 5 shows four tables TC1, TC2, TC3, and TC4 that constitute the material handling system that was built, while the roller lift table (RLT) is a part of the blank cutting machine. The four tables are much lower in height compared to the elevation of the RLT. The TC1-A, TC2-A, TC3-A, and TC4-A are proximity (inductive) sensors, while TC1-B, and TC3-B are optical (retro reflective) sensors. The arrows show the direction of flow of pallets. The rollers at the boundary of the system restrict the pallet from moving in any other direction. The whole system is controlled with a Programmable Logic Controller (PLC), while the blank cutting machine runs on a separate PLC.

3.2 Primary function of the system

The moving rollers on the RLT push the loaded pallet towards table TC1. Table TC1 has to be in raised position with the chains moving forward in the direction of table TC2 during the arrival of pallet from RLT. When the proximity sensor TC1-A senses the presence of pallet the table is lowered and is pushed towards table TC2 if the table is empty. Then the loaded pallet is pushed towards table TC3 and where it is unloaded. After it is unloaded, the pallet is pushed towards table TC4. The pallet is pushed from TC4 to TC1 if and only if RLT is empty. Sensor TC1-B cannot sense the

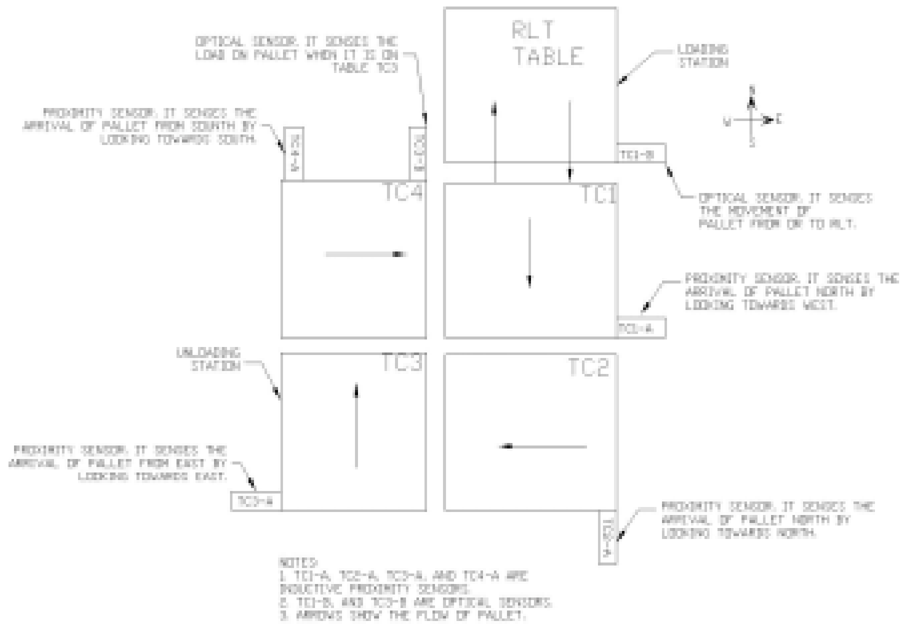

Figure 5. Present system layout

presence of a pallet but it can only sense the passing of pallet. The structural hindrances on the RLT are the cause for this phenomenon. The operator should have the flexibility to run the system in manual or automatic mode. He should have the capability of an emergency stop, and alarm buzzer to acknowledge the emergency situation. The material handling system should send a command to the blank cutting machine before pushing the pallet towards RLT for the blank cutting system to start the motion of its rollers.

3.3 Detailed system description

3.3.1 Actuators

Rodless pneumatic cylinders are used for the moving the pallets over the tables. The bore is 60mm and the stroke lengths are equal to the distance they move the pallet over the table, which is 60” for table TC2 while 48” for tables TC3 and TC4.

3.3.2 Sensors

Four proximity sensors and two optical sensors are positioned on the tables as shown in the Figure 5. Proximity sensors are inductive in nature while optical sensors are retro reflective.

3.3.3 Tables

Table TC1 has different configuration compared to the rest of the three tables TC2, TC3, and TC4. It has two axis of motion; in one axis it has chains driven by an electric motor and has rollers to support the movement of pallet in the other axis. This table was bought from Allied Technologies. It was designed to lift itself to the same height as the RLT. The rest of the three have gravity conveyor rails on the border and ball-transfer conveyor rails as the floor of the tables for the ease of motion of the pallet. Pictures of the tables can be seen in Figures 6 & 7.

3.3.4 Control system

The control system comprises of a micro controller from GE Fanuc, which has the capacity of 16 DC inputs, 1 DC output, 11 relay outputs and power supply. A micro

Figure 6. Table TC1

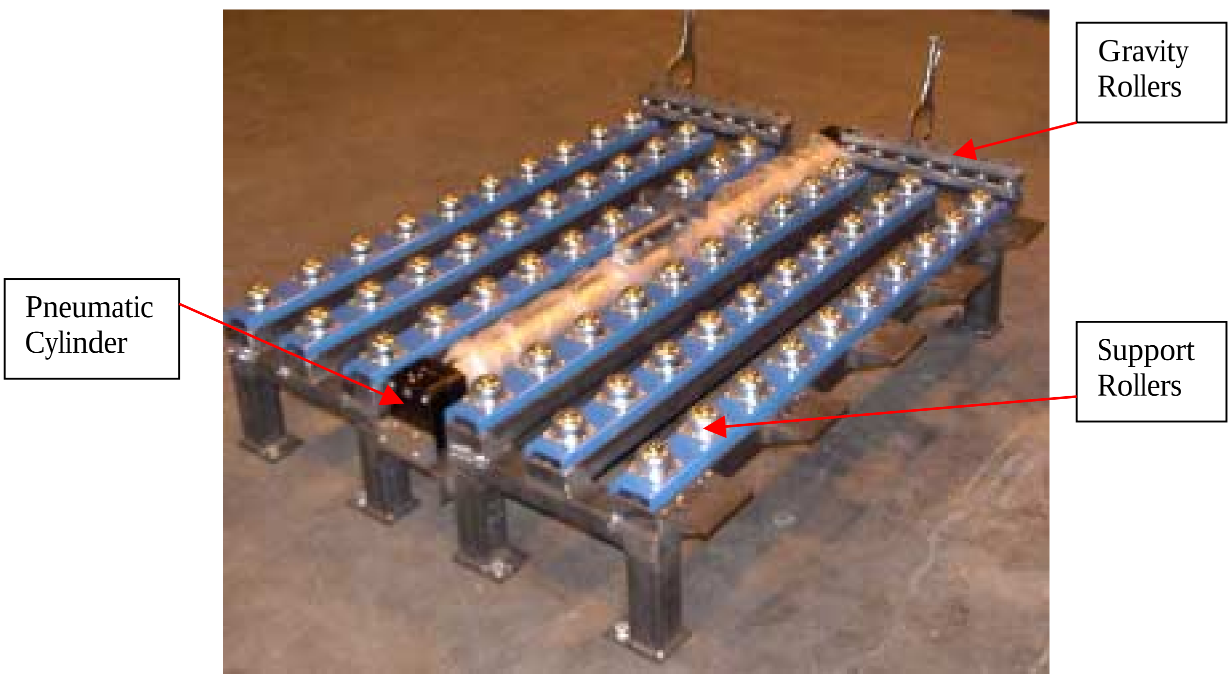

Figure 7. Tables TC2, TC3, TC4

controller extension (with eight DC inputs six-relay outputs and power supply) was also included to facilitate the required functioning of the system. The programming of the PLC was done based on ladder logic. The system works in both automatic and manual mode. Even in the manual mode, all the commands go through the logic and software interlocks for the safety of the system. The following are the external switches for the system:

1) 3- position selector switch for manual, automatic and off mode.
2) Six push button switches (for manual operation) for commanding the pallet to move from one table to another.
3) 3- position selector switch for selecting the number of pallets in the system.
4) One emergency push button.
5) One alarm buzzer.

3.3.5 Working principle

The motion of the pallet from TC1 to RLT and TC1 to TC2 occurs by the movement of the chains on the table. The motion from TC1 to RLT occurs when the table is the up position while the motion from TC1 to TC2 occurs when the table is in down position. The motion of cylinders controls the movement of load from TC2 to TC3, TC3 to TC4 and TC4 toTC1 (the cylinders on the earlier table controls the motion onto the next table). In the manual mode, commands for the movement of the pallet are accepted from the operator, but the command is executed only if the criteria for the movement of pallet are met. The system disregards the command until the various other rules are cleared.

In the automatic mode the system decides which cylinder has to be moved in the correct direction for the motion of pallet using the signal inputs from various sensors located on the peripheral of the table.

In any mode (manual/automatic) the motion from the RLT towards the table number 1(TC1) occurs automatically after the cutting of the sheets is completed. As the loaded pallet comes towards TC1 the sensor TC1-B acknowledges the pallet, which makes the chains on the TC1 to move in the direction of TC2. As soon as the pallet is completely on TC1, the sensor TC1-A stops the motion of the chain.

The movement of the pallet from TC1 towards TC2 is started when there is a load on TC1 and TC2 is empty (sensed by the sensor TC2-A). As soon as this condition is satisfied the chains push the loaded pallet towards TC2 and are stopped by the sensor TC2-A. In any mode for the motion of the pallet TC2 towards TC3, TC3 table should not have any pallet. The motion from TC3 towards TC4 is started only after the load on pallet is removed when the pallet is on TC3. The sensor TC3-B checks whether the load is removed, sensor TC4-A checks whether the table TC4 is empty or not, only after which the process is initiated. The loaded is pushed from TC4 to TC1 only if there is no pallet on TC1 (sensed by TC1-A) and there is no pallet in RLT. This process is done using sensor TC1-B and the logic of the program. The pallet moves onto TC1 when the table is in the lower position. The chains are not active, but the rollers on TC1 aid the motion.

After the system was built at TPG, Applied Technology and delivered to the customer, the customer experienced the following faults in the system due to low interaction of the controller with the mechanical components of the system. The major faults were,

1) PLC was locked in a state of confusion (jammed) when any of the proximity/optical sensors were accidentally activated by human/machine interference. This was mainly due to various timers used in the ladder logic and the commands to the actuators were interlocked with different stages of the program. The sensors ware not positioned appropriately.

2) The pallet was bouncing from gravity conveyor rollers during its traverse from table to table.

3) Active sensors for cylinder stroke were absent; hence the controller was ignorant of the exact position of the cylinder.

4) Oblique movement of the pallet occurred during its travel from table to table. The design of the cylinder pusher was such that the force applied on the pallet was not distributed along the face of the pallet.

CHAPTER FOUR

IMPROVED DESIGN AND ANALYSIS

4.1 Revised design

In engineering scenarios, the designer has the ultimate responsibility to make decisions, which define the basic characteristics of the system. Based on the designer’s experience, advice from manufacturers and customer requirements, the previous design was modified to incorporate:

- The cylinders have proximity switches at the beginning and end of the stroke.

- The shape of the pusher is altered so that the force is applied at two symmetrical places on the pallet. Guide rails are added on tables TC1 and TC2 to avoid zigzag motion of pallet and shock absorbers on TC2 to avoid bouncing of the pallet.

- Limit switches are added for the up and down movement of the table TC1

- The whole of program is rewritten so as to meet the discrete event system criteria (each event is independent of other and determined by its sensors), avoiding timers and to make the system intelligent.

4.2 Structural

The proposed system consists of two shock absorbers, the same pneumatic cylinders with proximity switches at the end of each stroke and two limit switches to recognize the up and down position of the table TC1. The entire system can be run in both automatic and manual mode. The position of the sensors on the tables is shown in Figure 8.

The position of sensors TC2-A, TC3-A, TC4-A is to be altered so that they are activated only when the pallet reaches the end position. The proximity switches at the beginning and ending of the strokes of cylinders provide active feedback. These switches help the cylinder to hold in the fully extended position for a few seconds so that the pallet is pressed against the boundary, avoiding bouncing back. Since table TC1 does not has a pneumatic cylinder, shock absorbers are added on table TC2 so that the pallet does not bounce during the travel from table TC1 to TC2.

The addition of guide rails on tables TC1 and TC2 in the proposed systems aids the pallet to move in a straight path. The proposed structural change in the push rod of the cylinder also aids the above objective. The shock absorbers on table TC2 avoid bouncing of the pallet from the guide rails along the boundary of the table.

4.3 Programming

A manufacturing process can be viewed as a sequence of discrete events. These events are a result of characteristics inherent in such systems as job shops, flow shops or flexible manufacturing systems. In typical time history of events, more than one event can occur at the same time, the time intervals between events are usually different

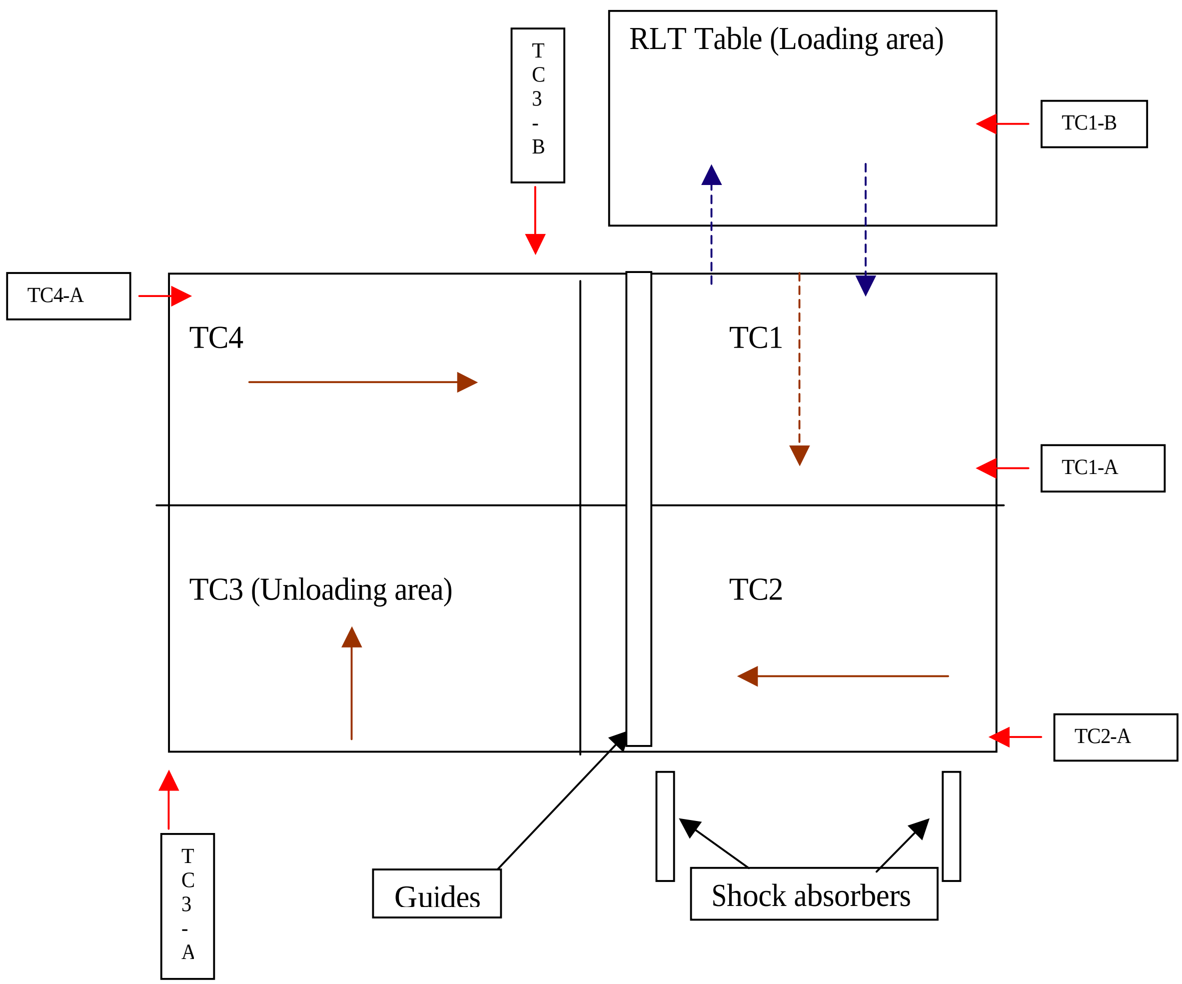

Figure 8. Proposed system

such that it is possible for one event to trigger a series of events and cause the system operations to take place simultaneously (concurrency or parallelism) or asynchronously. In the case of inappropriate event triggering, system operations may cause a deadlock or conflict. The stage programming method helps to avoid deadlock in a discrete event control system. This method can reduce programming time by up to 70% and also drastically reduce the troubleshooting time by up to 85% [11]. Stage programming breaks a program into logical stages, making complex systems design easier. The stages can be programmed individually without concern for how they will affect the rest of the program. At each stage, all the output actuators are dependent on the status of input sensors and they can be easily identified and programmed. The concept of independent I/O combination logic between stages simplifies the interlocking programming process of a complex logic diagram. Output of every actuator is a function of all the inputs from the sensors, which affect the actuator.

The movement of the pallet from one table to another is considered as a single event. To determine the state of the system, sensors are placed to track the events they react to, and to events they generate. Each event is controlled by logic, which is dependent on the table sensors. This type of dependence suggests stage programming. When all the interlocks for the movement of pallet are satisfied, the logic gives a command to the actuator on that table to move the pallet. This makes the system mechanically more robust than the previous system.

4.4 Summary of logic complexity

The program to control the system used number of basic Boolean gates. Table 5 gives a detailed list of number of inputs, outputs and major logic blocks used. Item 6 in Table 5 includes various blocks required for the control of the simulation, performed to verify the control logic. This is discussed in section 5.3 and 5.4 along with the conditions under which the simulation was executed.

Table 5. Control system complexity

S. No	Description	Number
1	Inputs	23
2	Outputs	9
Major Logic Blocks		
1	AND	114
2	OR	16
3	Flip-flop	38
4	Timers	5
5	Counters	4
6	Other blocks	134

CHAPTER FIVE

IMPROVED DESIGN AND PERFORMANCE

5.1 Hardware setup

The PLC hardware consists of the power supply, the central processing unit (CPU), the communication processor (CP), a 32-channel digital input module, and a 16-channel digital output module. The model of CPU and CP is 416-2 (DP) and CP443-1 respectively. All are mounted on an active back plane bus. This system communicates with the computer (Programming Device) through an Industrial Ethernet link.

5.2 Software setup

Siemen's software PCS-7 (Process Control System 7) and WinCC (Windows Control Center 5.0) are used to simulate the system. PCS-7 is the resident software in which PLC logic can be programmed using all four IEC languages stated in section 2.2.2.2. FBD programming language was used to develop the logic of the system.

WinCC is the software to develop graphical interface between the user and PCS-7. It helps the operator/user to have real-time control on the system. The graphical interface can in fact give commands to the system, and display data from the system. It helps the operator/user to monitor the system constantly. Each element in the human machine interface (HMI) is made real-time by tagging them to their respective input/output (I/O) blocks in the logic.

5.3 Simulation

The graphical screen, which controls the whole system, can be seen in Figure 9. The sensors and actuators are represented graphically on the screen. An HMI button is provided on the screen to initiate simulation. When this button is made active by clicking the mouse on its icon, control inputs to the PLC logic are shifted from the real-world field I/Os to the simulated screen inputs. In this simulation mode, clicking on a sensor will toggle the simulated input of that particular sensor to the PLC logic. The top and side view can be seen in the Figure 9.

The improvised system with additional sensors and structural changes is simulated with the setup mentioned in section 5.1. The aim of the simulation is to depict the

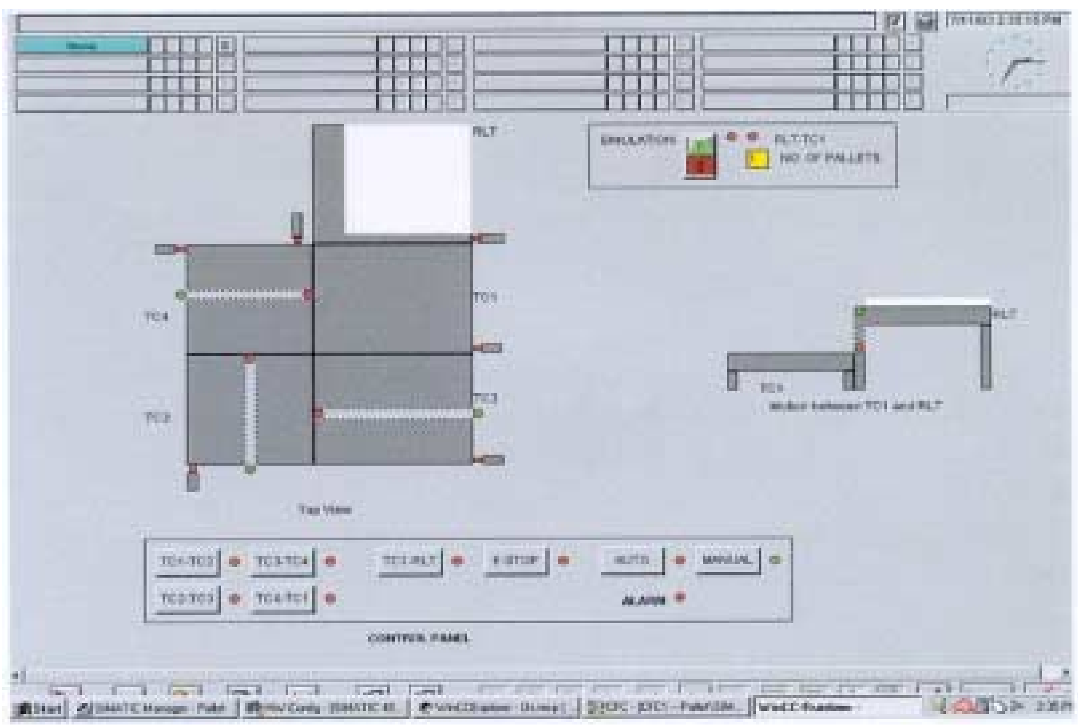

Figure 9. Initial setup of the simulation

response of the system to various field conditions. The system is simulated with a slight level of abstraction. The following are the limitations of the system:

1) The logic developed is independent of the number of pallets in the system (not exceeding three). But at the start of the simulation we need to input the number of pallets to be simulated.

