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AUTOMATION OF PETROLEUM STORAGE TANK LEAKAGE THROUGH PRODUCT TRANSFER CONTROL USING PROGRAMMABLE LOGIC CONTROLLER

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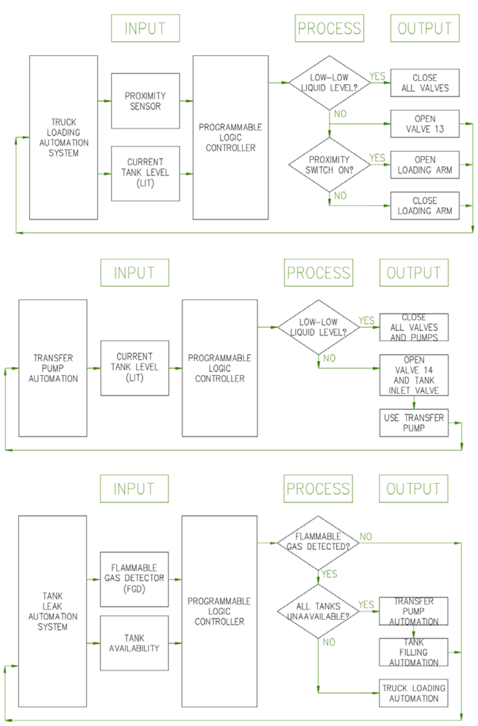
Graphical abstract



Abstract

Industrial storage tanks have always been a critical part of the petrochemical industry due to their capacity to either act as a buffer to other plant processes or simply to store enormous amounts of fluids for a long period of time in a controlled environment. These petroleum storage tanks are supposedly constructed to follow specific sets of instructions guided by the American Petroleum Industry from the type of material used up to the welding procedure. But due to inefficient construction, unmaintained and uninspected problems, welding defects, and environmental concerns among others, a leak in a storage tank can occur and will be a major problem as this can cause fire, explosion, and environmental hazards. Additionally, due to tensions between Ukraine and the Russian government and the succeeding Russian ban on oil imports, the cost of 1 barrel of oil rises at an alarming since 2020. With that in mind, an automation procedure is proposed by the researchers, to save as much of this oil from leaking and being unusable and to reduce the causes of further accidents. This paper not only seeks to use an existing tank layout, with currently installed level indicator transmitters, motor-operated control valves, and other equipment, but also to introduce flammable gas detectors that could detect the leaked petroleum on the ground and would initiate the automation procedure. The automation setup was realized by flowcharts, PLC, and ladder logic simulation using Picosoft software. Automation procedures are analyzed wherein the tanks are being filled, the trucks are being loaded, a leaking tank has its contents pumped to another tank, and a leaking tank has its contents pumped to the truck loading station. Results show that a minimum number of 8.89 barrels of oil saved could breakeven the cost of an estimated amount of $80-90 dollars per barrel of oil can be saved by the proposed automation.

Keywords: Flammable Gas Detector (FGD), Ladder diagram, Leak, Programmable Logic Controller (PLC), Storage tank

1.0 INTRODUCTION

The storage tank facilities or tank farms are an important part of the petrochemical industry [1] due to its flexibility for production planning and ensuring sufficient feedstock and product ullages to meet the product demands at the defined period. Despite the minimal operating process involved in these facilities, process safety and risk management of storage tanks are important concerns for safe production in the petrochemical plant since it highly involves large volumes of flammable and hazardous materials. This is because the release of service fluid from these tanks can lead to escalated consequences such as fire and explosion leading to human, property, and environmental hazards. According to statistics recorded from 1960 to 2003, accidents in terminal and storage facilities are the second most frequent with 26.4% occurrence. Studies have concluded that most of these tank accidents would have been avoided if good engineering design, operation and safety management had been in place [2].

Smart manufacturing has been gaining attention and was heavily encouraged to be implemented in developed countries. It employs computer-integrated manufacturing, high levels of adaptivity and rapid design changes, digital information technology and flexible technical workforce training. Smart manufacturing is widely used to optimize the process operation and product quality using advanced sensors and instrumentation and integration of digital platforms and data analytics to control and optimize the process. In Mexico, a study is conducted in introducing IEC-61850, a communication standard to Intelligent Devices (IEDs), to its oil refinery plants in hopes to improve their automated electrical systems [3]. On the other hand, Chinese researchers seek to implement Smart Manufacturing on the Petrochemical Industry in hopes of increased production value with minimal costs. One of the challenges and opportunities for smart manufacturing is the abnormal situation management which aims to reduce safety accidents [4].