2) All the proximity and optical sensors, and limit switches are to be activated by clicking the computer mouse on their respective screen icons.

3) A "Start" command has to be issued by clicking on the "Start" HMI button on the screen. This initiates the automatic function logic.

4) When the system starts in the automatic mode, there should be no pallet on the RLT table. If a pallet is present on that table, the system should start in manual mode and then the system should change into automatic mode. This is exactly not a limitation of the simulation as even the actual system has been programmed to meet this criterion. This gives the controller a start position.

5) The shock absorbers are not shown in the simulation.

The above stated limitations create a small difference between the simulated and the real-world systems, but it helps us understand the reaction of the proposed system to real-time problems.

The following are the evaluation criteria performed in order to meet the requirements of a robust system.

1) The movement of pallets on the tables, regardless of the number of pallets in the system.

2) Response of the system when emergency stop is pressed under various conditions of motion.

3) Discrete control of each event (motion of pallet from one table to another).

4) To verify that system logic can prevent the system from a “grid-lock” in the incidence of inadvertent activation of a sensor, or a sensor malfunction.

5) To verify intelligent decisions by the controller regarding movement of pallet from TC1, thereby avoiding gridlock.

6) To verify that system logic will take appropriate action to avoid gridlock due to movement interruptions caused by mechanical problems such as jamming etc.

5.4 System states

During the execution of simulation various screen shots have been taken to give a clear picture of how the system responds. Pictures of system state are included in this section to give a clear idea of the sensors are active and which sensors to be inactive for a particular event to take place. All the sensors and commands active are shown green and the inactive ones are shown as red.

During the motion of pallet from RLT to TC1 sensor TC1-B is activated. The table TC1 is in raised position. After the pallet is completely on TC1 than table TC1 is lowered until the low limit switch is hit. This stops the lowering of the table and than the event RLT to TC1 is complete. This is shown in Figures 10 and 11. Now the controller verifies whether a pallet is present on TC2 or not. If and only if there is no pallet on TC2 (sensed by TC2-A) and there is a pallet on TC1 (sensed by TC1- A), which has arrived from the RLT (sensed by TC1-B) and TC2 cylinder is at home position (sensed by the proximity switch at the beginning of the stroke of cylinder) does the event TC1 to TC2 is enabled. If the system is in auto mode it immediately activates that event and if it is in manual mode it waits till the manual command is given from the panel. When all these conditions are satisfied TC1 to TC2 motion is executed with guides raised. This is depicted in Figure 12.

Similar interlocks are present for the motion of pallet from TC2 to TC3 and other events. This is represented in Figures 13, 14, 15, 16, 17, 18, 19 and 20.

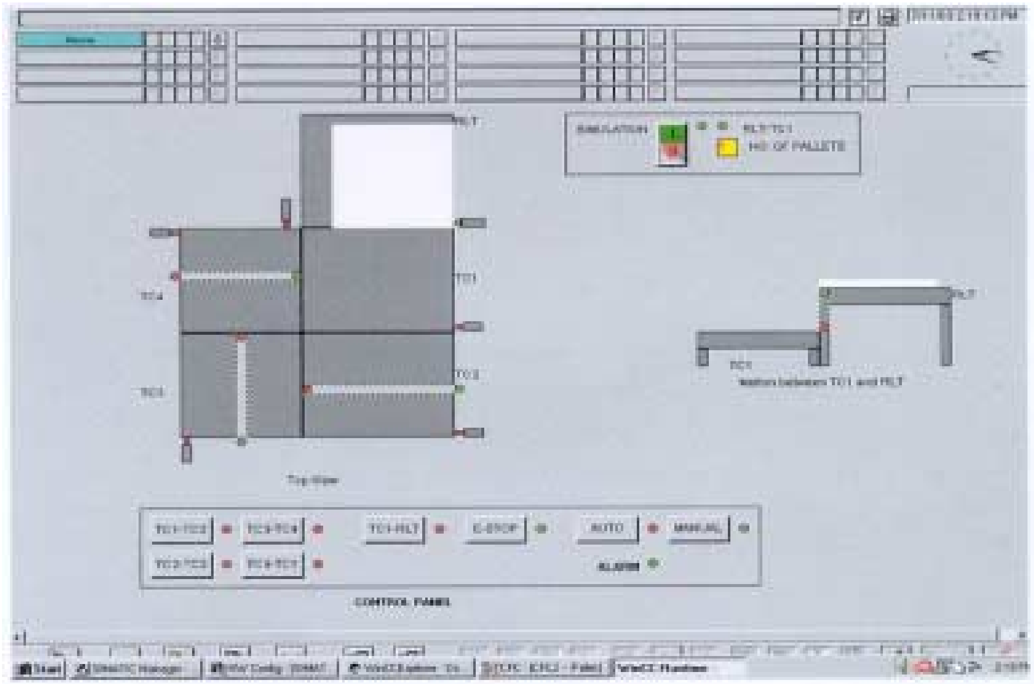

Figure 10. The state of system during motion of pallet from RLT to TC1

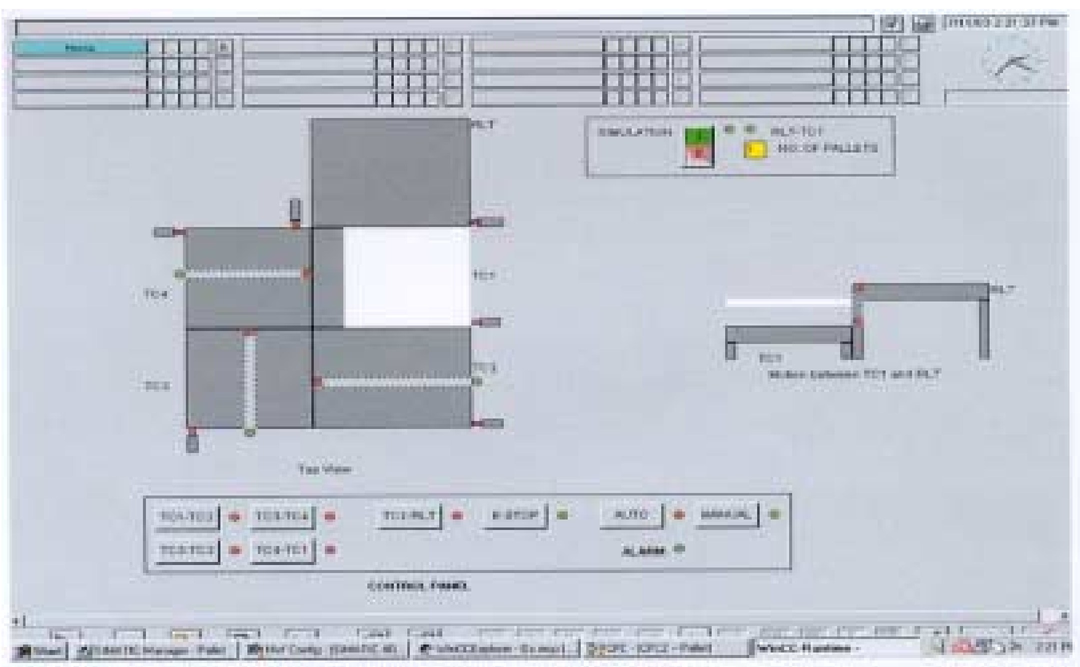

Figure 11. Downward motion of pallet during RLT to TC1 table

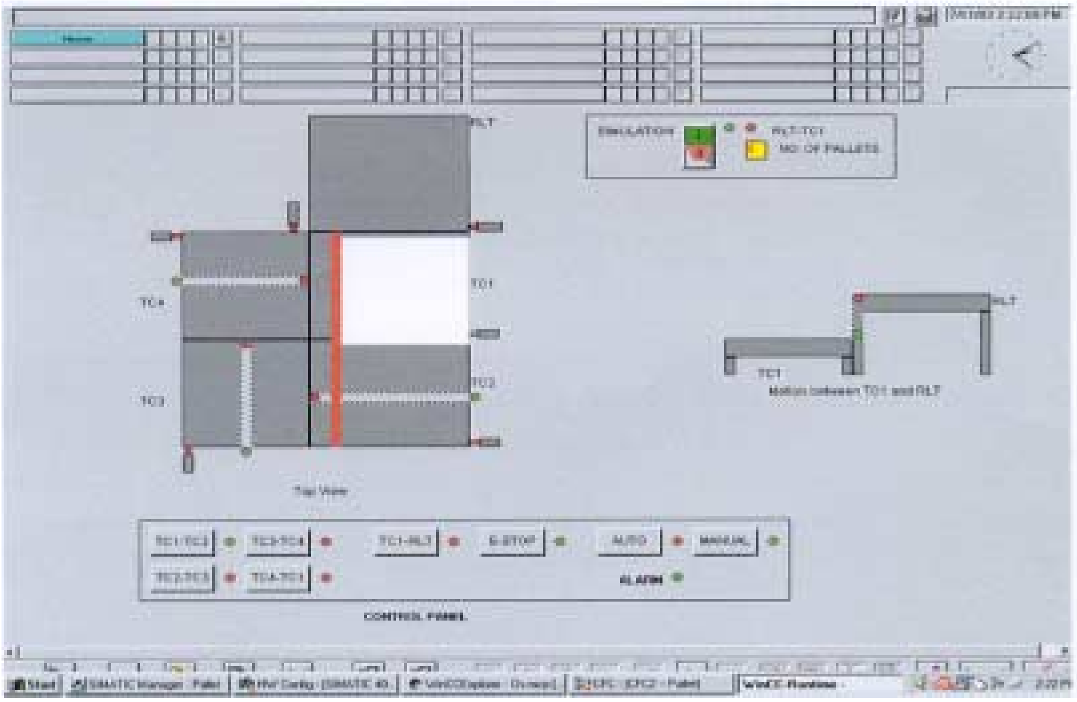

Figure 12. Motion of pallet from TC1 to TC2 table

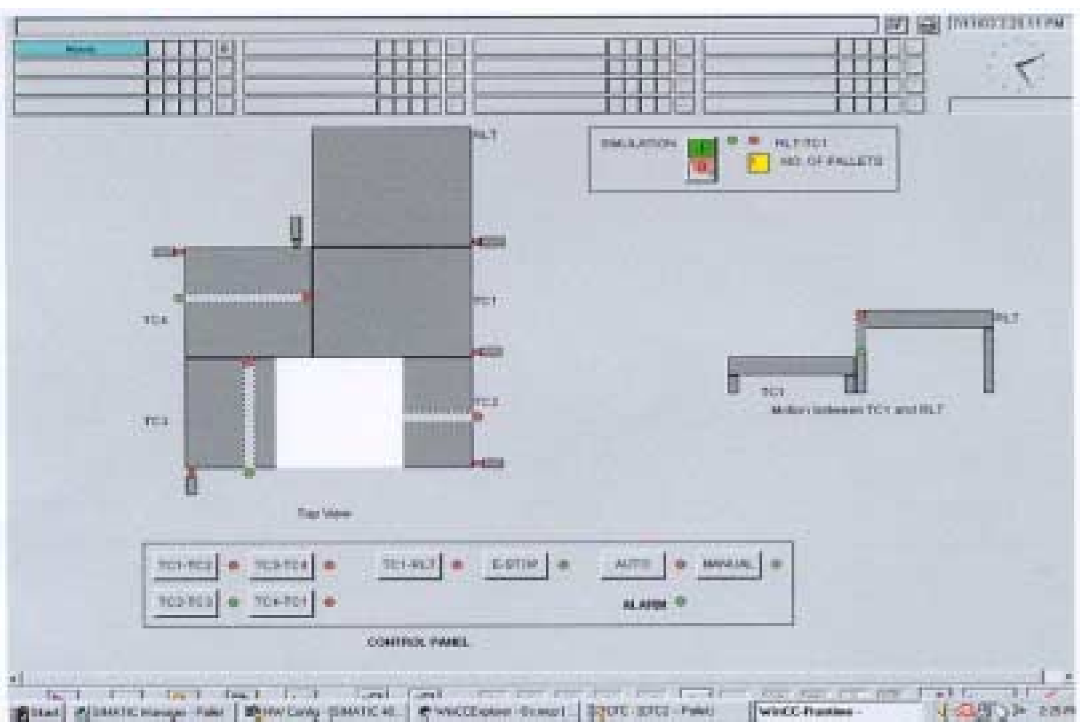

Figure 13. Motion pallet from TC2 to TC3 table

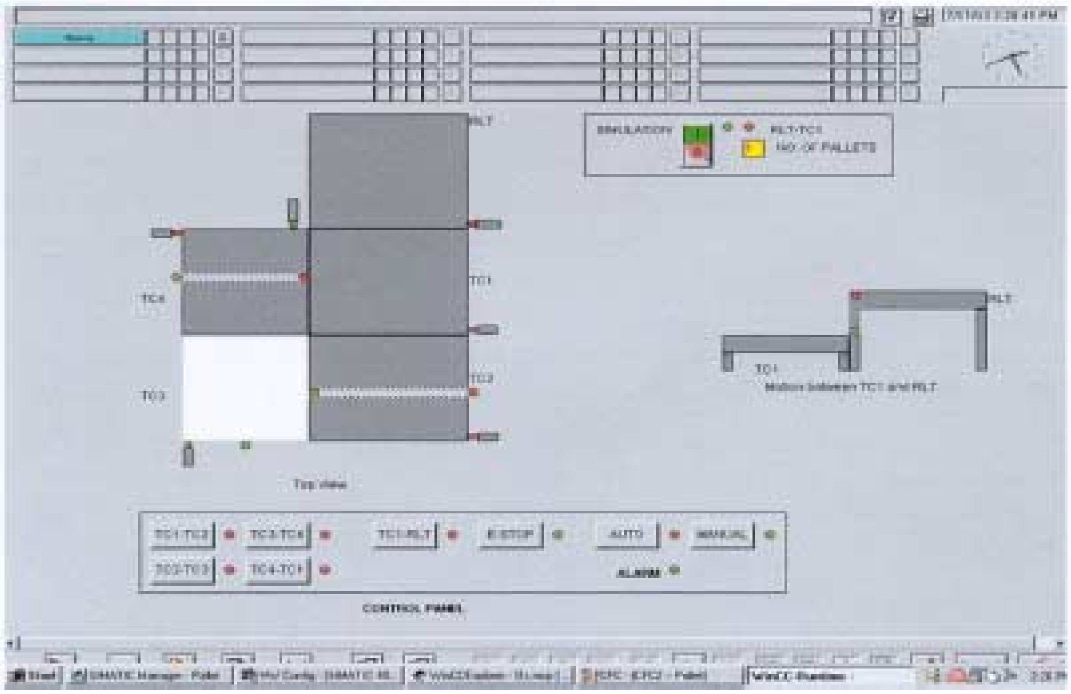

Figure 14. State of sensors when loaded pallet is present on TC3 table

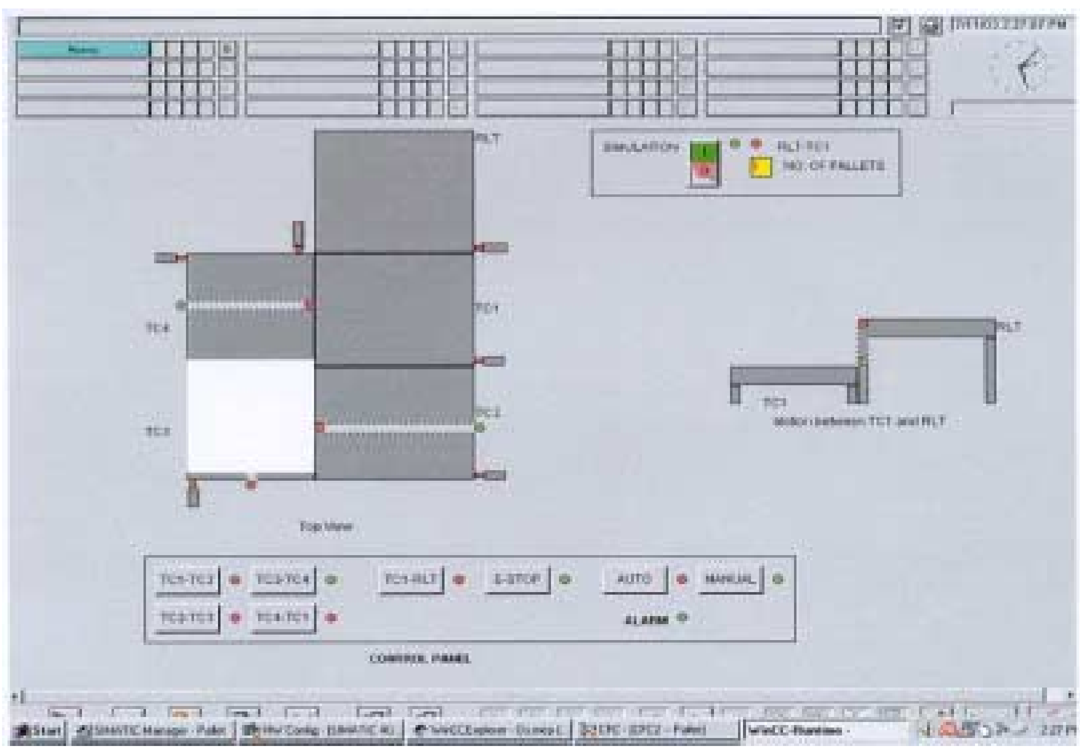

Figure 15. Motion of pallet from TC3 to TC4 table

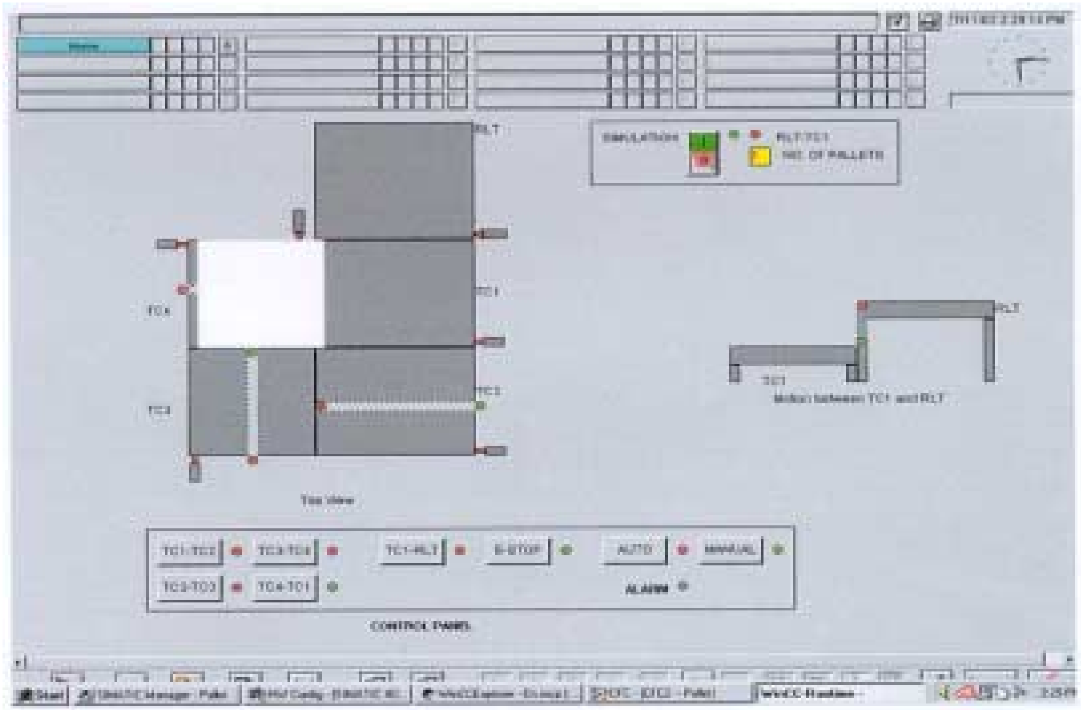

Figure 16. Motion of pallet from TC4 to TC1 table

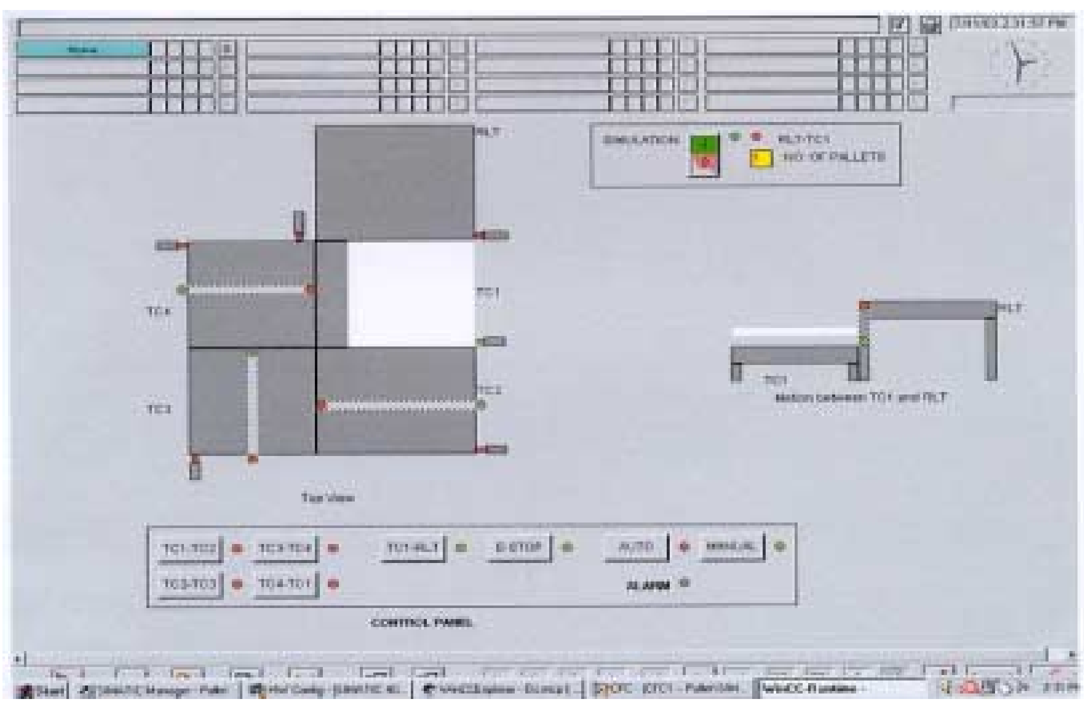

Figure 17. Motion of pallet from TC1 to RLT table (raise)

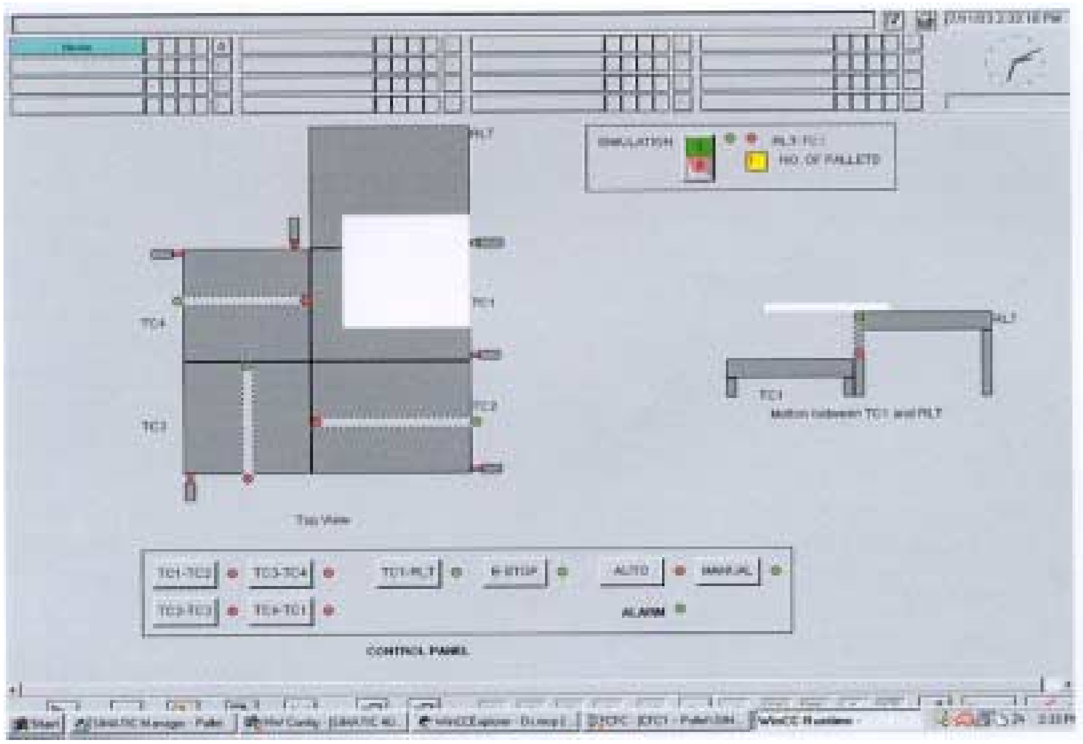

Figure 18. Motion of pallet from raised TC1 to RLT table

CHAPTER SIX

CONCLUSION AND FUTURE WORK

6.1 Summary

The improved design and simulation of automated material handling system is the culmination of over 18 months of research at TPGAT. To improve the present system, all the problems in the system were studied and analyzed. A new system with better controller and structural changes is thus proposed.

The proposed system mainly solved two significant issues: blocking and deadlock. These problems exist in the present system primarily due to insufficient sensors. Also, the logic of the controller was based on timers that were activated/deactivated as soon as their preset limit of time ended. This occurrence of events independent of the position of the cylinder/actuator causes deadlock. Hence a discrete event system philosophy has been suggested to handle this issue.

A well-simulated model provides a good path to build the improved system. Simulations were performed under various real-time situations such as deadlock, jamming, accidental activation of sensors and faulty sensor. These simulations indicate that the proposed system is more robust and autonomous. They also help us to conclude that the improved system will be able to meet the requirements safely.

The simulation covers most practical aspects and suggests that the improved design can be implemented with little cost impact.

6.2 Future trends

An immediate research topic that arises is the formulation of the analytical model of the system. This will lead to an improved simulation that is closer to the real-world system. The system can be modeled as closed cyclic queuing process with loading and unloading tables as serving stations with the intermittent tables as waiting stations. To model the system cyclic queuing process, the serving time for loading and unloading has to be computed using empirical data from present system.

In addition, further research may explore the possibility of a more optimized system. In order to minimize the travel time for a pallet to complete a cycle, the relation between the numbers of pallets and tables has to be developed. This will help the engineer to decide upon the number of pallets that can exist in a given number of tables and improve the performance of the material handling system.

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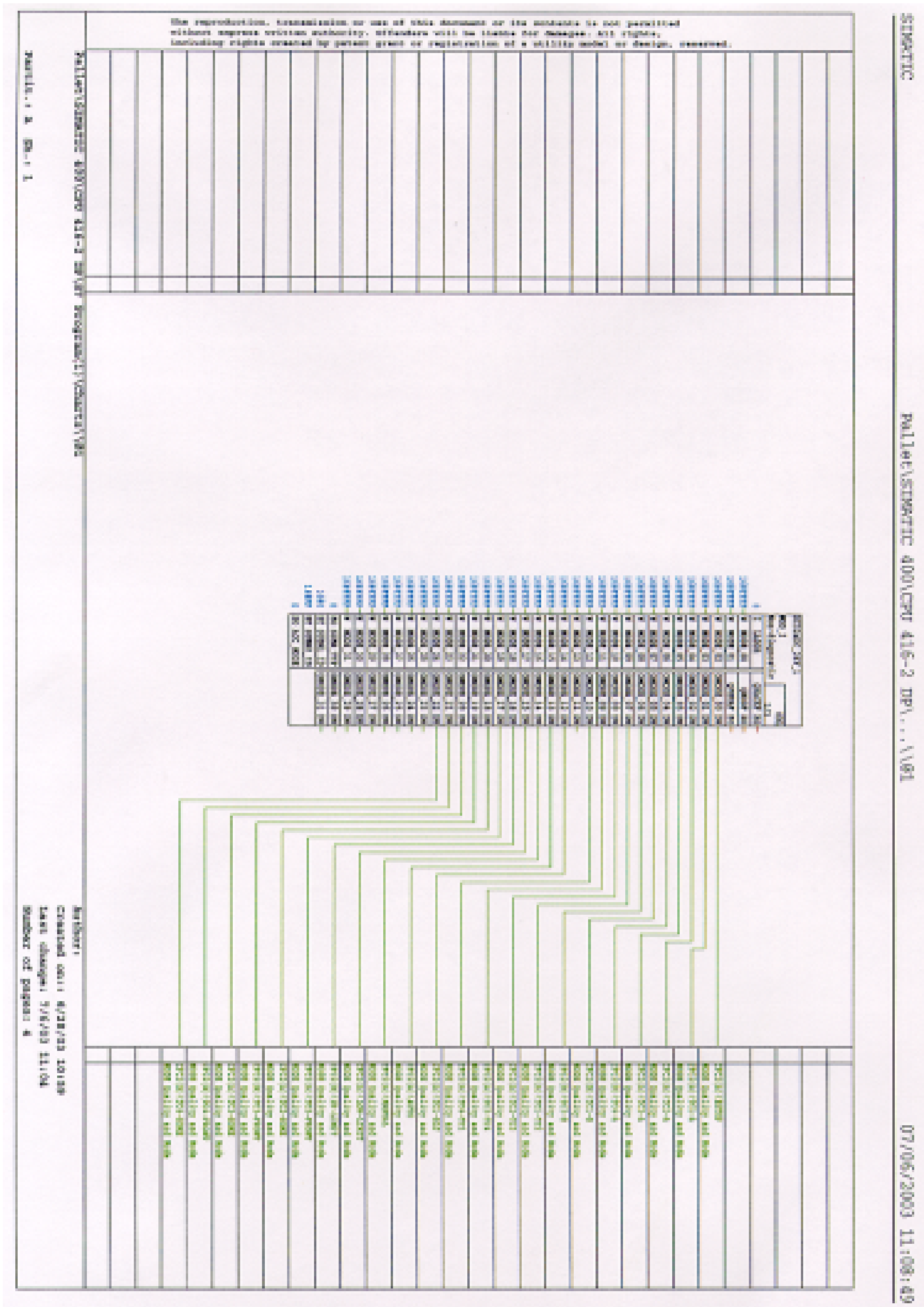
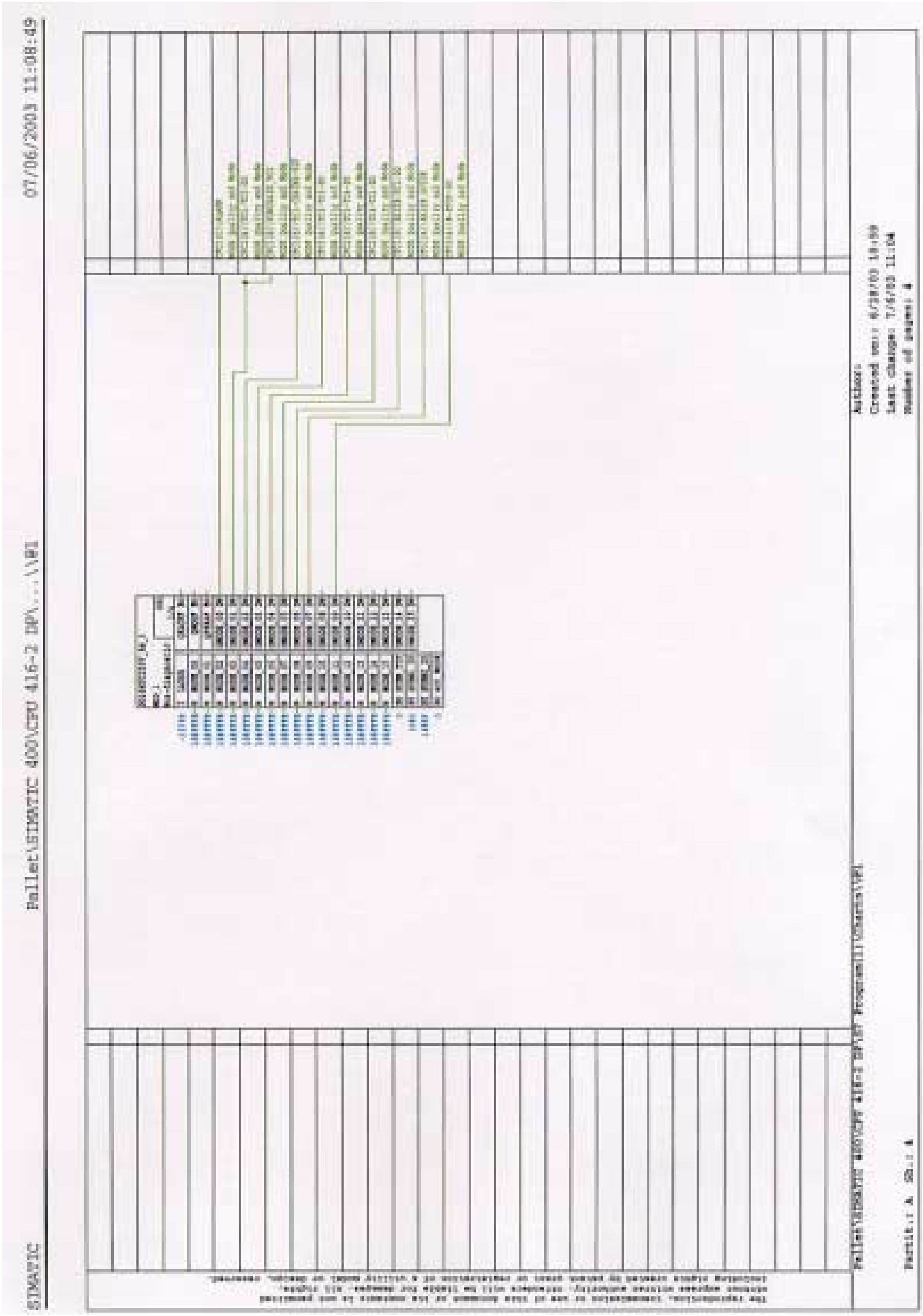
APPENDICES