A leak on a petroleum storage tank can cause serious problems especially in these trying times wherein a barrel of oil costs more than 100.00 USD [5] due to political and environmental reasons [6]. A leak in a storage tank is an existing risk although regular maintenance for static equipment such as tanks is implemented throughout the life cycle of the equipment. Several factors including, but not limited to tank wall structural integrity or valve weld defects can cause leaks to occur [7,8]. Natural calamities such as flooding, storms, and earthquakes can also greatly damage the structural integrity of the tank and cause leakage [9,10,11,12], and from these leaks the spread of the fluid by evaporation could potentially be harmful [13,14].

Instrumentation such as fire and gas detectors have been implemented to these systems to detect any leakage or fire that may occur. Several studies have been conducted to improve the detection capability of these sensors for rapid response to any leakage. One study proposed a detection method for a small leakage from underground storage tanks which employs full coverage of the three-dimensional capacitance array sensor with optimized parameters and higher sensitivity for early detection of small leakage. The proposed method offers high accuracy and a quantitative estimation of the leak that can be used for process safety and risk prevention [15]. Additionally, another study analyzed the stages of the storage tank leakage and the factors affecting the key detecting parameters at the alarm time such as relative positioning of the gas detectors and the jet point location, wind direction, dispersion accumulation of the liquid pool during continuous leakage [16] as shown on Figure 1. These parameters were used to strategically locate the flammable gas detectors for early warning and emergency response.

Current studies suggest improvement on the sensor for accurate and early detection of the leak source [15,16,17]. However, these are passive measures which potentially escalate the consequences in case of leak if emergency response was not executed as soon as needed. Hence, engineering controls and automation are required to proactively address the leak from storage tanks.

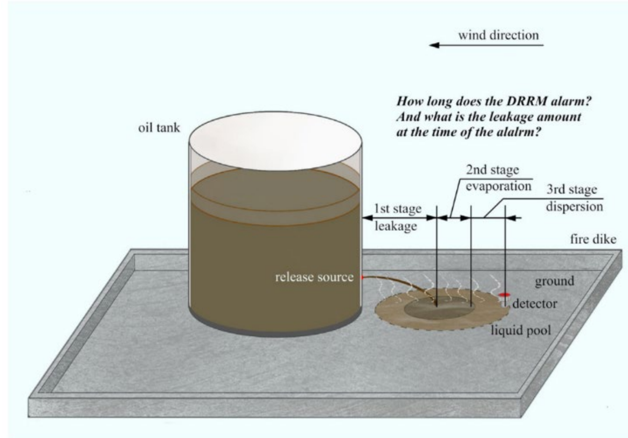


Figure 1 Flammable Gas Detectors [16]

This paper presents a proposed automation solution for leaking petroleum from newly built storage tanks with the use of instrumentation, actuated valves, and motor controls that are typically found in most petroleum tank farms and the introduction of a flammable gas detector that starts the automation process. The aim is to automate the system to stop petroleum inflow towards the tank and to transfer the product from the damaged tank to other available tanks upon detection of the leakage to prevent further loss of product or to load this product towards a tanker truck for storage. This paper provides controllers and instrumentation with a nod to its specifications for the automation solution that provides remote control over these processes and employs the use of programmable logic controllers and ladder diagrams. With the upgrading of the said control system and measurement, the proposed automation is applicable to incorporating it into tank automation setup regardless of its containment and is expected to increase the productivity and use of the storage tank by automatic control and a more automated approach on tank leaks.

2.0 METHODOLOGY

Figure 2 shows the step-by-step procedure of this research. It is ideal to provide an actual facility to understand the flow of the automation procedure. Therefore, in this paper, an existing storage tank farm facility is studied for application of robust process control automation in the event of tank leak scenario. The configuration of the tank design is considered for currently installed instrumentation, valves, and pumps which are utilized for the automation logic. Flowchart of the process are illustrated to determine the automation control of the tank farm. A novel tank leak detected automation is then added to the flow of processes of the tank farm. Equipment and instruments from the tank farm were also identified to determine the processes actual input and output and flammable gas detectors were introduced as the primary instrument that determines the leak in a particular tank. These equipment are used as the main elements in the ladder programming using Picosoft software and follows the piping and instrumentation diagram and process flowchart for its procedure. Simulation analysis is employed to determine the effectivity of the ladder diagram and the economic analysis was studied on the use of a specific type of PLC on a tank farm against the amount of oil saved from employing this automation to determine its financial benefit.