Appendix A. Description of FBD programming

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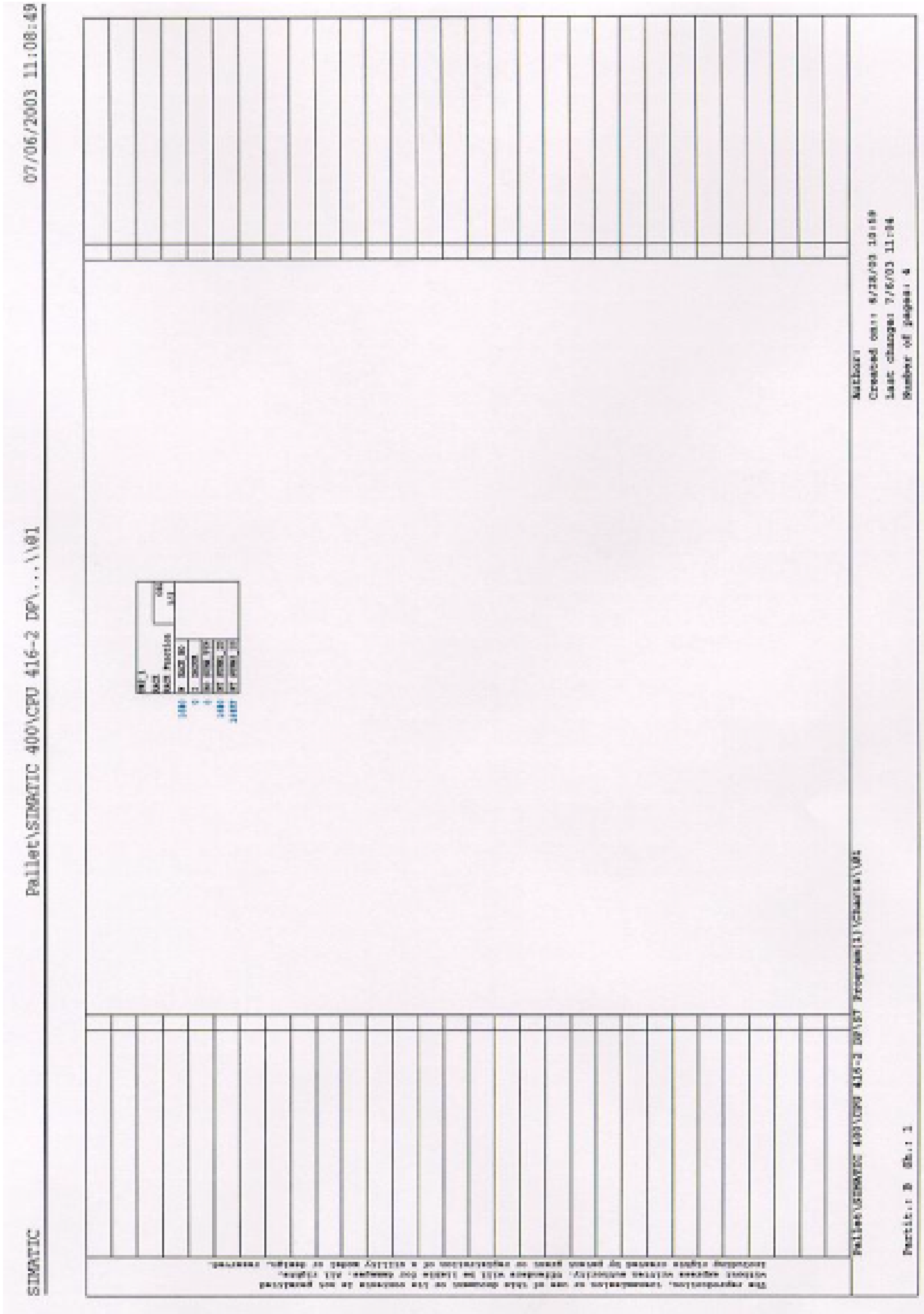
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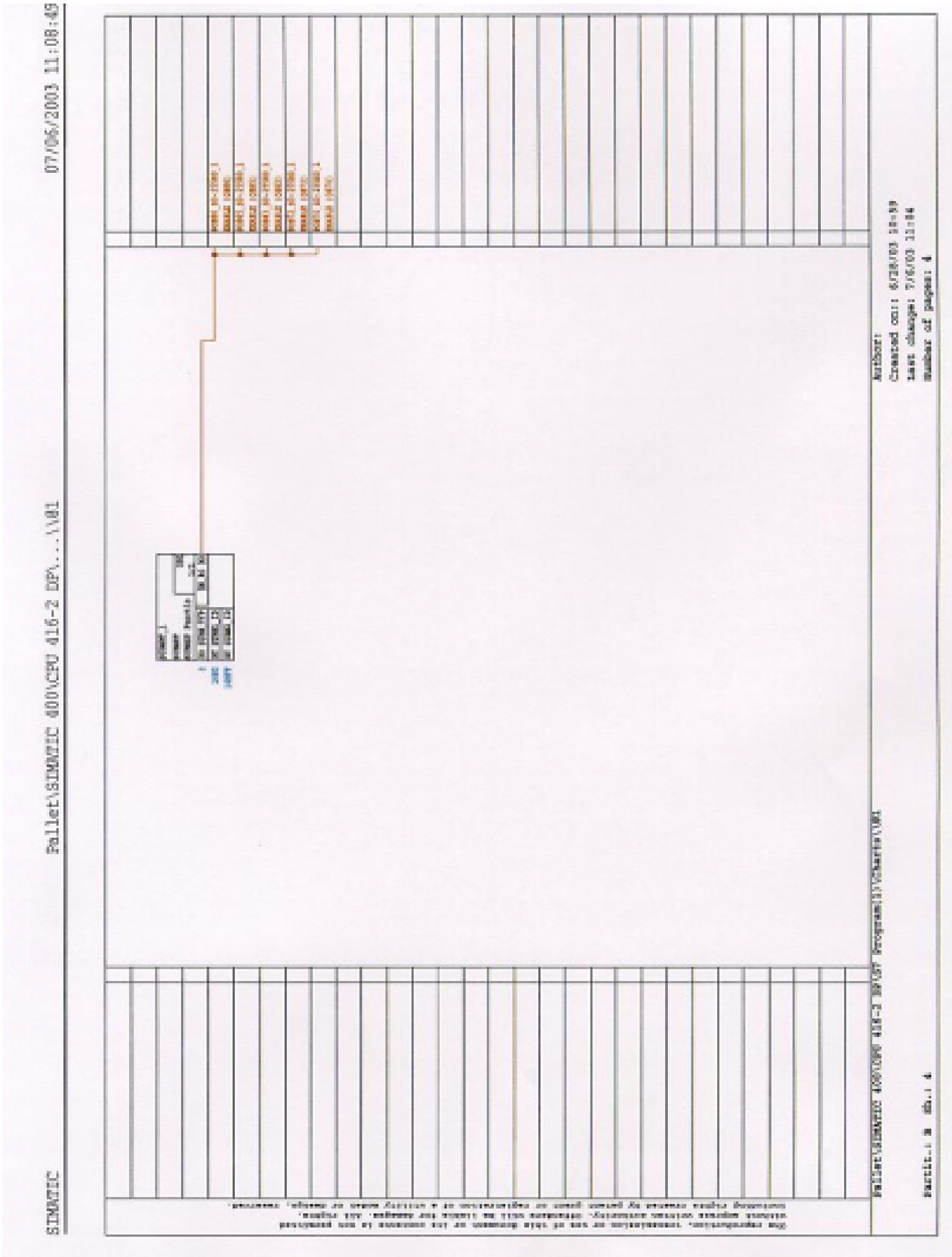
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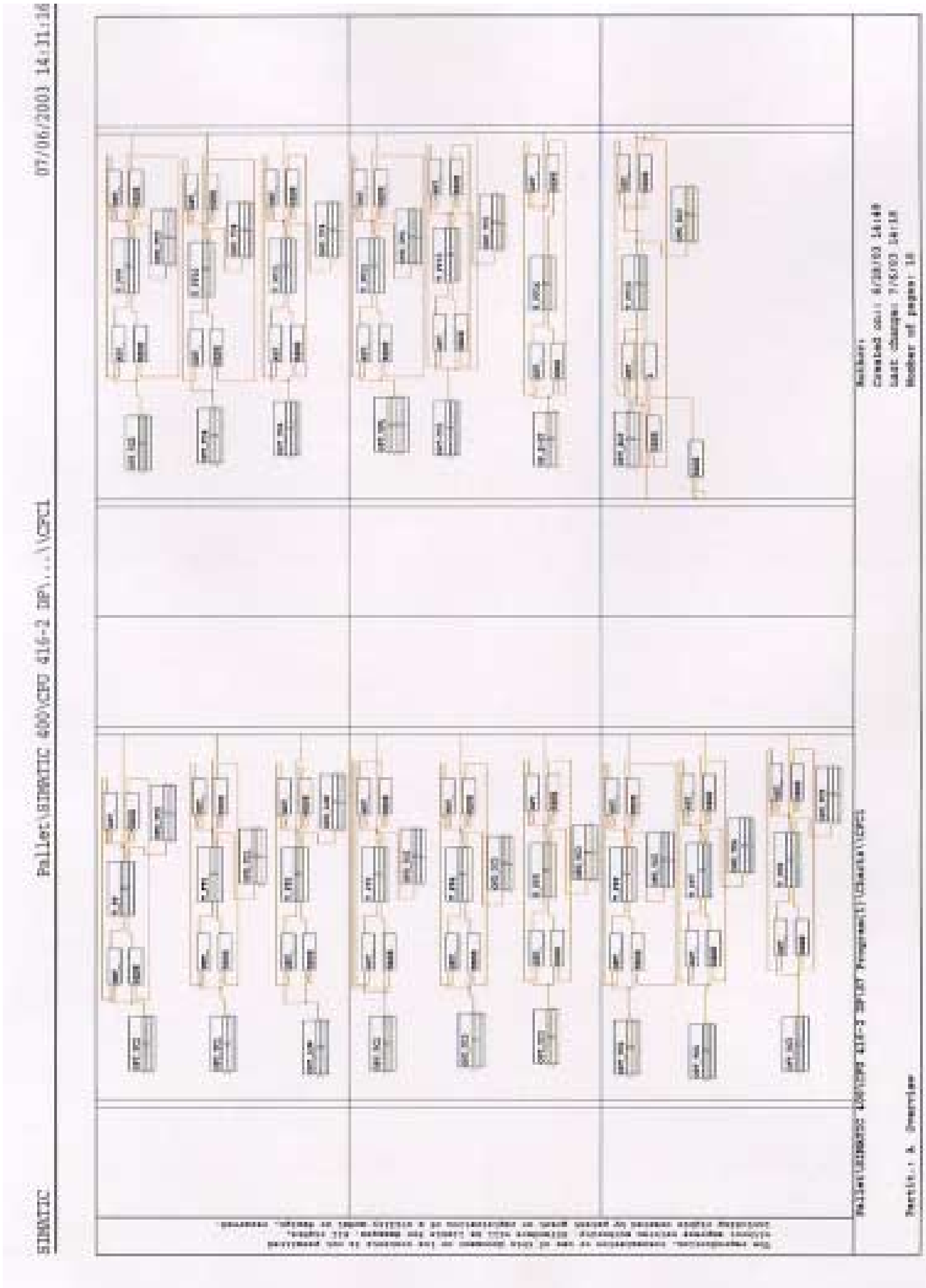
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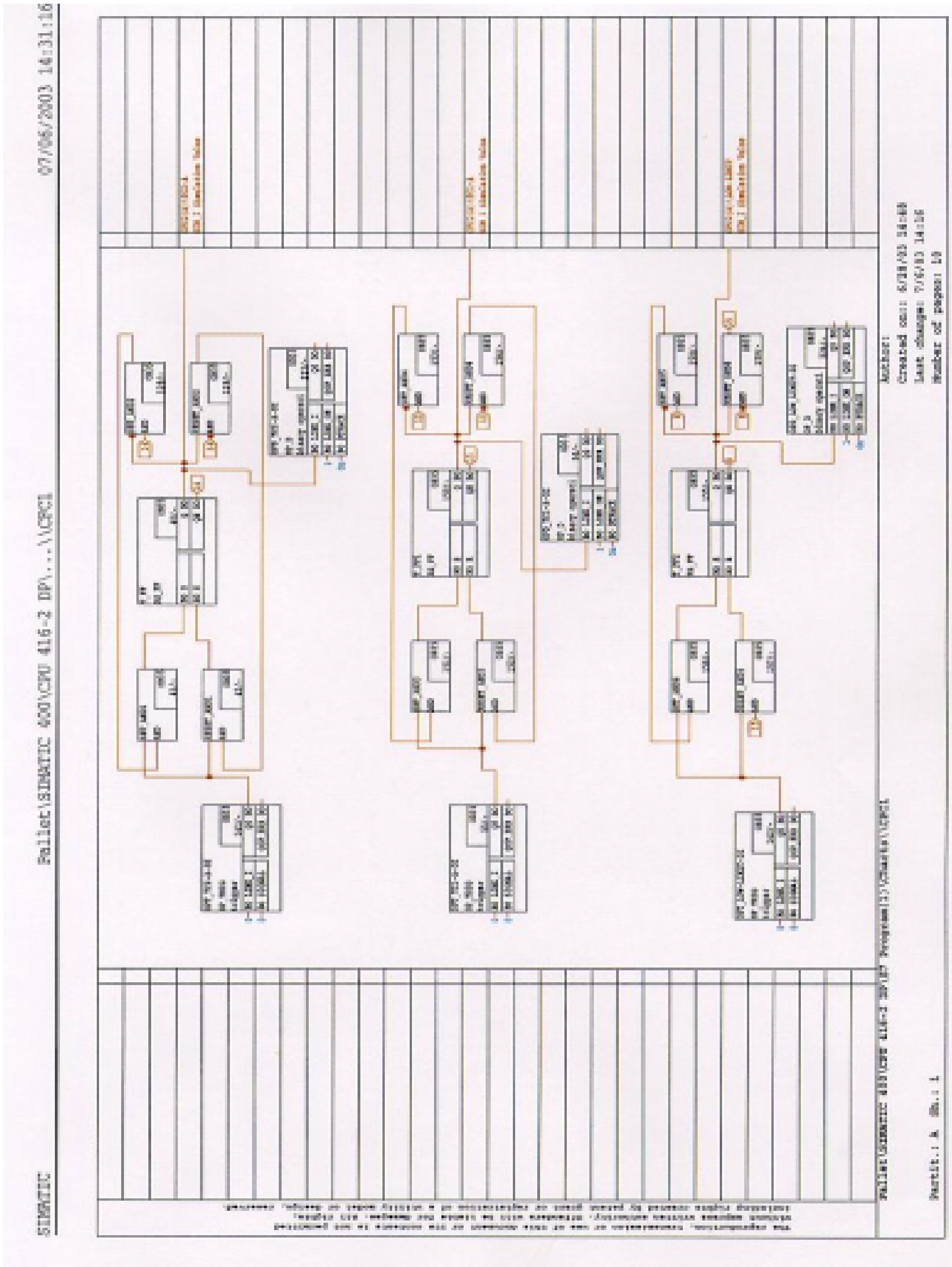
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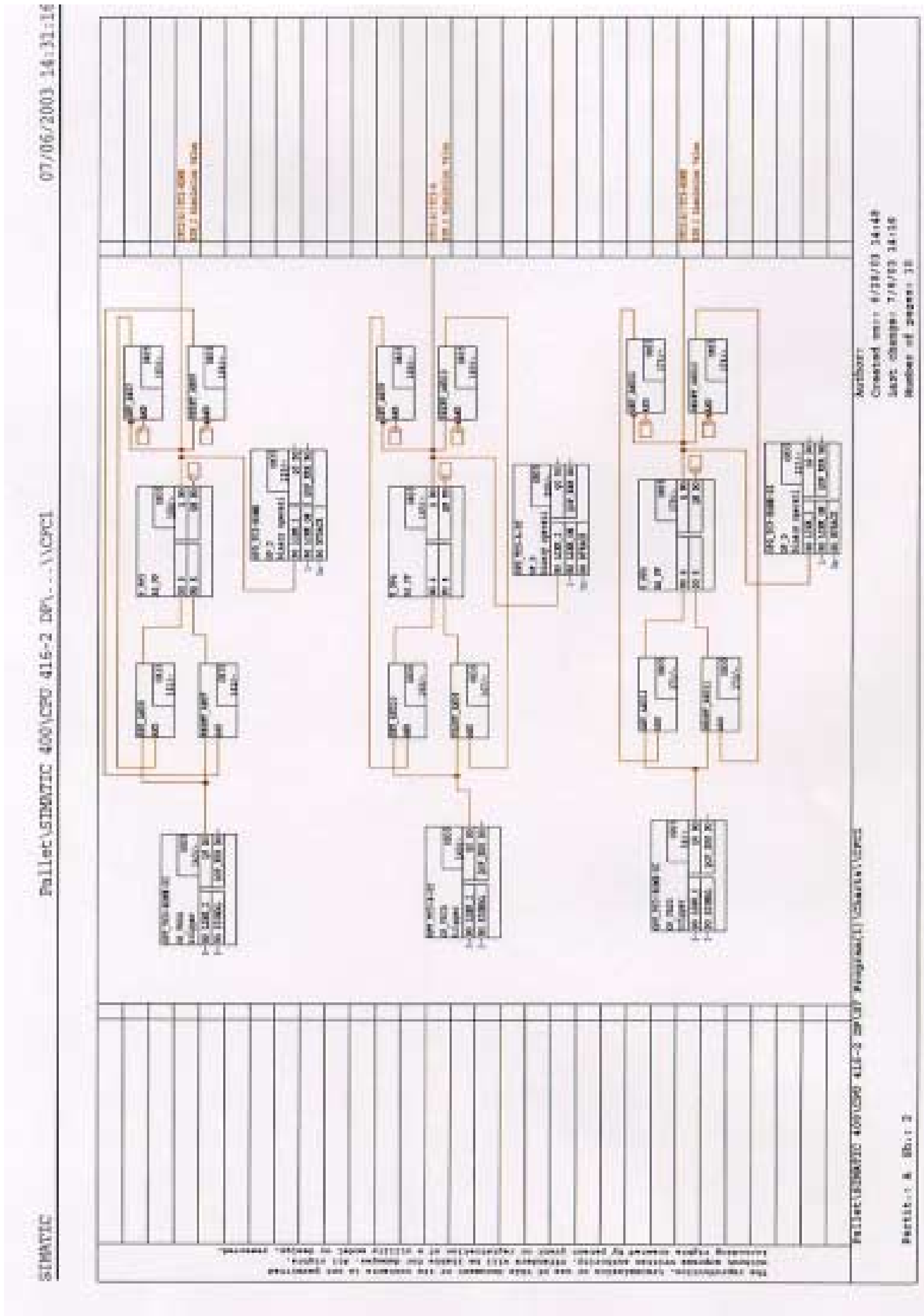
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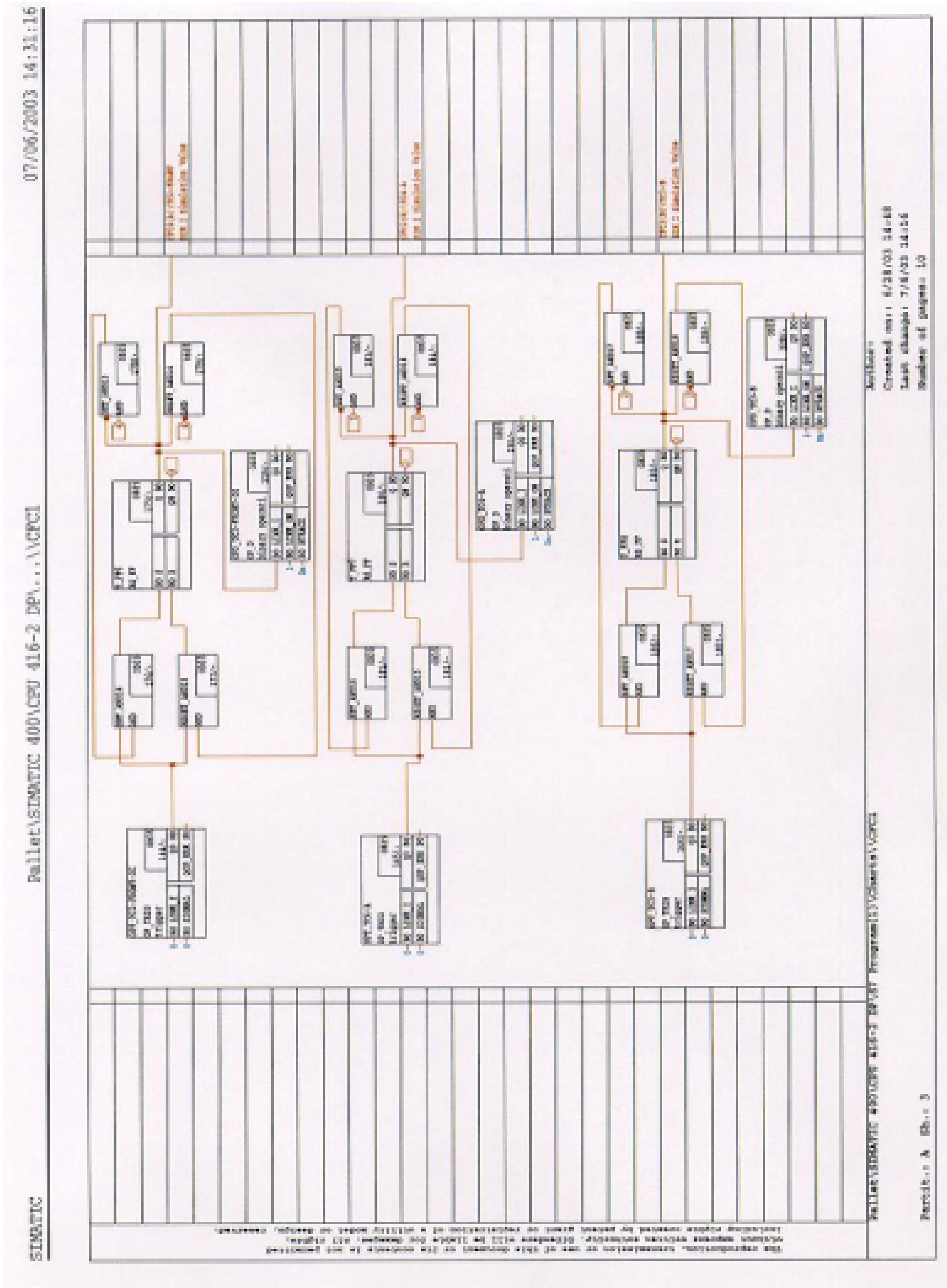
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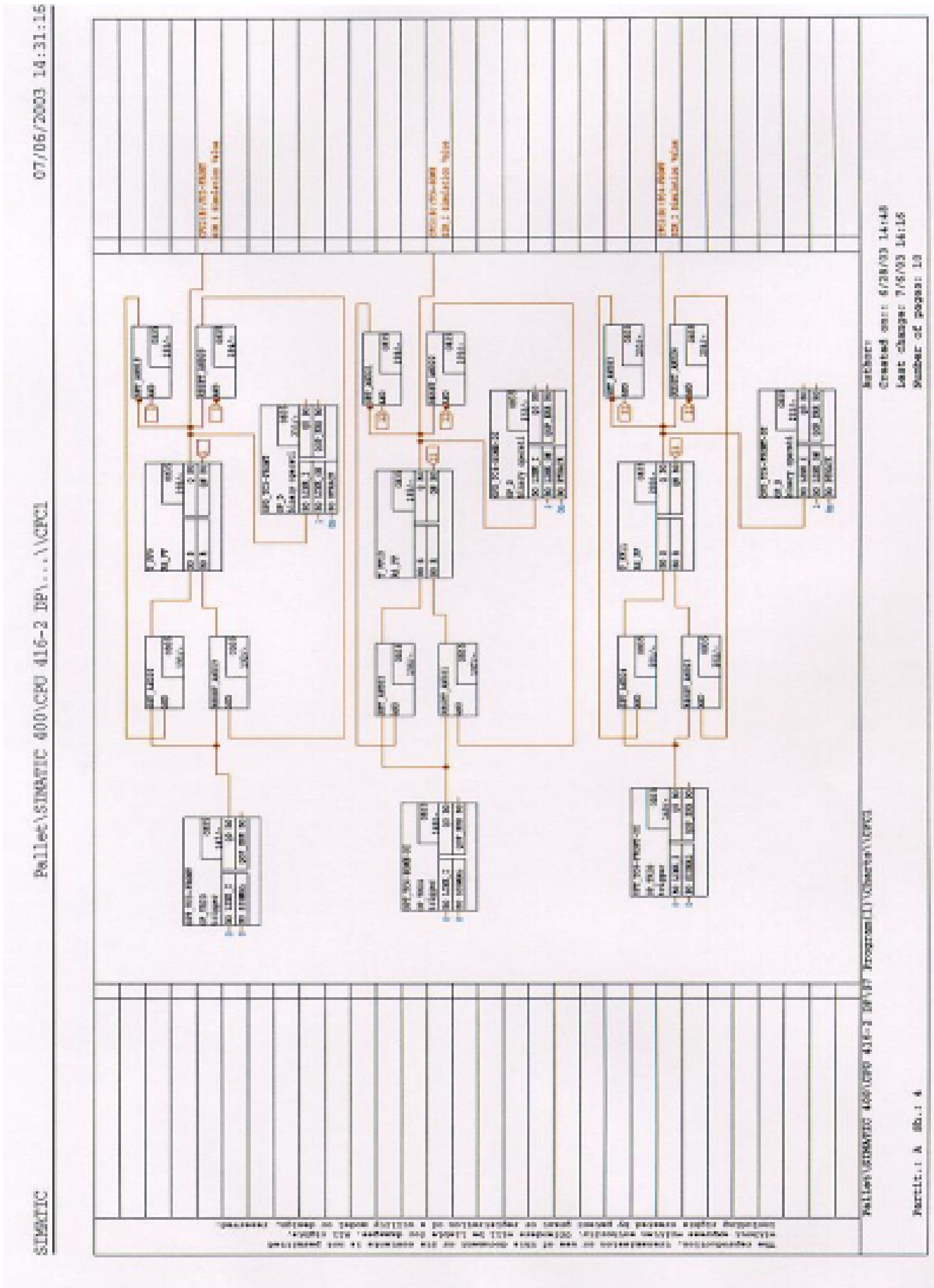
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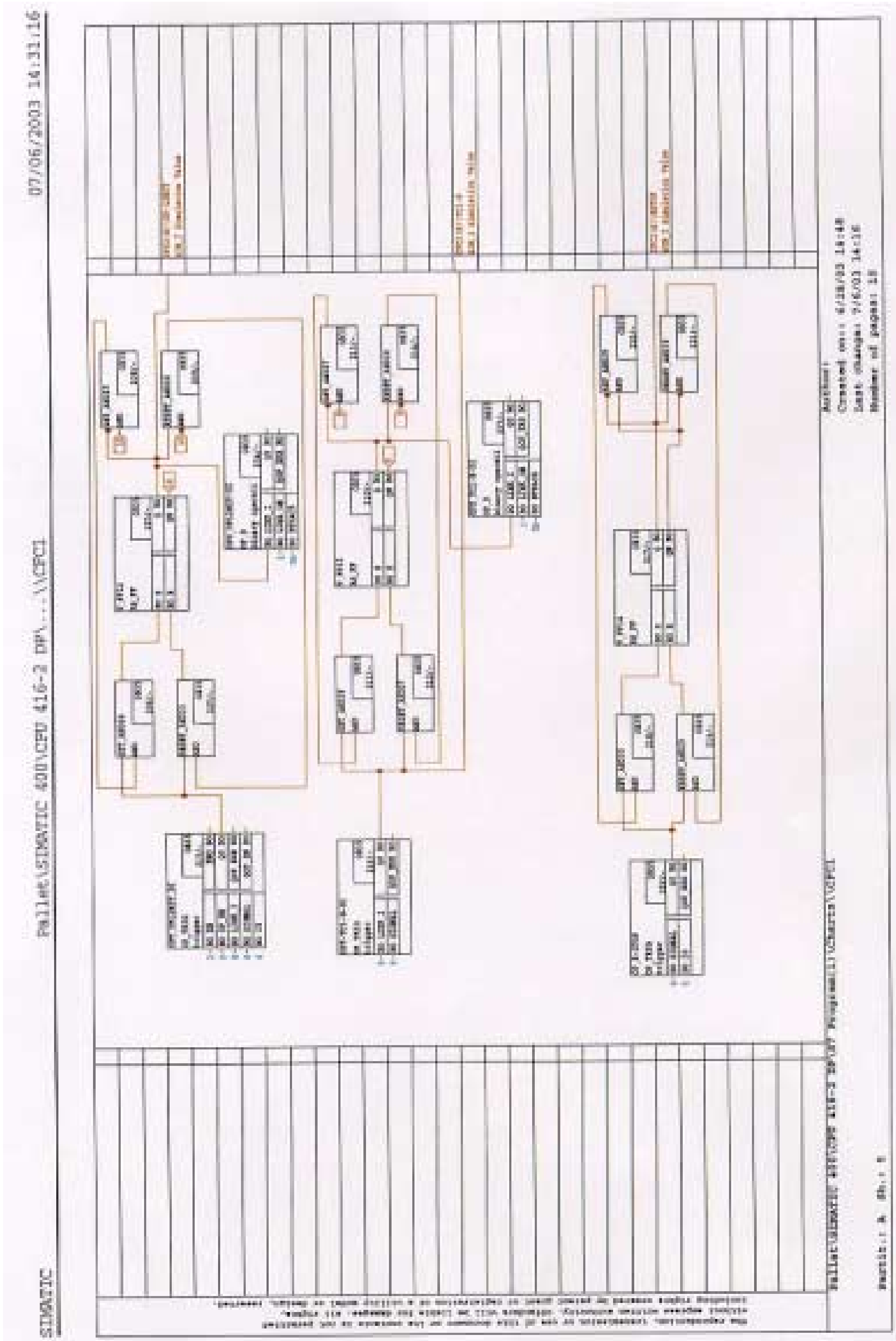
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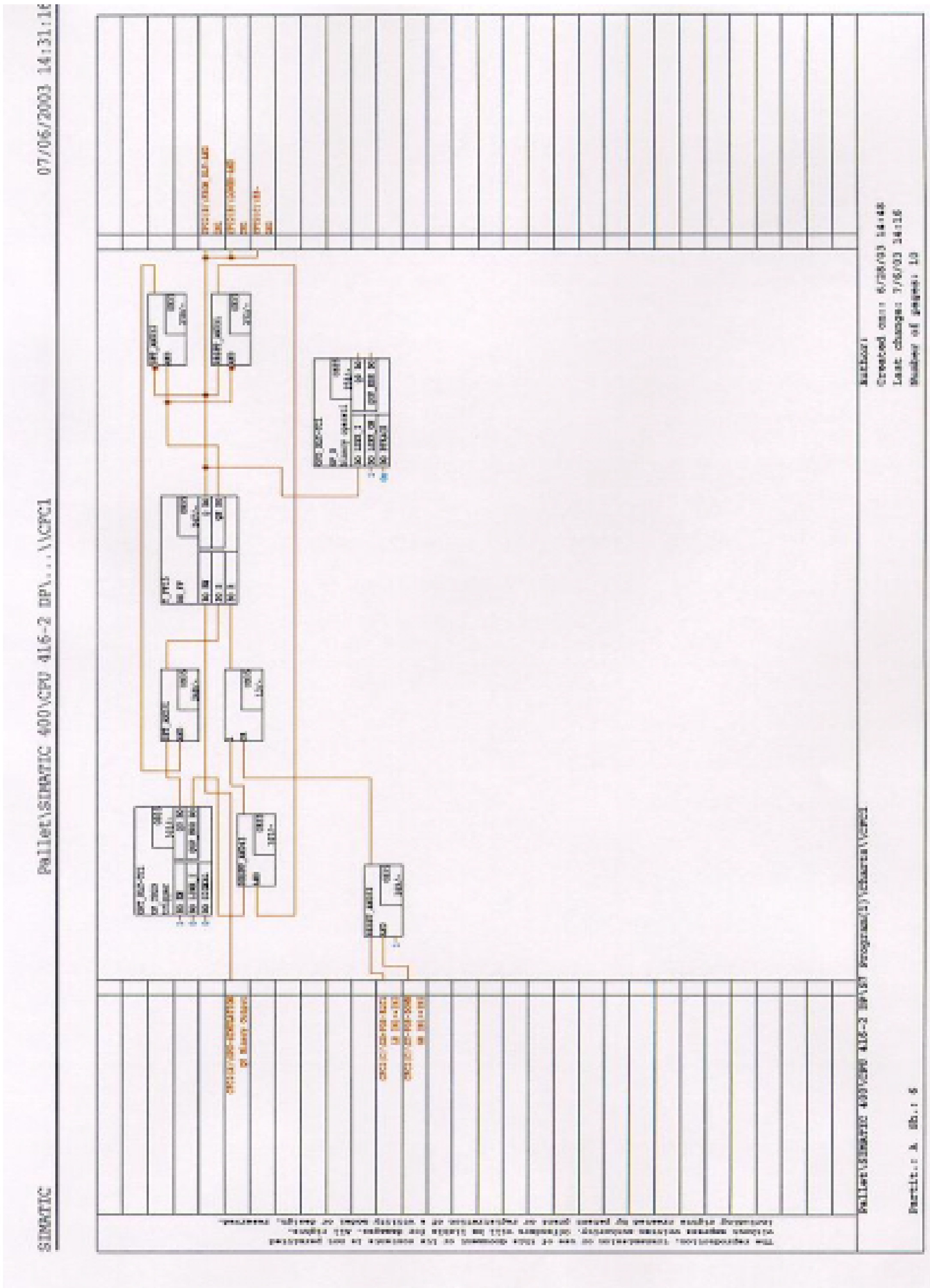
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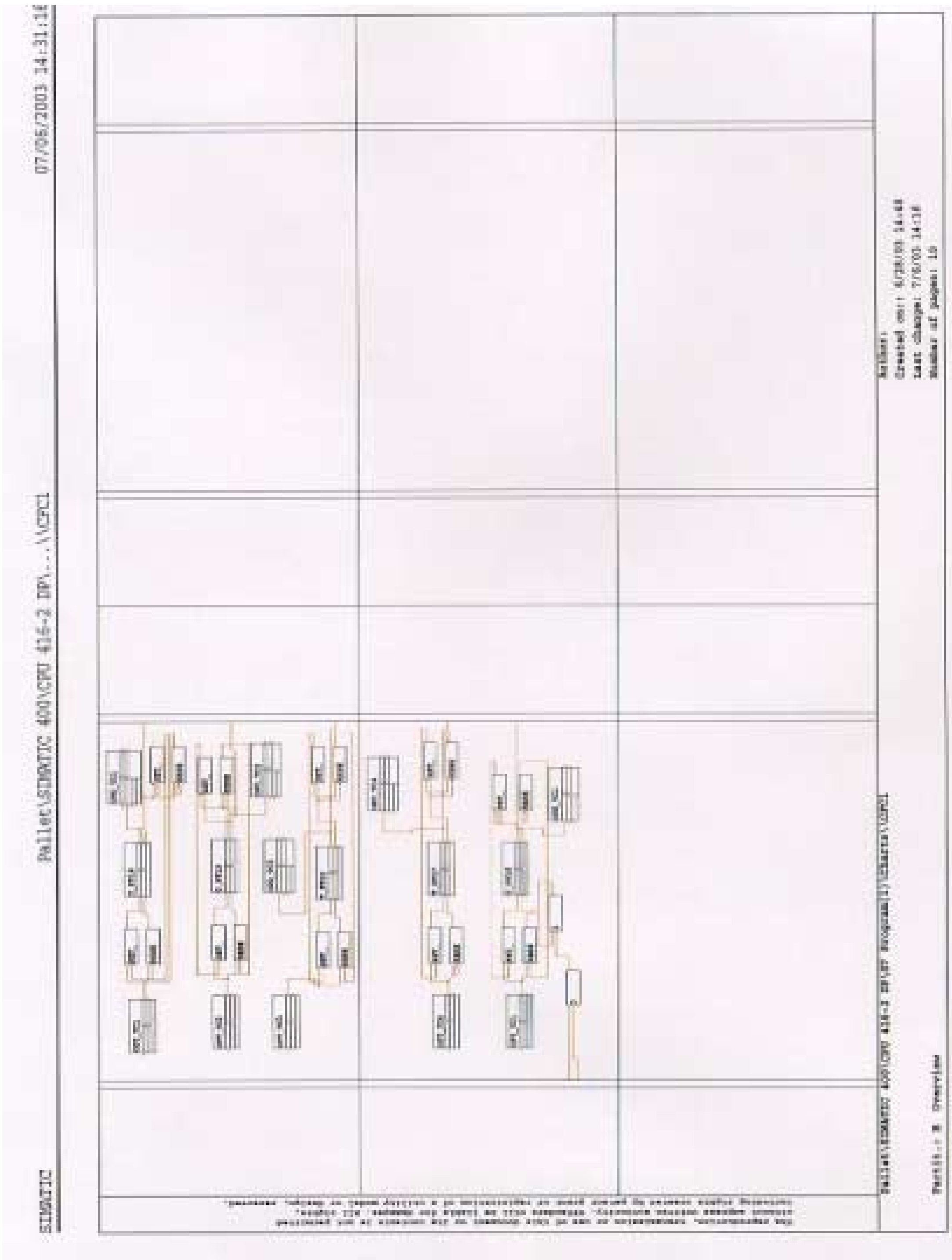
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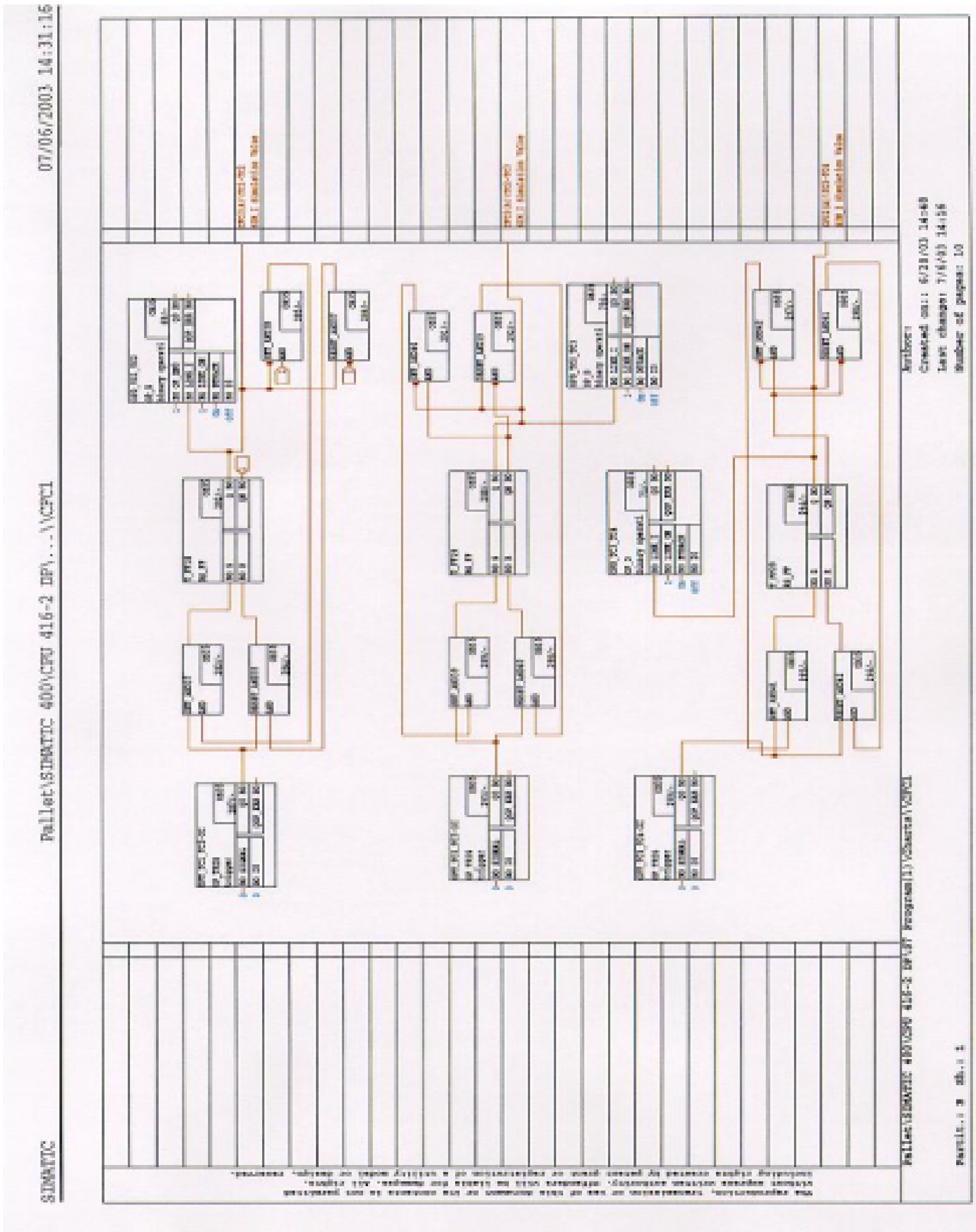
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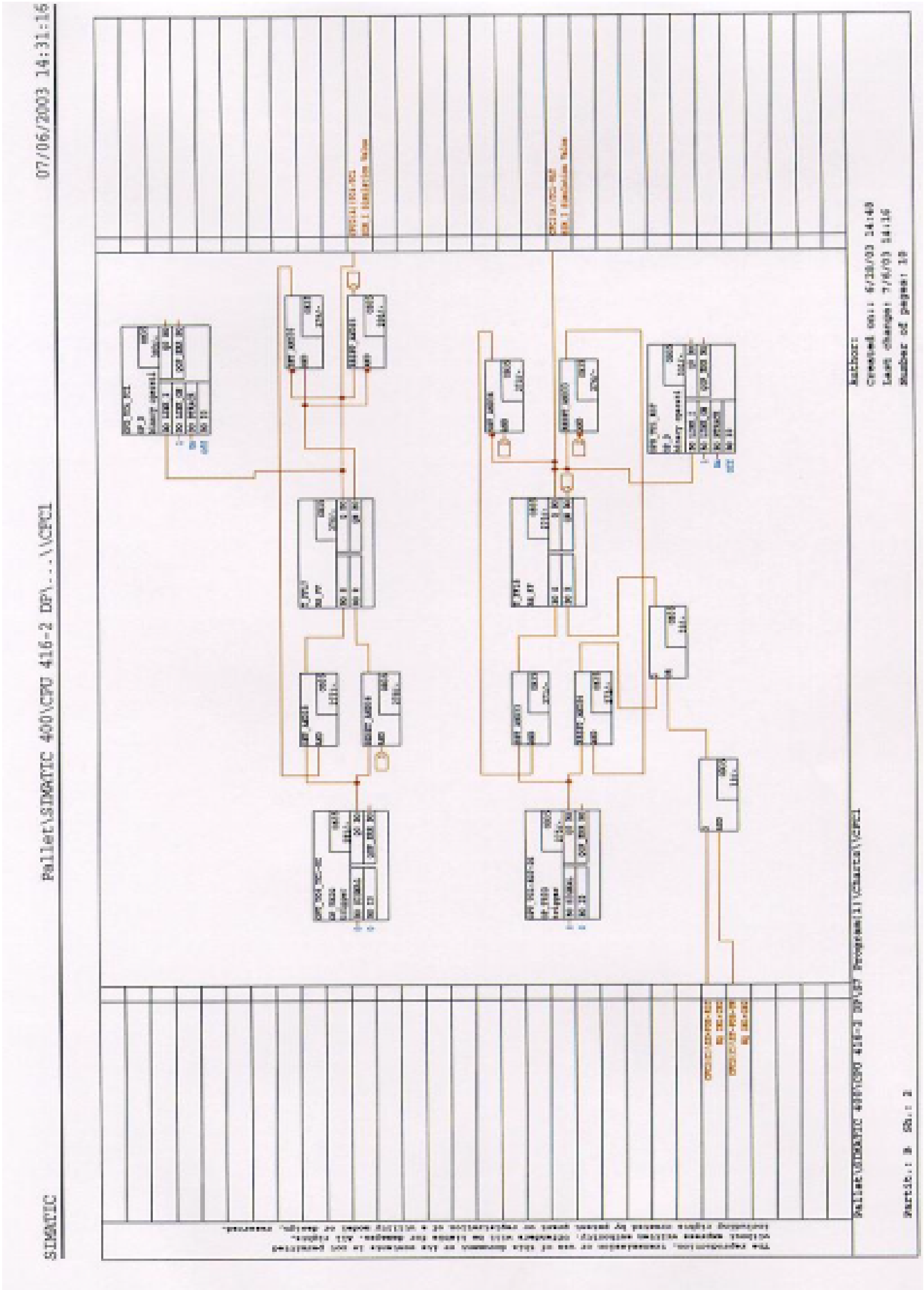
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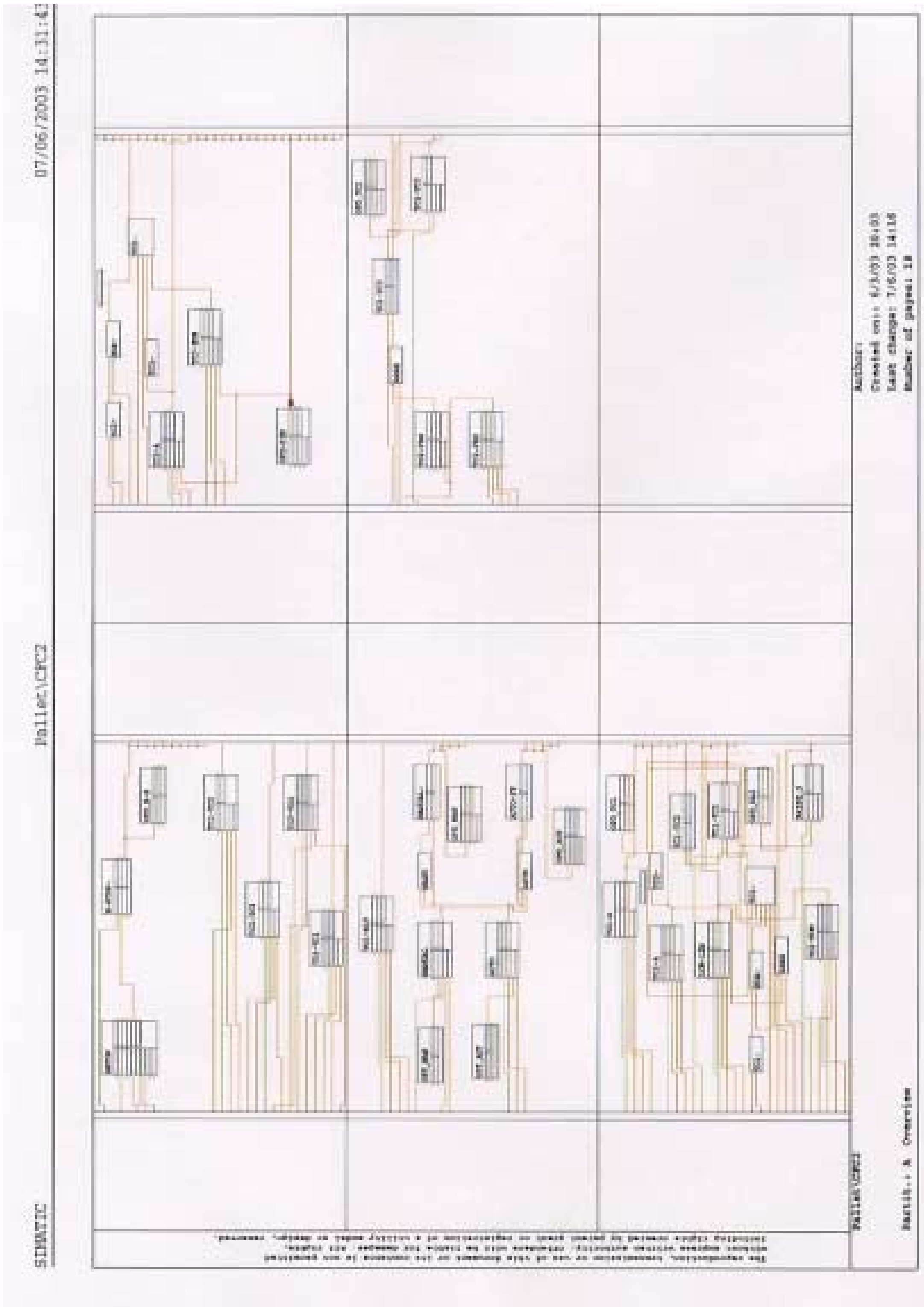
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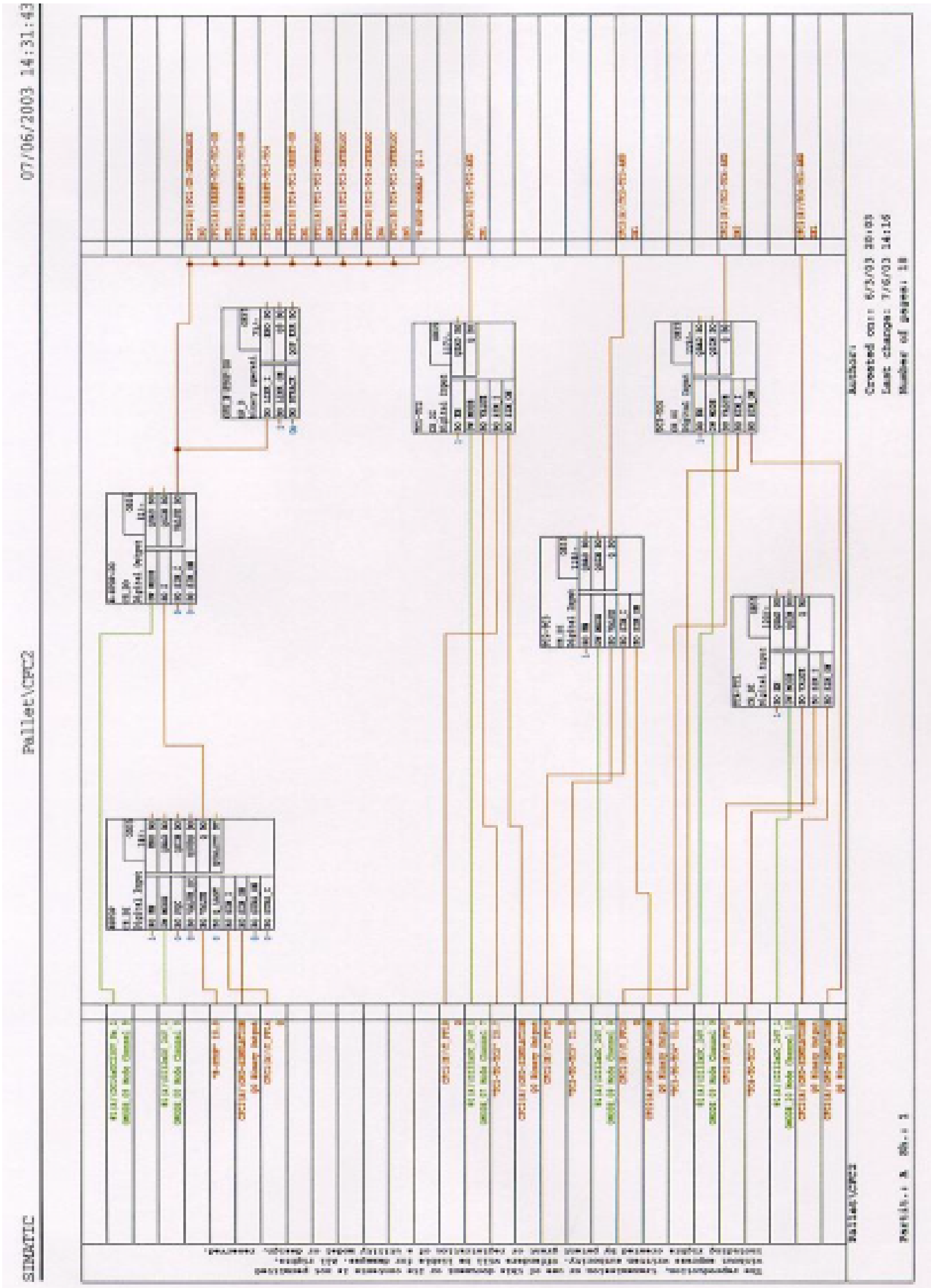