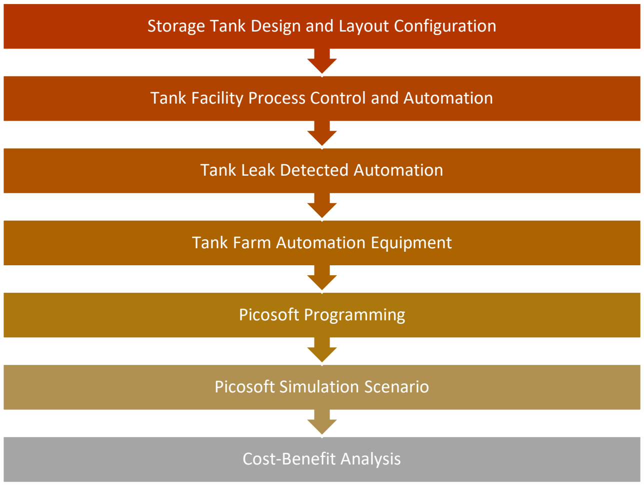


Figure 2 Methodological Framework

2.1. Storage Tank Design and Layout Configuration

The storage tanks design used in this study follows the API 650 13th Ed Codes and Standards for the use safely storing petroleum, petroleum-based products, and other types of liquids. The conical-roof tank used in this study has a 10m diameter, a height of 14m, and a safe volumetric capacity of 1000m^3. It is designed to take a maximum operating pressure of a pressure equal to 14m of water plus 200mm factor of safety.

The tank is installed and is welded with different kinds of nozzles such as: gauge hatches, manholes, sampling nozzles to check the quality of the petroleum inside the storage tanks, a liquid drain nozzle is also installed at the bottom of the tank to fully empty the insides of the tank in case of maintenance and repair, vent at the top of the tank in case of overpressure, and foam and sprinkler systems in case of fire. Other accessories that are welded on the shell sides and carry load are the stairs, connecting bridges to the other tanks, platforms, and pipe risers.

Although the tanks are installed with different types of nozzles, the nozzles that would be focusing on this paper are those that are used by the automation system as shown in Table 1. The nozzle location is shown in Figure 3.

Table 1 Nozzle Descriptions

Mark	Service	Size	Nozzle Type
N1	Liquid Outlet Nozzle	4B	Jacket Type w/ Dip Nozzle
N15	Liquid Inlet Nozzle	3B	Jacket Type w/ Dip Pipe
N23	Radar Nozzle	4B	Jacket Type w/ BF
N24	Level Alarm Nozzle	4B	Jacket Type