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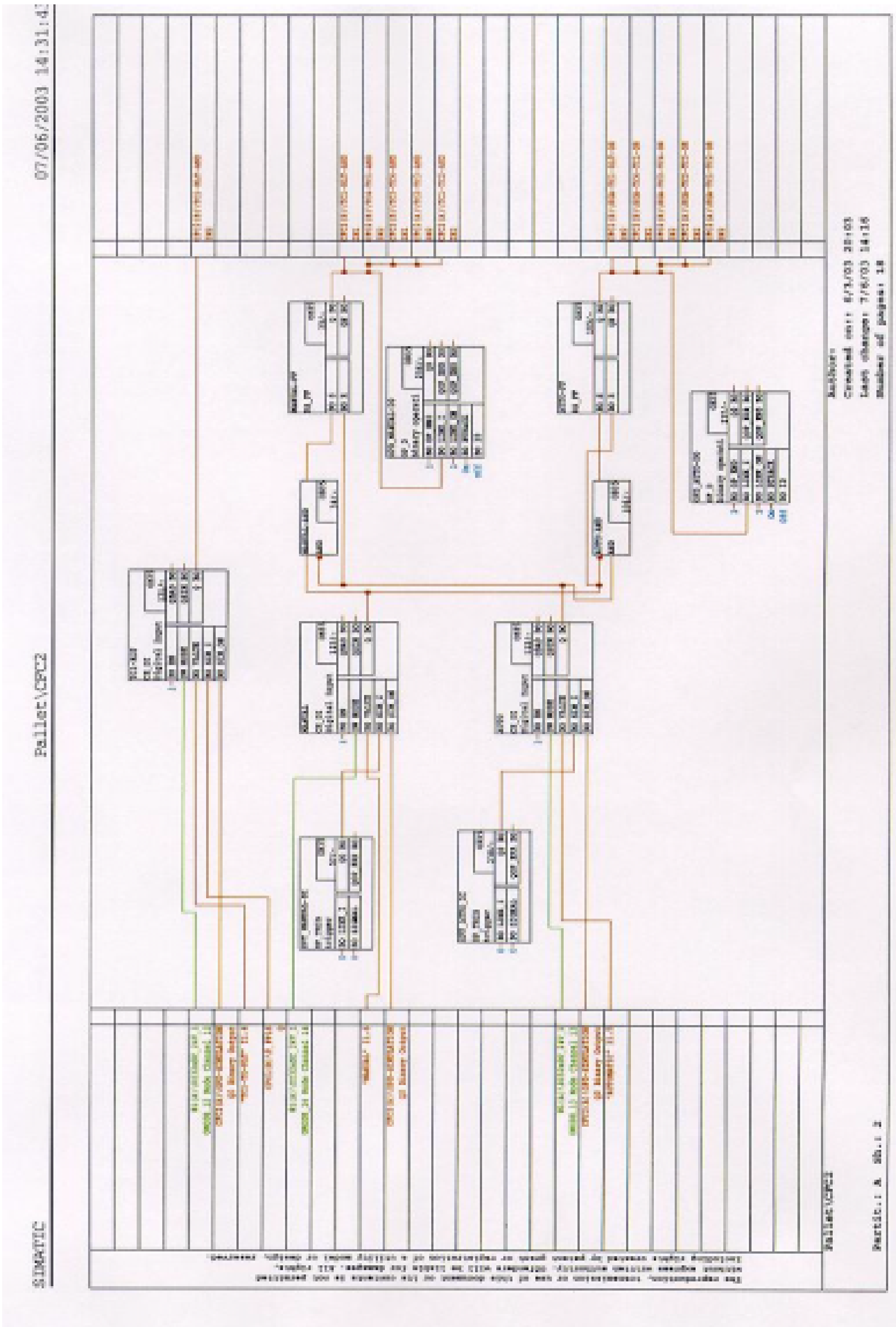
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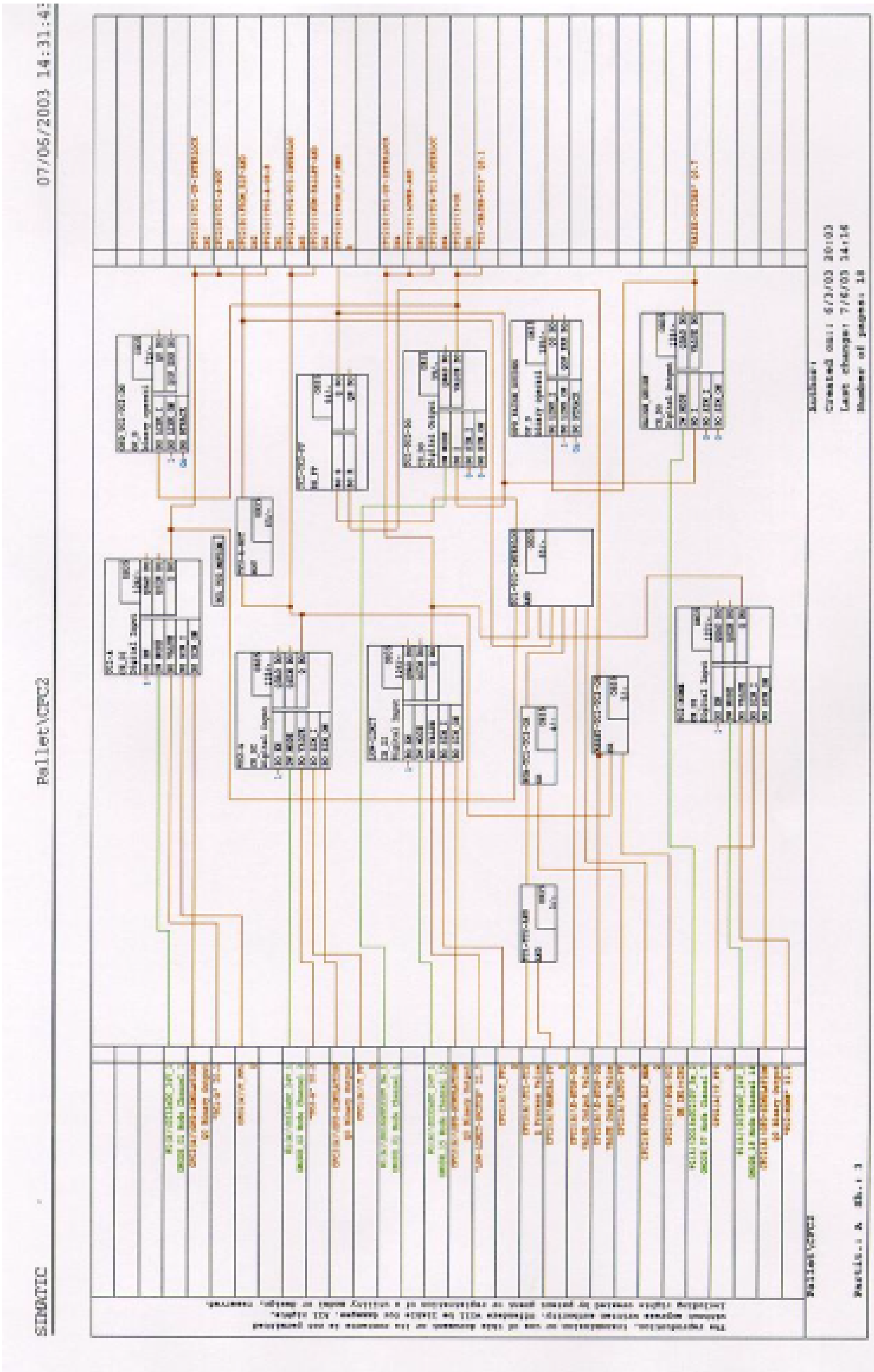
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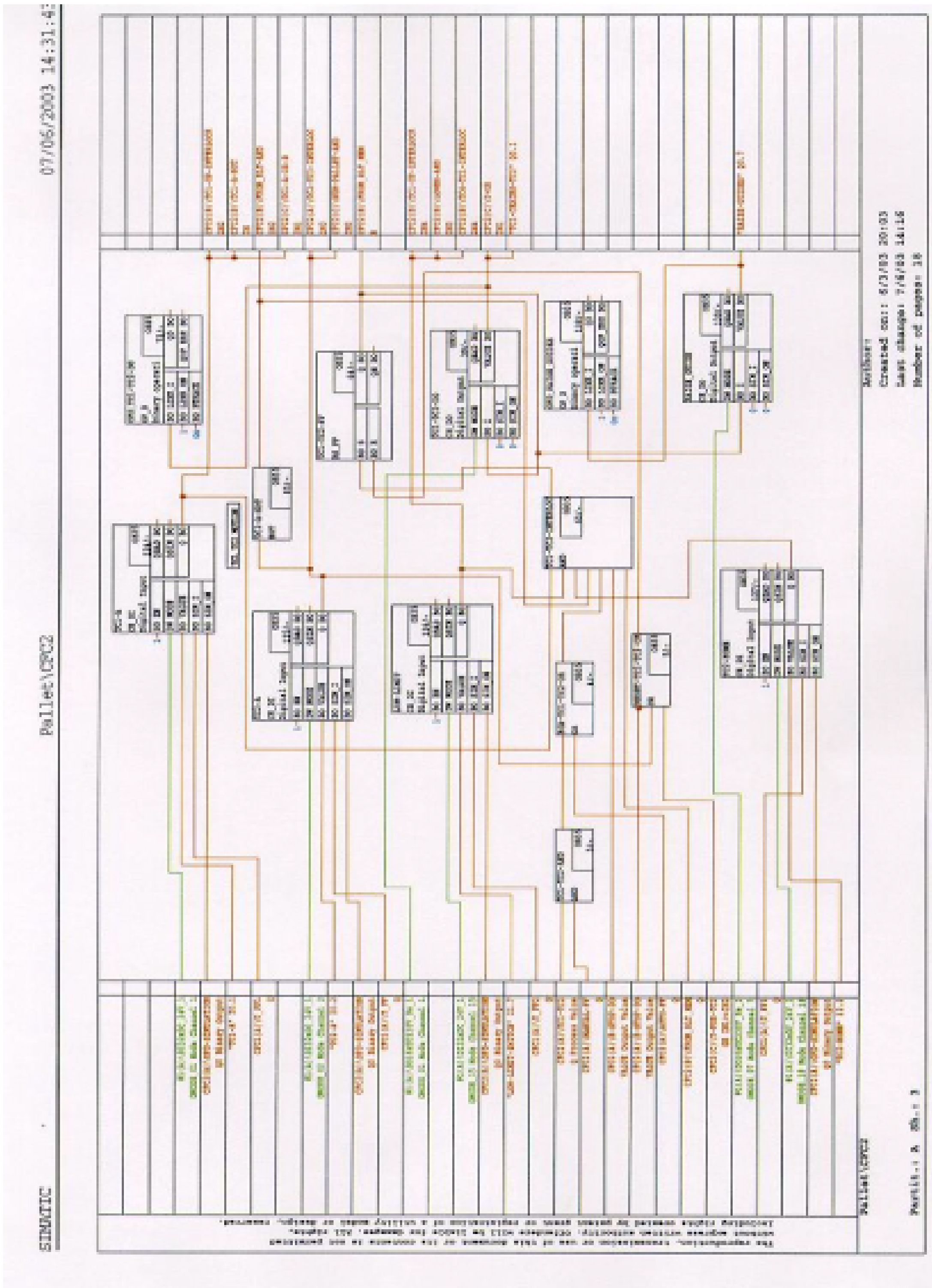
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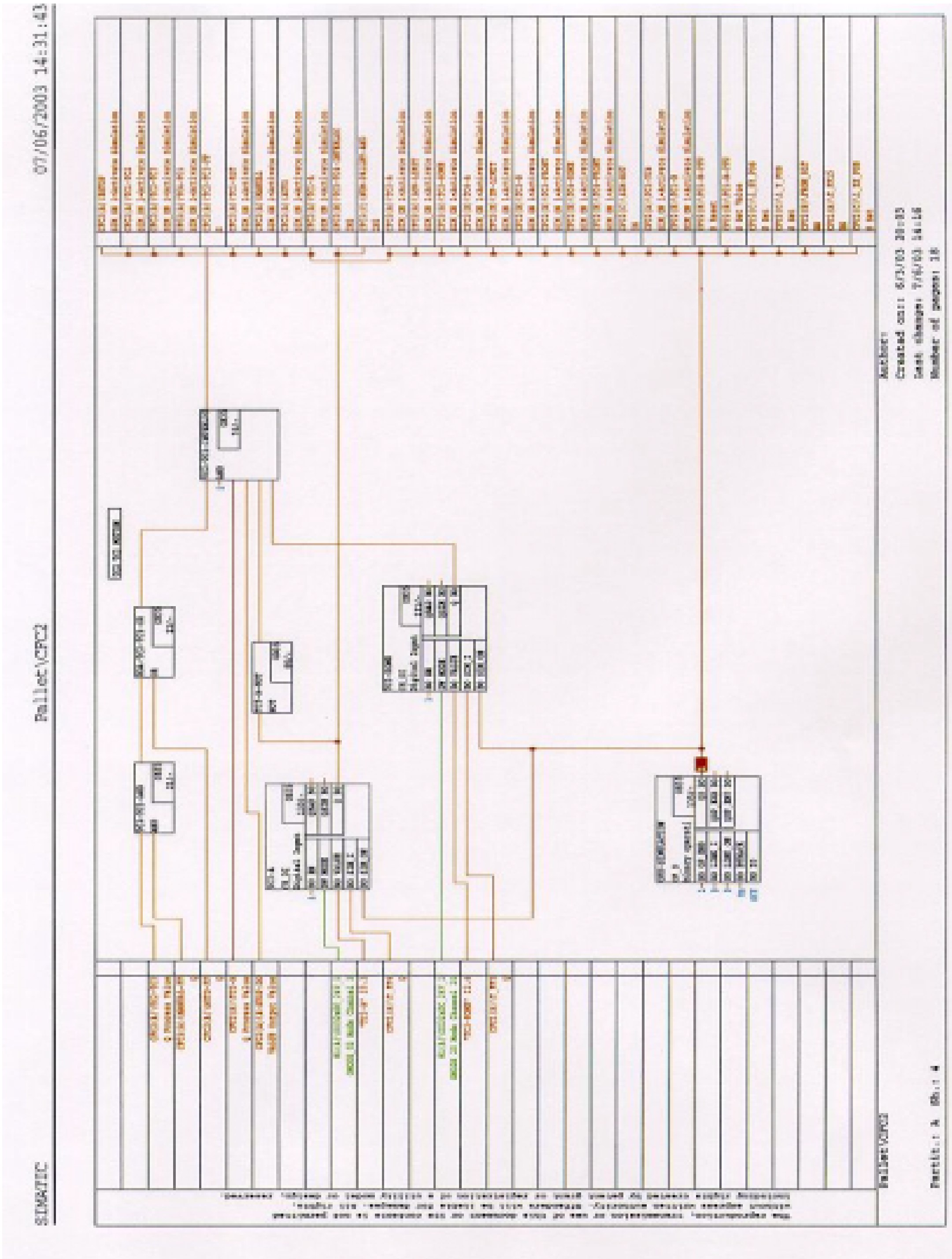
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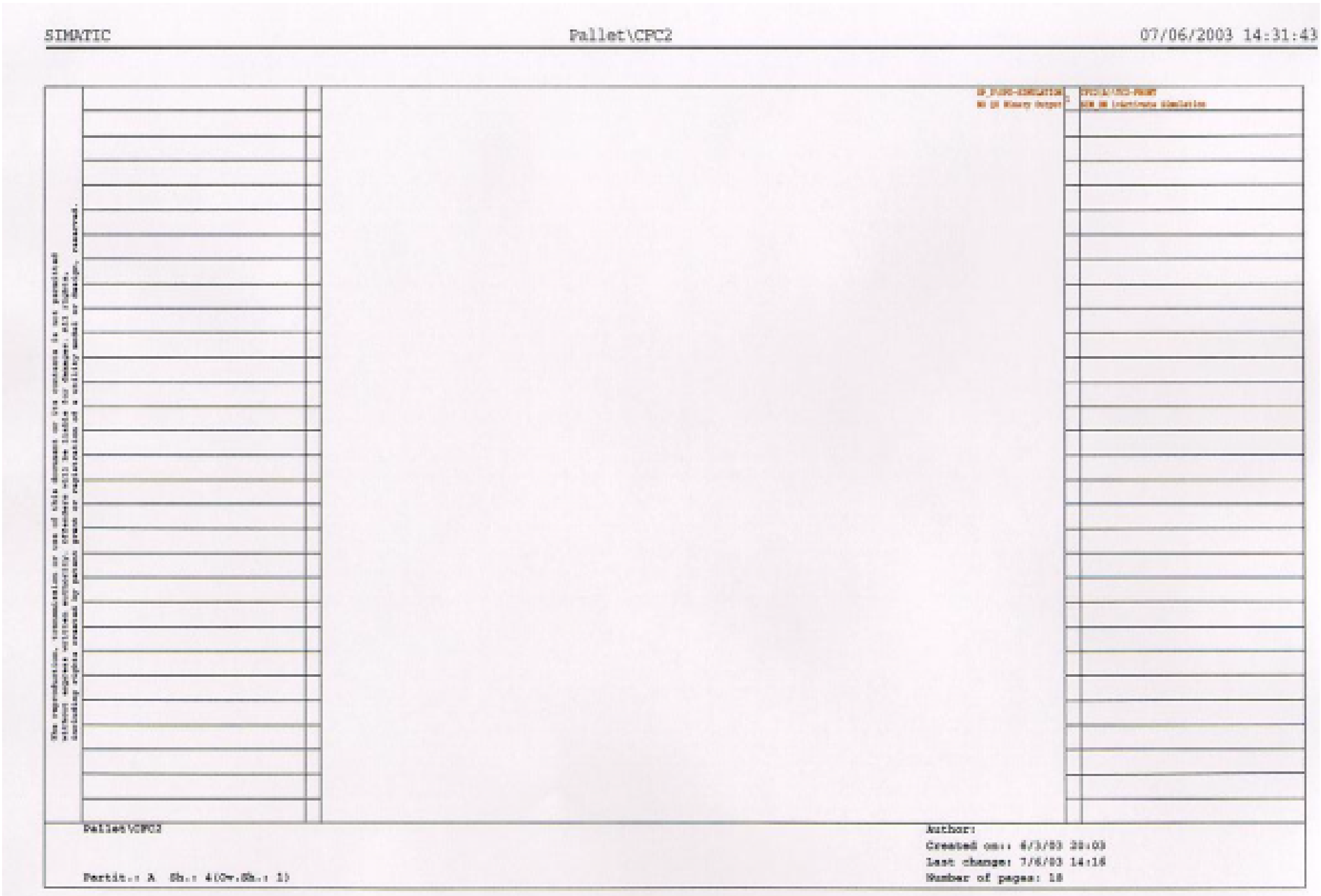
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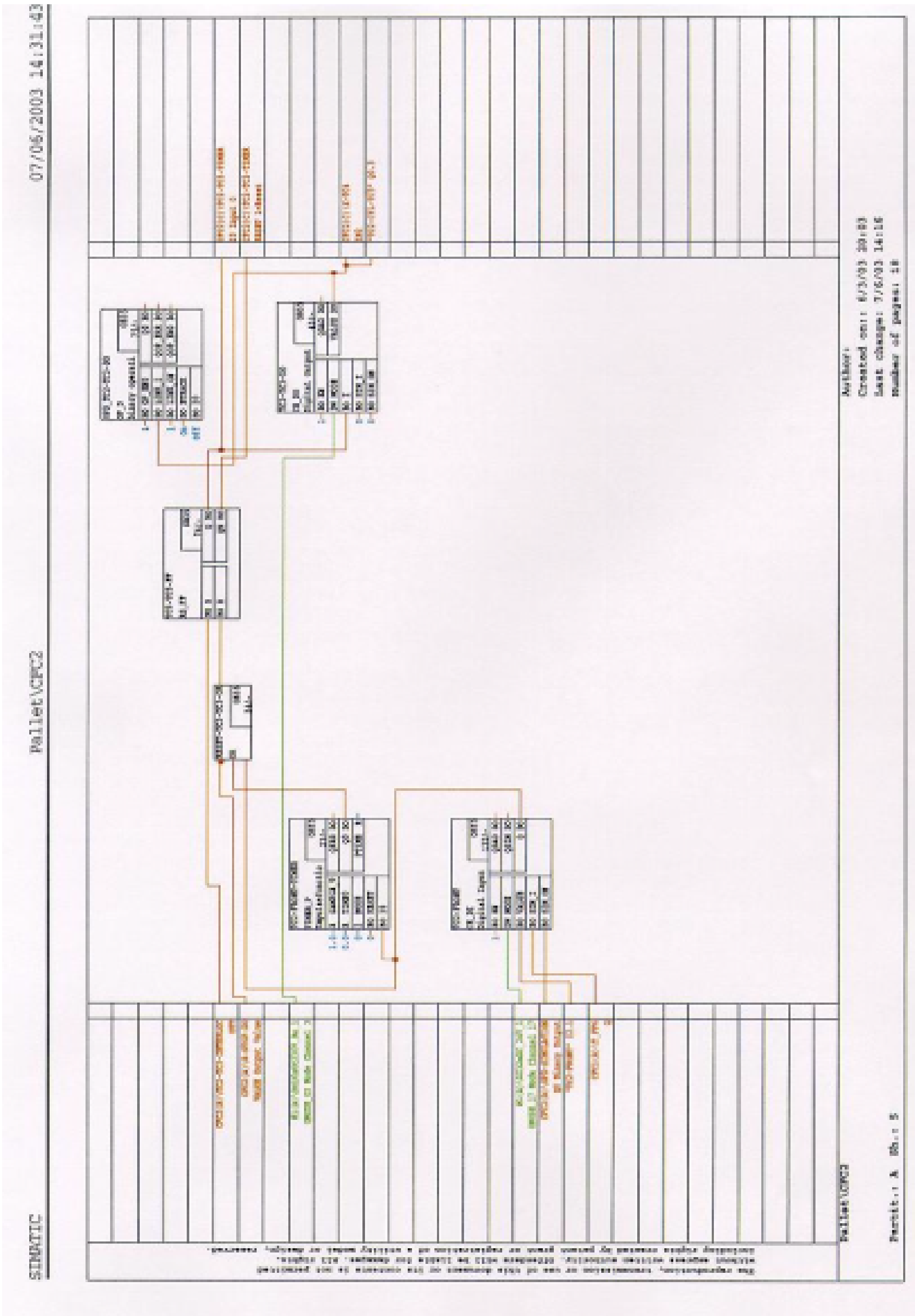
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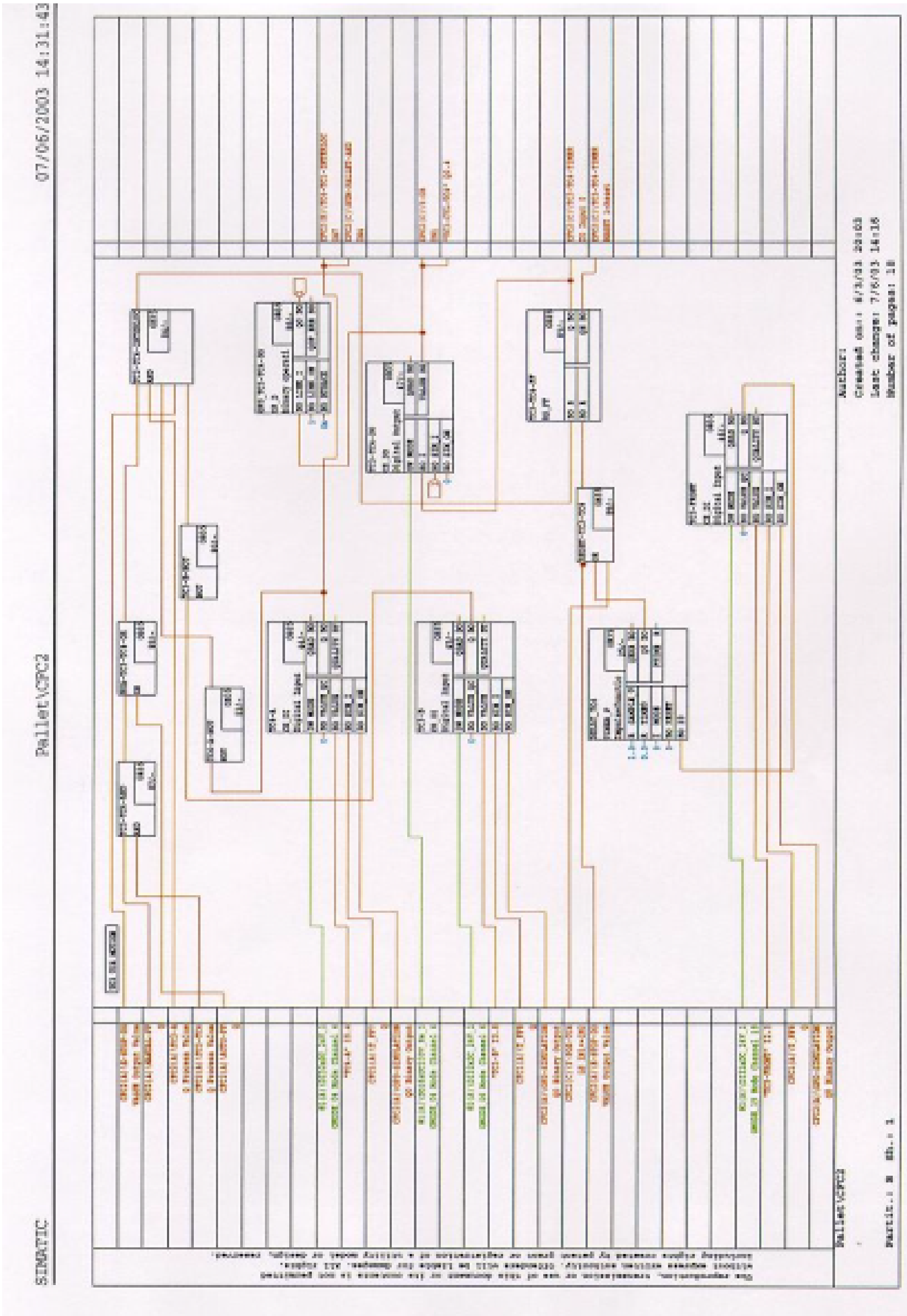
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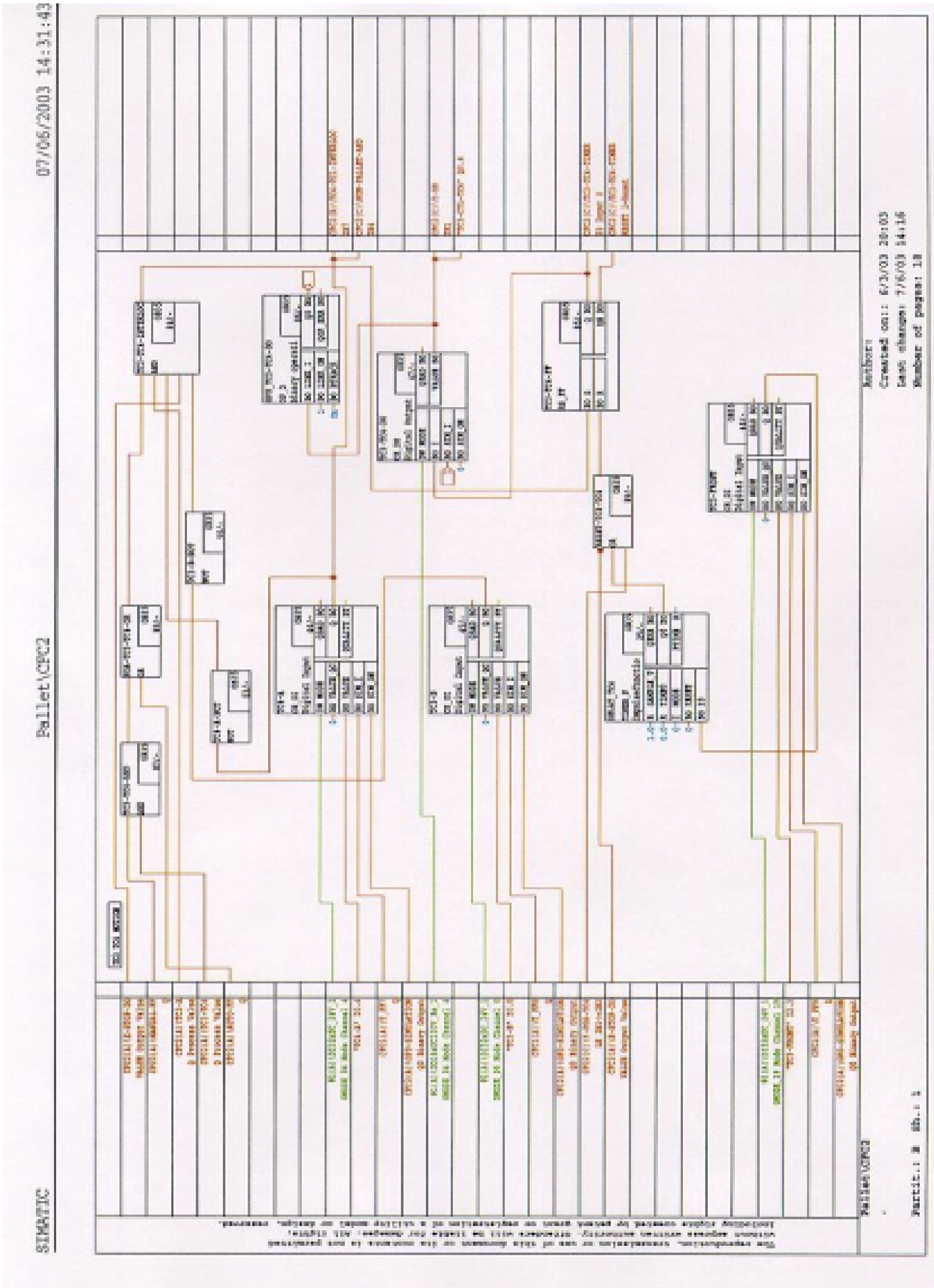
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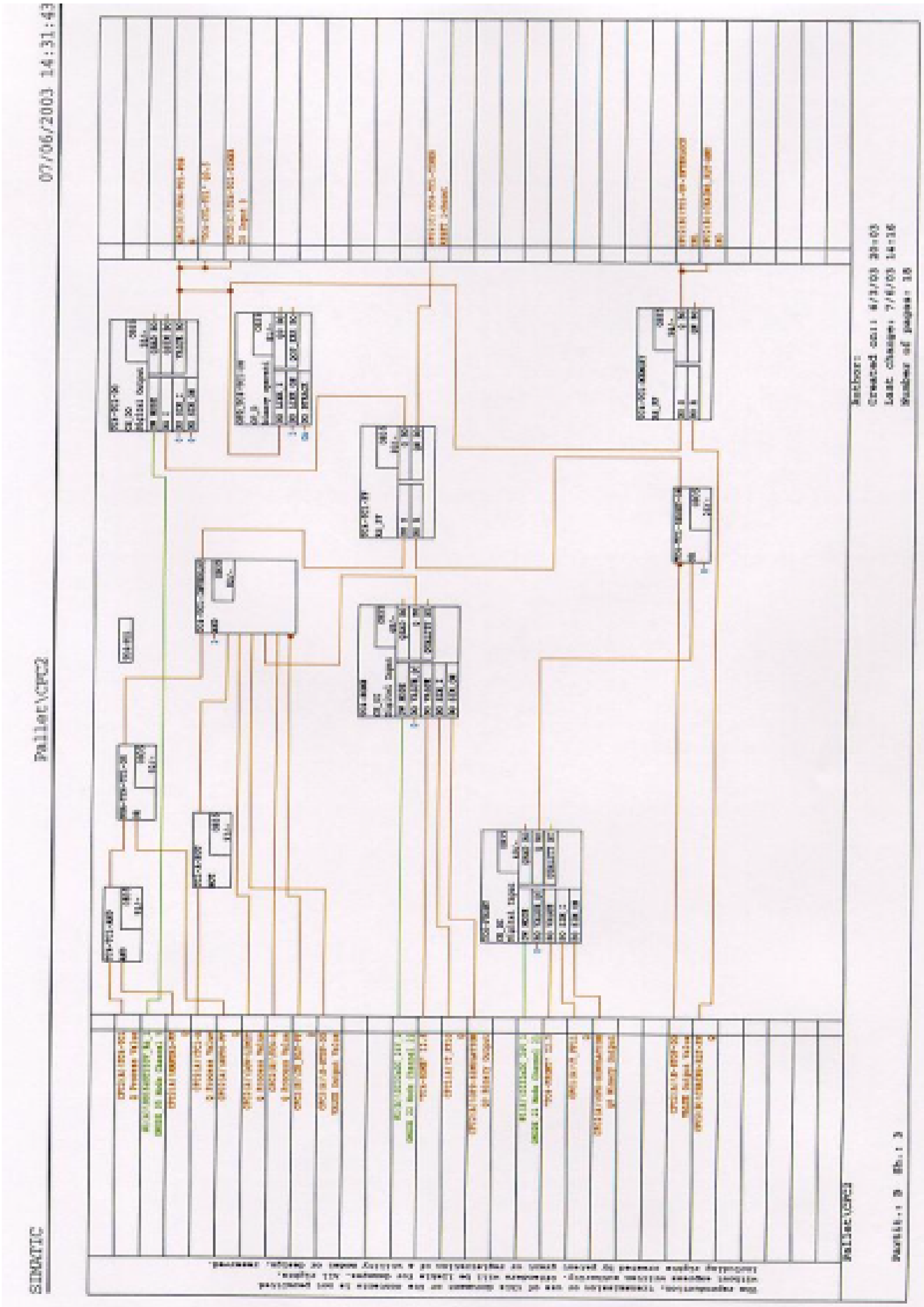
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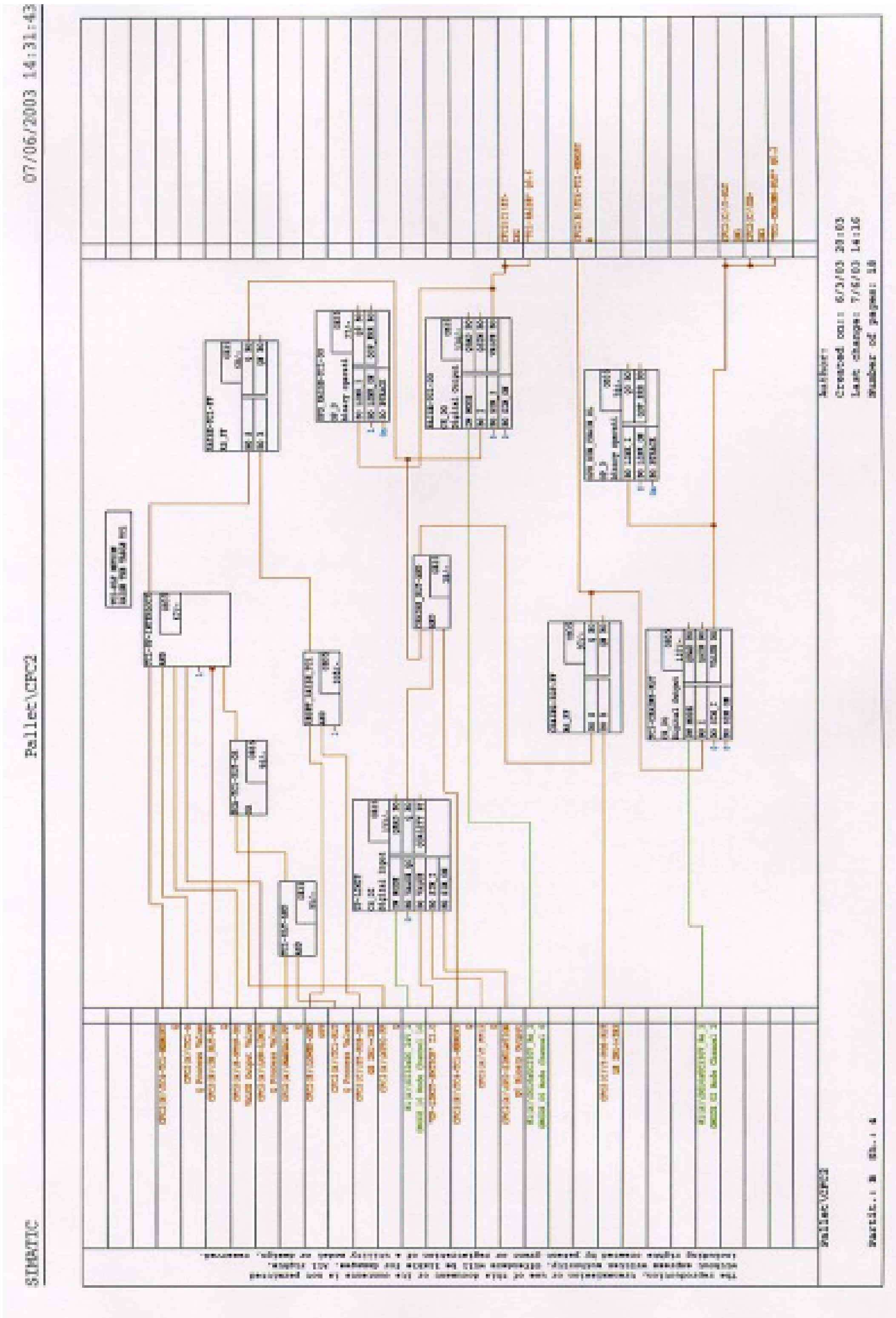
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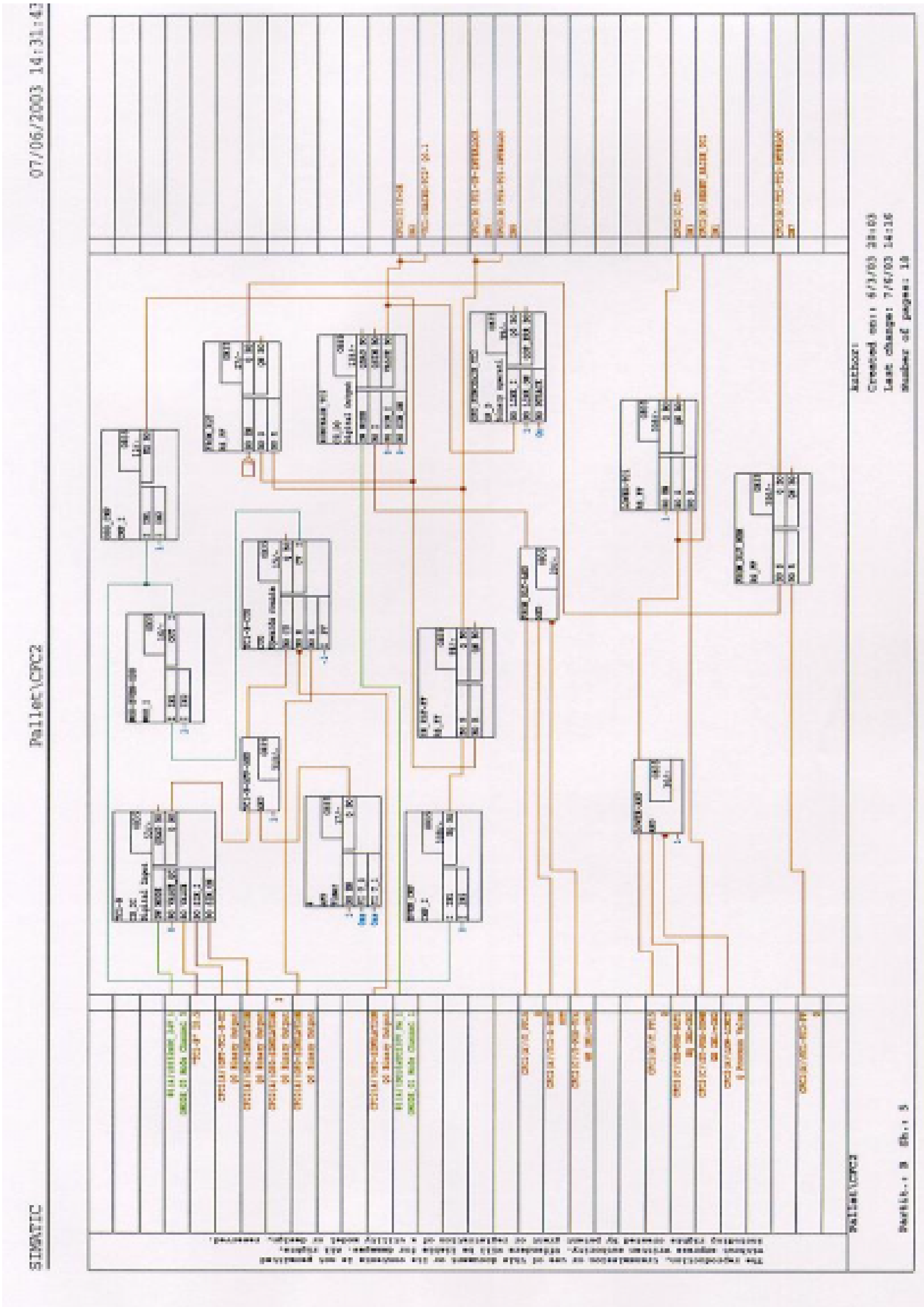
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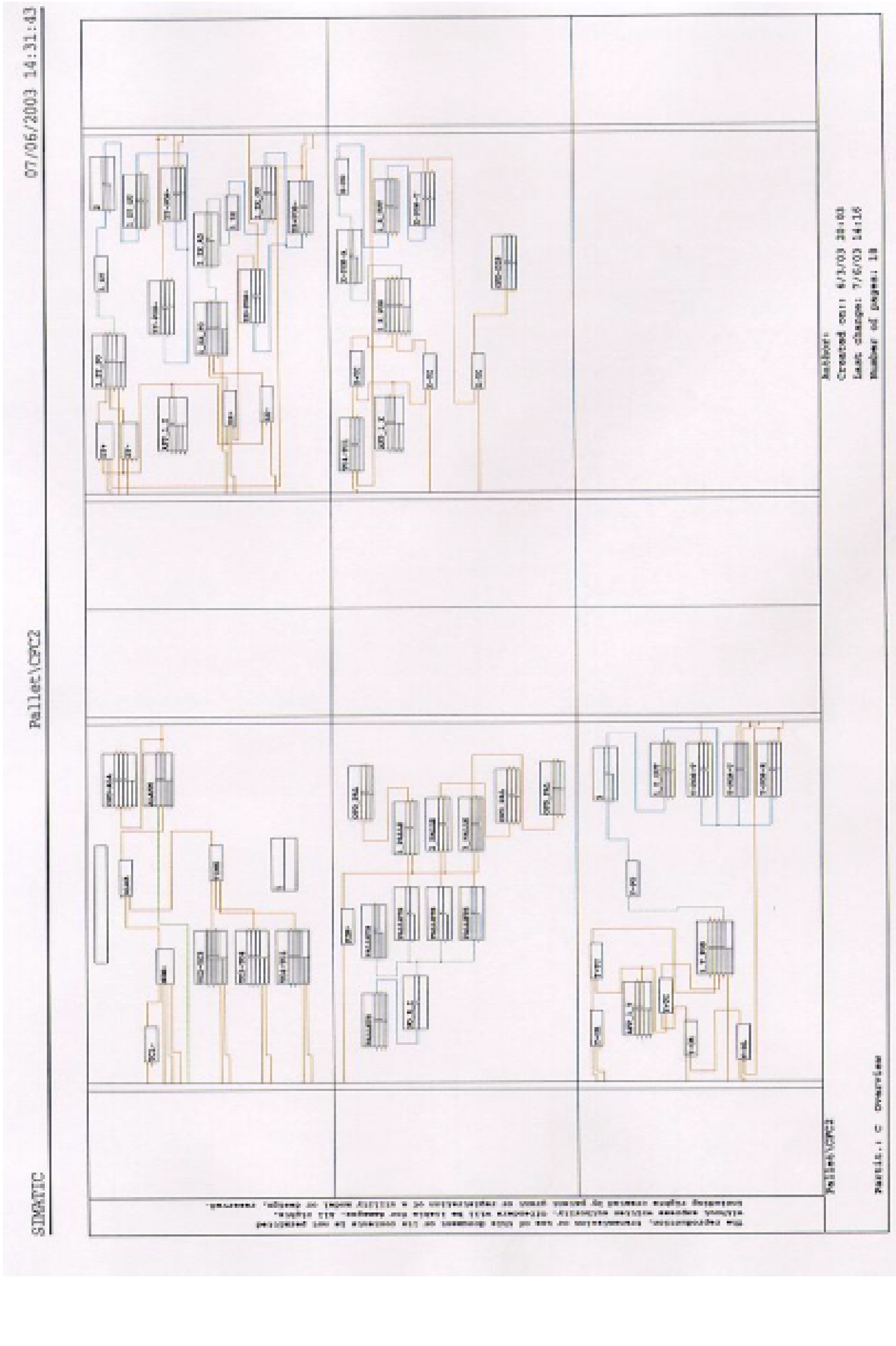
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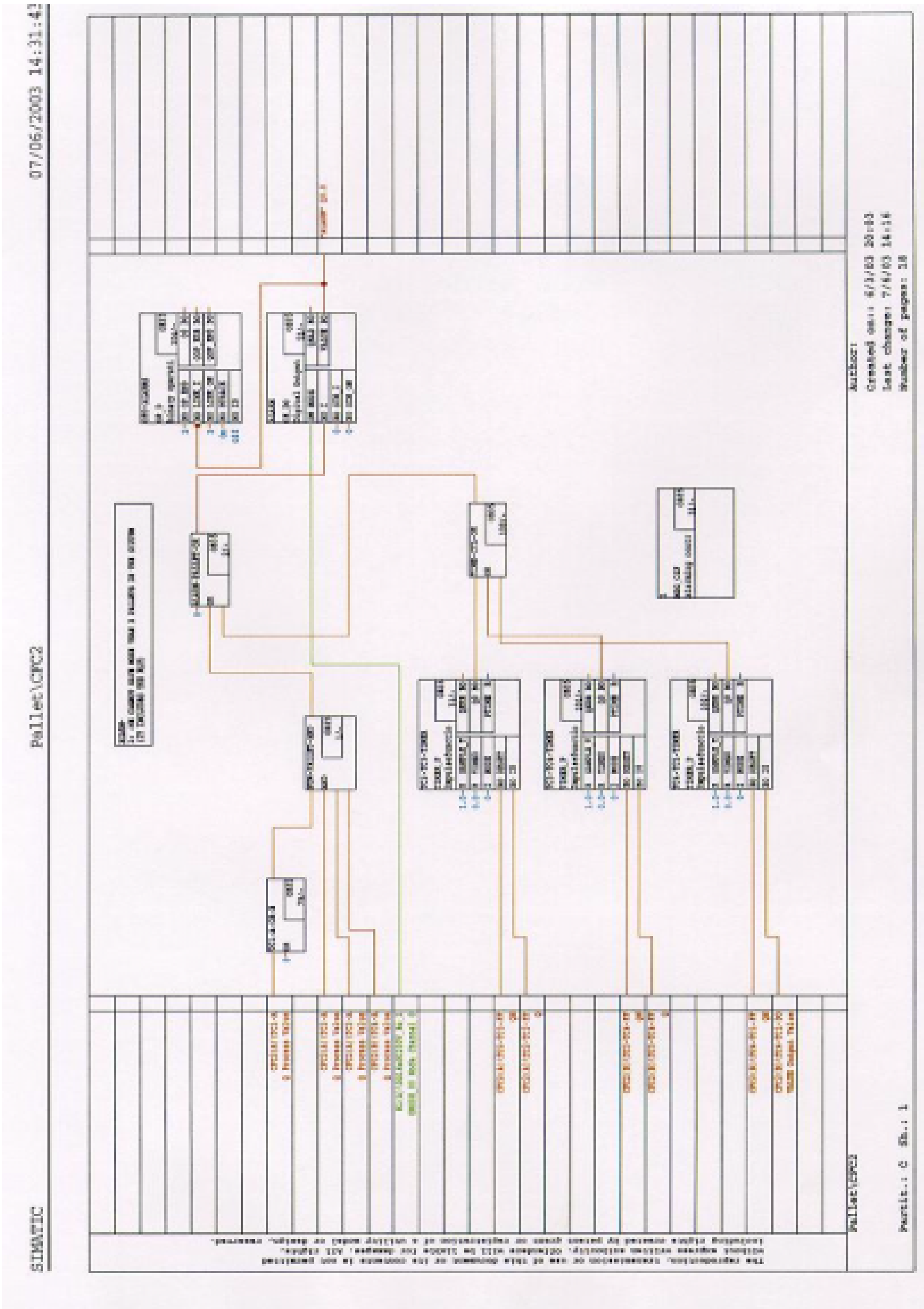
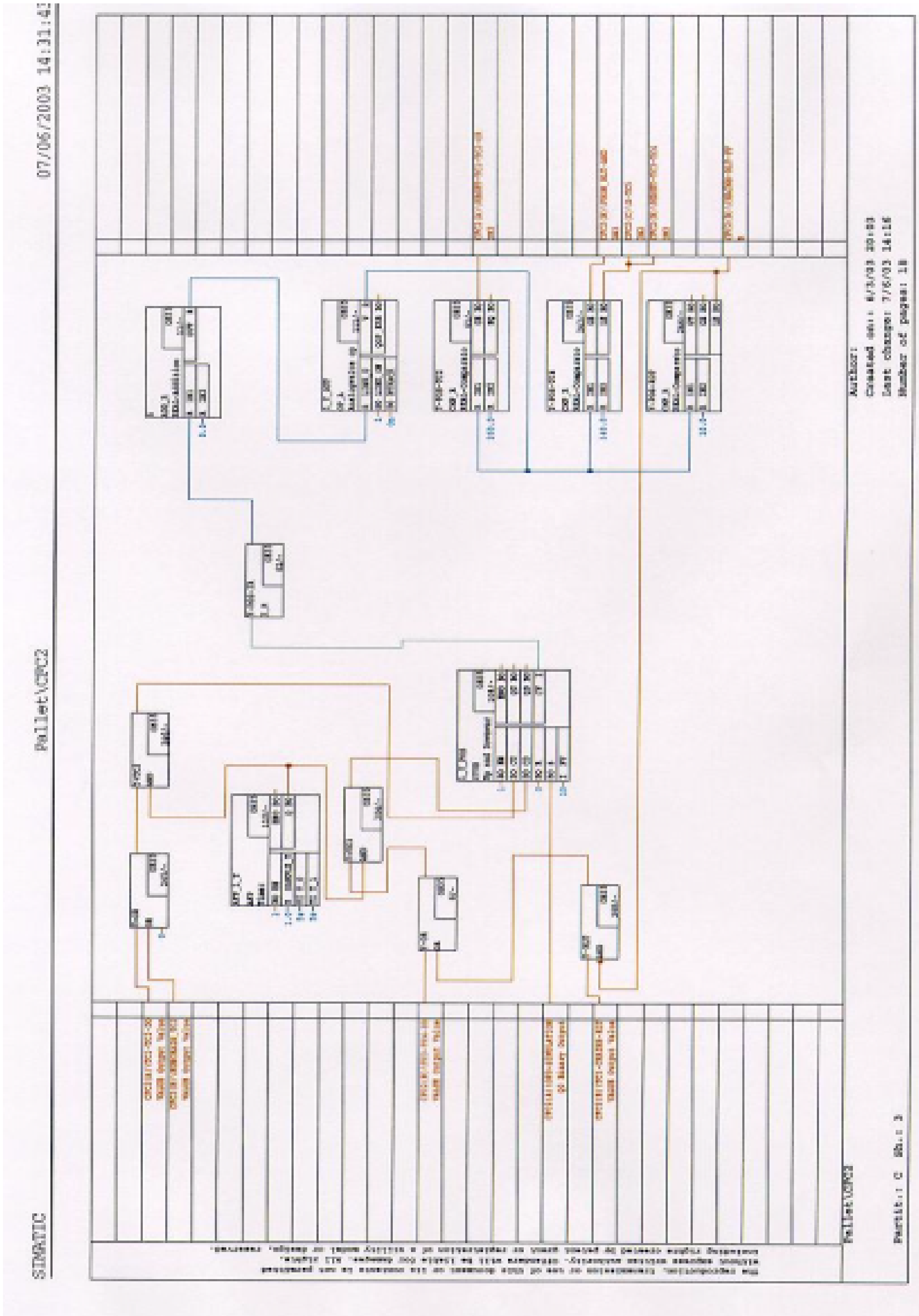
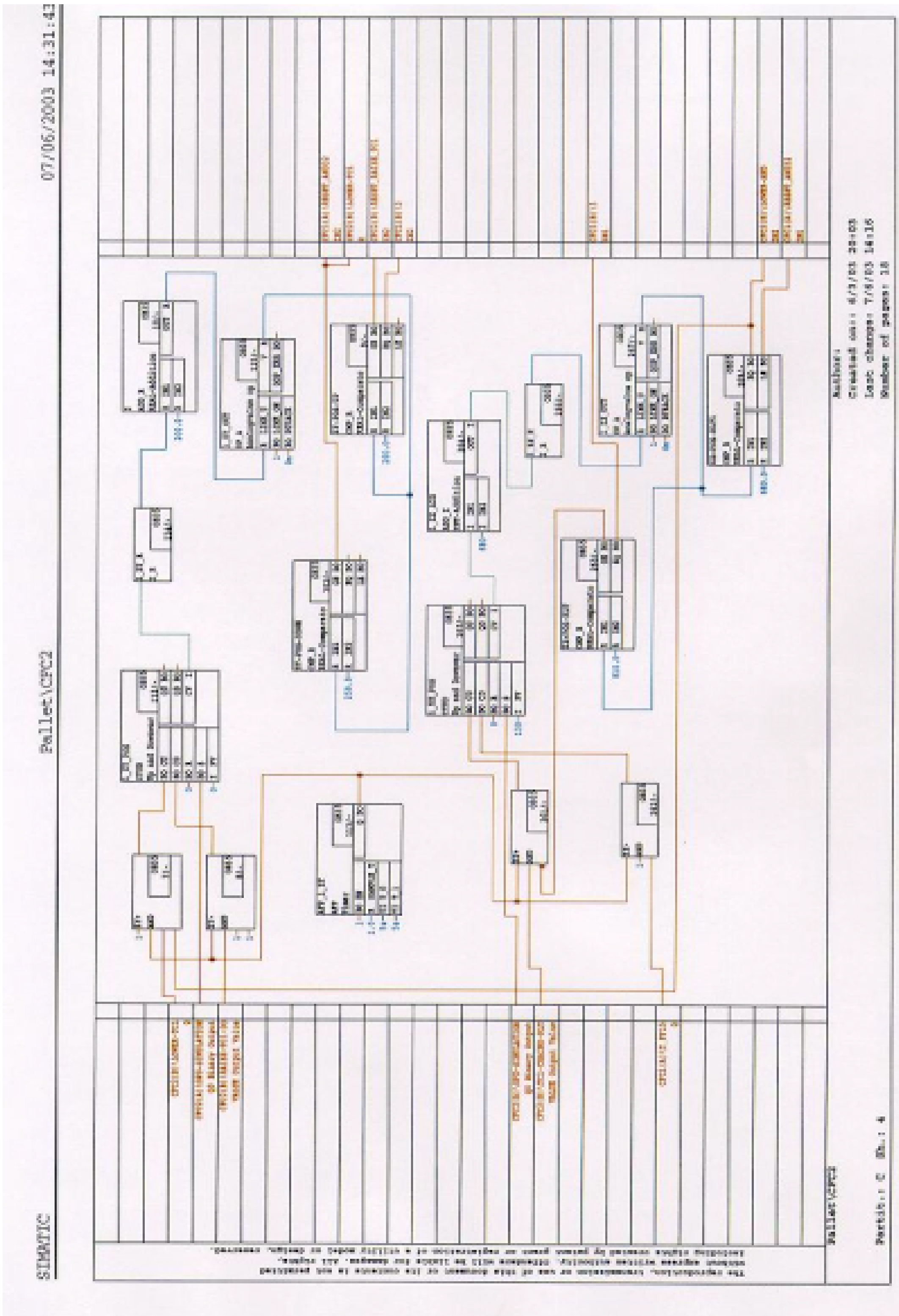
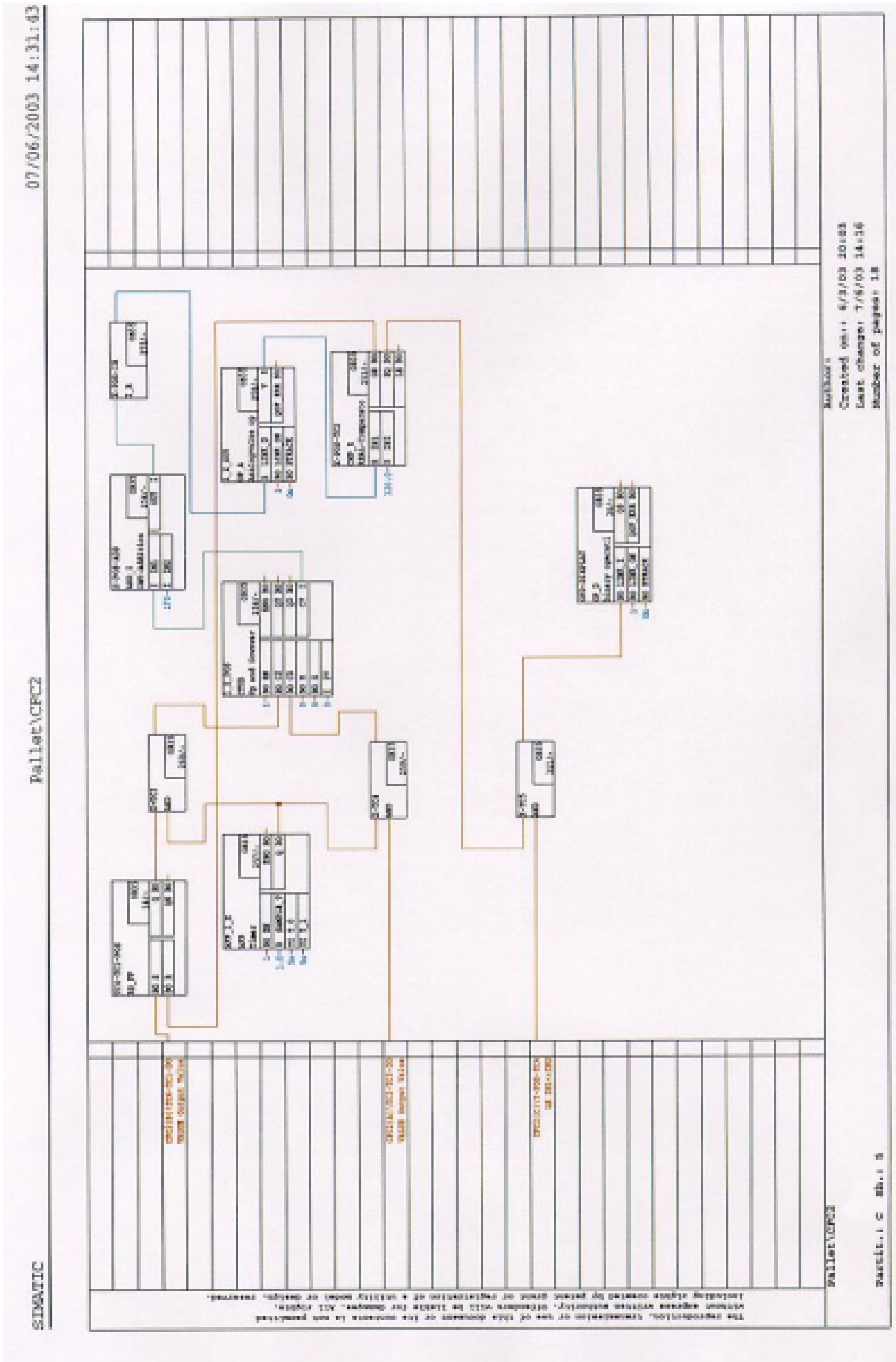