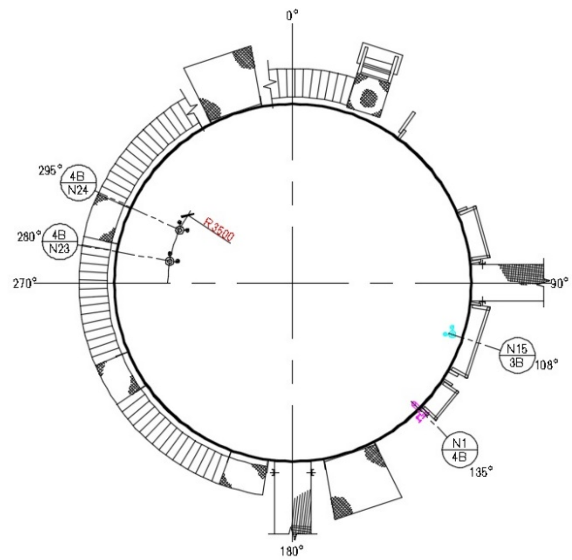


Figure 3 Design of tanks used in this study

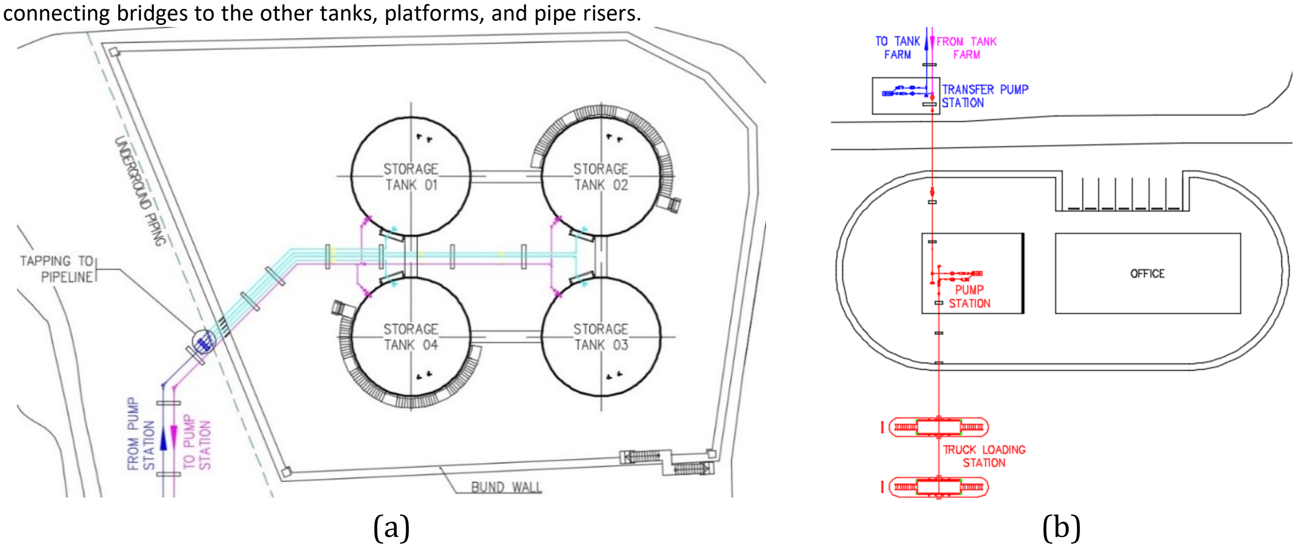


Figure 4 Plant layout used in this study: a.) Tanks and b.) Truck Loading Station

In this study, four cylindrical storage tanks were used to store Petroleum Product 1 from a refinery plant and are arranged equidistant to each other with 6m margin from the bund wall. The tag name for these storage tanks that will be used throughout this study would be ST-01, ST-02, ST-03 and ST-04. Moreover, the high-high and the low-low liquid level are 90% and 10%, giving a safety margin of 10% from the tank overfill scenario and the pump running dry, respectively. The layout of the tank is depicted in Figure 4a wherein the tanks are spaced 16 by 13.5 m apart. All the storage tanks receive their petroleum content from an underground pipeline, while the outlets are connected via a single pipe towards the pump station. The petroleum product is either pumped towards the truck loading area for local sales or pumped to an export facility for international sales.

The piping and instrumentation diagram for this facility is shown in Figure 5 where the various processes are color-coded for differentiation. Lines colored green in the diagram is the motor-operated valves (MOV-01 to MOV-04) are valves from the underground pipeline. Lines colored dark blue are from the transfer pump system with the motor operated valve (MOV-05 to MOV-08 and MOV-14) and Pump-01. The two pipelines converged into a tee connection towards the inlet of the tank denoted by the cyan colored lines. Magenta colored lines and valves (MOV-12 to MOV-12) are for the outlet of the tank and is separated to two separate lines, to the transfer pump or the valve with the loading arm denoted in red lines. The level of oil inside the tanks is measured by the Level Indicator Transmitter (LIT-0X) connected in each tank and is shown that the design High-high level is 11,460 mm and the design Low-low level is 290 mm.