SIMATIC
Pallet\CFC2
07/06/2003 14:31:43


SIMATIC
Pallet\CFC2
07/06/2003 14:31:43


SIMATIC
Pallet\CFC2
07/06/2003 14:31:43


SIMATIC
Pallet\CFC2

Appendix B. Description of Function Block CHDI

CH_DI: Digital value input

Type/Number

FC 277

Calling OBs

The watchdog interrupt OB into which the block is installed (for example OB 32). If you use the CFC driver wizard, it interconnects the input MODE automatically to the respective output OMODE_xx of the module diagnostic block.

Application

The block is used for signal processing of a digital input value from S7-300/400 SM digital input modules.

Functional description

The block processes all the channel-specific signal functions cyclically.

Operating principle

The block reads a digital value from the (partial) process image. If the high byte of the MODE input parameter = 0 (value status), the digital value is handled as invalid. If the input parameter PQC = TRUE, the value status of the digital value is read from the (partial) process image.

A quality code which can have the following states is generated for the resultant value

State	Quality code
Valid value	16#80
Simulation	16#60
Substitution value	16#48
Invalid value	16#00

Addressing

The symbol generated with HWConfig in the symbol table for the digital input channel has to be interconnected to the VALUE input parameter. If the value status of the digital input channel is also in the (partial) process image, you have to interconnect the corresponding symbol with the input parameter VALUE_QC and set the input parameter PQC = TRUE.

Normal value

The digital value of the (partial) process image is output to the output parameter Q with quality code (QUALITY) = 16#80.

Simulation

If the input parameter SIM_ON = TRUE, the value of the input parameter SIM_I is output to the output parameter Q with quality code QUALITY = 16#60. Simulation has the highest priority.

Substitution value

If the input parameter SUBS_ON = TRUE, the value of the input parameter SUBS_I is output to the output parameter Q with quality code (QUALITY) = 16#48, in as far as the digital value of the (partial) process image is invalid.

Hold last value

If the input parameter SUBS_ON = FALSE, the last valid output parameter is output if the non-linearized value is invalid. The quality code is set to (QUALITY =) 16#00.

Error handling

No plausibility checks are carried out with reference to the input parameters.

Start-up characteristics

Does not exist.

Time response

Does not exist.

Message characteristics

The block does not have message characteristics.

Operator control and monitoring

The block does not have a faceplate.

See also:

I/O bar of CH_DI

VITA

Siva Kali Prasad Dasari was born at Tuni, Andhra Pradesh in India on May 13, 1979. He was raised in Visakhapatnam and went to grade and junior school at Timpany School. He graduated from Bharatiya Vidya Kendra Junior College in June 1997. From there he went to Regional Institute of Technology, Jamshedpur and received his B.S. (Eng.) in Mechanical Engineering in June 2001.

After completing his undergraduate career, he decided that he would continue his education pursuing Master of Science in Mechanical Engineering at University of Tennessee, Knoxville.