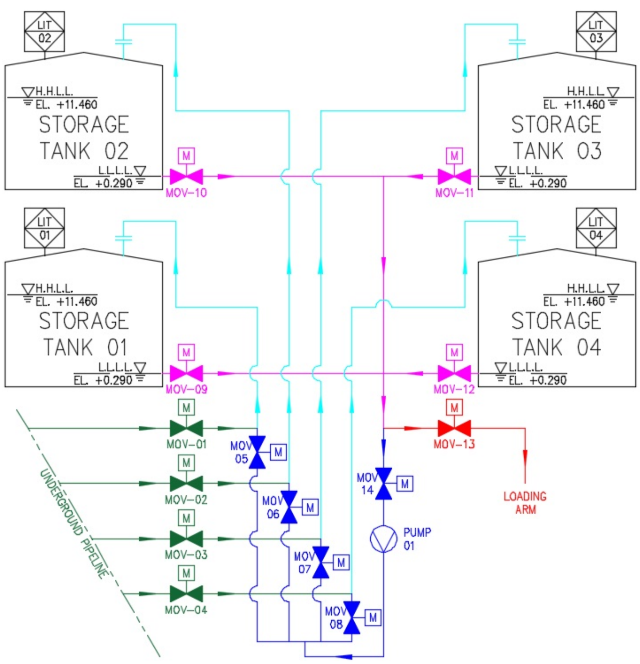


Figure 5 Piping and Instrumentation Diagram of tank farm

2.2. Tank Facility Process Control and Automation

In this paper, tank availability is introduced and is defined as the availability of the tank to use for petroleum storage. There are three main reasons for the tank unavailability – (1) tank is at its full capacity which is indicated by a High-High Liquid Level alarm (LAHH) from the Level Indicator Transmitter, (2) the outlet valve is open which indicates that the product is unloading for export/sales or (3) that flammable gas detector (FGD) has detected a leak on the tank. The availability of the tank is the main factor for the product transfer automation that decides the product destination in the tank facility. The process control logic for the tank's availability in the tank farm facility is summarized in Figure 6 wherein the three main factors were considered in the flow chart for decision making on the product destination.

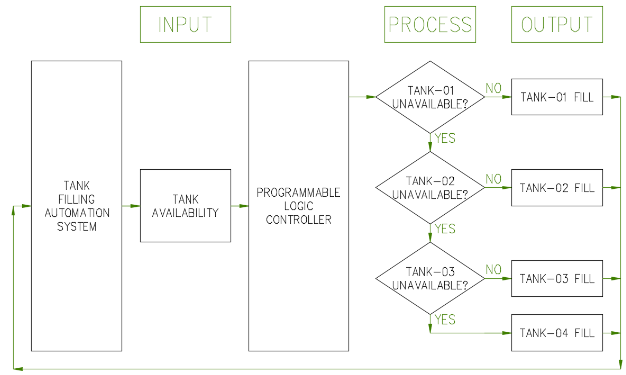


Figure 6 Tank Automation for Tank Availability

This study considers the flow of petroleum in a typical multiple tank farm wherein the petroleum from the operating plant is stored in the tanks via underground pipelines. It assumed that the tanks are being filled every Monday, Wednesday, Friday, and Sunday at 12AM to 7PM. In a storage tank system logic, the product is routed to the first storage tank, ST-01 until its high-high liquid level of 90%. Once the high-high level is reached, the product will be diverted to the next available storage tank which has sufficient allowable level for filling hence below 90% capacity. The basic process control logic of the system continues to divert the product to the available tank in the following order: ST-01 > ST-02 > ST-03 > ST-04. Figure 7 shows the logic diagram for this process automation.

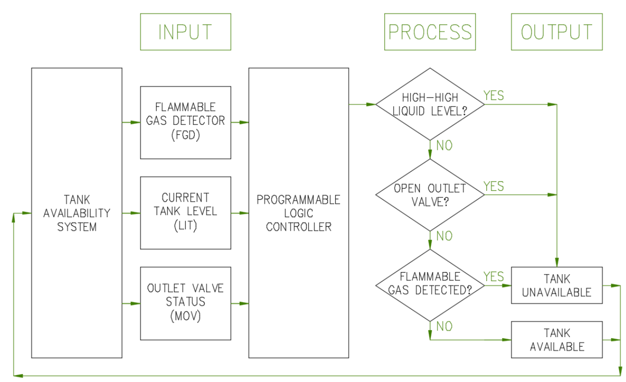


Figure 7 Tank Automation for Tank Filling

In this study, it is assumed that there is continuous loading of products to trucks for local sales. It assumed that the tanks are loaded from 8am – 5PM and that Tank 01 is loaded every Monday and Friday, Tank 02 is loaded every Tuesday and Saturday, Tank 03 is loaded every Wednesday and Sunday, and Tank 04 is loaded every Thursday. In loading the petroleum to a truck, the outlet valve of the storage tank in operation is opened, as well as the inlet valve (MOV-13) of the loading arm (LA-01). Furthermore, there is no inlet product routed to the tank which is unloading to trucks hence unavailable for product diversion from the operating plant. Proximity sensor (PS-01) is used to detect if there is a truck at the truck loading station. If a truck is detected, the loading arm (LA-01) will transfer the petroleum towards the trucks [18]. Once the storage tank is at its low-low liquid level alarm, the logic will signal to close all the valves used in the automation.

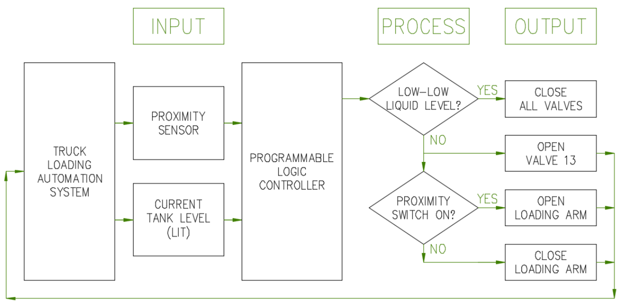


Figure 8 Tank Automation for Tank Loading

2.3. Tank Leak Detected Automation

The scenarios below illustrate the automated logic configuration of the tank inventory transfer and switching of the tank loading in case of leak detection to any of storage tanks.

2.3.1. Leak in a Storage Tank with Available Spare Tanks (Scenario 1)

On a plant standby period, all the inlet and outlet valves of the tanks are normally closed, and the level is assumed to be constant all throughout. In case a flammable gas detector detects the presence of leak at its dedicated storage tank, the system logic automatically opens the tank outlet valve and the transfer pump's suction valve (MOV-14) to route the inventory of the tank with leak to the next available storage tank. The program would then open an available tanks inlet valve that comes from the transfer pump. Before the transfer pump (Pump 01) is used to transfer the liquid out of the tank with leakage, a delay of 10 seconds is observed to ensure that all the valves are fully opened. A Low-Low Level alarm (LALL) would stop the pump and close all the valves used in the automation when the level of the tank is at 10% to prevent running dry of the transfer pump. Figure 9 shows the logic of the transfer pump automation.

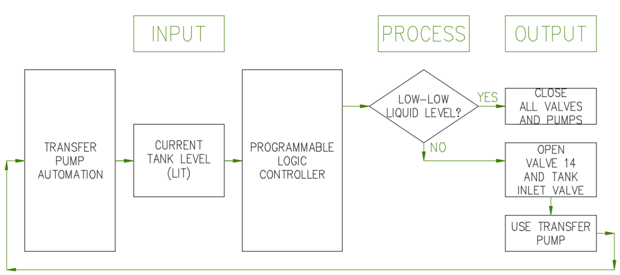


Figure 9 Transfer Pump Automation

2.3.2. Leak in a storage tank with all tanks unavailable for use (Scenario 2)

In a case where all the storage tanks are unavailable to be filled, the remaining petroleum is saved by pumping it towards the truck loading area and will be stored in multiple trucks on standby as shown in Figure 10. The same leak detection is applied but instead of using the transfer pumps, the loading arm is used to transfer the inventory from the tank with leakage to loading trucks. The same procedure is applied for conventional truck loading automation in Scenario 1. In the current industry, this configuration is done manually in various plants and has not yet automated liquid transfer to other tanks in case of leakage.

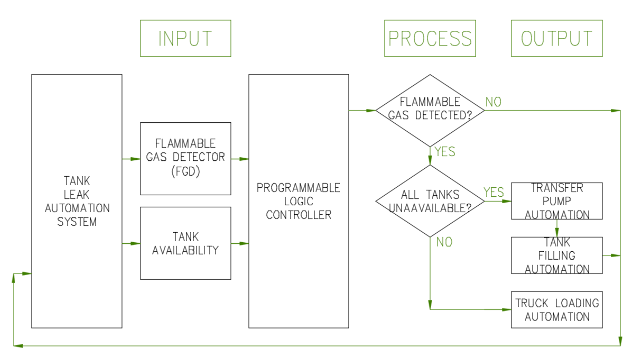


Figure 10 Tank Leak Detection Flowchart

2.4 Tank Farm Automation Equipment

Listed below are the instrumentation required for the storage tank facility with leakage control and product transfer automation and control system:

2.4.1. Input Automation Equipment

2.4.1.1 Level Indicator Transmitter

Non-contact radar level transmitter shall be used for storage tank area with high accuracy level readings without being affected by the service fluid mass density. The major advantages of radar level measurement technique are non-contact, maintenance-free measurement, and can accurately measure both liquid and solid media. Radar instrumentation can have accuracy up to ±2 mm. Besides, the instrument will not need recalibration after initial configuration and will not experience zero point drift or fluctuations due to change in specific gravity, temperature, or pressure. Non-contacting radar provides a top-down, direct measurement as it measures the distance to the surface [19].

2.4.1.2 Proxy Sensor

Proximity Sensor includes all sensors that perform non-contact detection in comparison to sensors, such as limit switches, that detect objects by physically contacting them. Proximity Sensors convert information on the movement or presence of an object into an electrical signal. AVENTICS™ Series SN2 Magnetic proximity sensors shows a magnetic proximity sensor from Emerson that is found in a variety of industries and applications with a robust reed sensor they are designed for a wide voltage range of up to 240 VAC.

2.4.1.3 Flammable Gas Detectors

Flammable gas detectors are widely used in oil fields, mines, chemical plants, smelting plants and other industrial sites, as well as family, hotels, and other domestic premises, which play a significant role to protect human life and production safety. There are four common types of sensors for flammable gas detectors: semi-conductor, catalytic combustion, infrared, and electrochemical. The first three types are mainly used for detection of hydrocarbon gases, and the other one is mainly used for detection of reducing gases, such as carbon monoxide, hydrogen sulfide and other toxic gases [20]. Rosemount™ 975UF Ultra Fast Ultraviolet Infrared Flame Detector shows a flammable gas detector from Emerson that can detect hydrocarbon-based fuel and gas fires, hydroxyl, and hydrogen fires, as well as metal and inorganic fires. The signals from both sensors are analyzed for frequency, intensity, and duration. Simultaneous detection of radiant energy in both the UV and IR sensors triggers an alarm signal. The UV sensor incorporates a special logic circuit that helps prevent false alarms caused by solar radiation.

2.4.2. Output Automation Equipment

2.4.2.1 Motor Operated Valve

A motor operated valve (MOV) consists of a motor, an actuator, and a valve. An MOV with such operational principles is an essential element used to control the piping flow in an industrial plant. In fact, the operational failure of a safety-related MOV could have catastrophic results. Therefore, it is necessary that the operability of the safety-related MOVs should be integral and required in the design basis conditions [21].

3.0 PICOSOFT 6 PROGRAMMING AND SIMULATION

3.1. Ladder Diagram Programming Elements

The programming of the automation employed in this paper was done using Picosoft Version 6 software. This software is used to program Allen Bradley PLC products. Unlike other software for PLC programming, the input and output of the Picosoft is denoted as "I" and "Q" respectively. Due to the huge number of inputs and outputs of the automation, an expansion device denoted by "R" and "S" for the input and output respectively are added to accommodate all the elements. Analog comparator is used to simulate the Tank Levels with A01-A04 for tank level high-high and A05-A08 for tank level low-low. Figure 11 shows an example of a 7-day time switch which is used to simulate the trucks being loaded and filled. Table 2 shows the weekly schedule of these processes where the trucks are being loaded from 7 am until 5 pm every Monday and Friday for ST-01(H01), Tuesday and Saturday for ST-02 (H02), Wednesday and Sunday for ST-03 (H03), and Thursday for ST-04 (H04)and the tanks are being filled from 12 am to 7 am every Monday, Wednesday, Friday, and Sunday (H05). The "I" inputs are spring-return inputs from the sensors. The inputs remain open when the sensors detect something and close immediately afterwards. Due to the many rungs in the automation in this paper, markers are used to simplify the automation program and the extended markers were also utilized. The M-markers are used for the tank automations while the N-markers are for the tank leak automations. Three types of markers are used in this paper. Contactor type markers denoted by the symbol "["are energized only when the input is energized. Set markers denoted by "S_" sets the marker only once to energize even after the input is off while Reset markers denoted by "R" resets the set markers. The "Q" outputs are used to control the motor operated valves of the inlets of the tanks while the "S" outputs are for the motor operated valves at the tank outlet, the transfer pump, and the loading arms. The "R" inputs are denoted for all push button spring-return services where R01-R04 is for manual truck loading instead of the scheduled truck loading while R05-R08 is used to reset the Flammable Gas Detectors. The last two "R" inputs R09 for manual tank filling, and R10 initialization for the leak detection automation are latches instead of spring-returns. Lastly, a timing relay is used to delay the start of the pump for 10 sec to give time to fully open the valves.

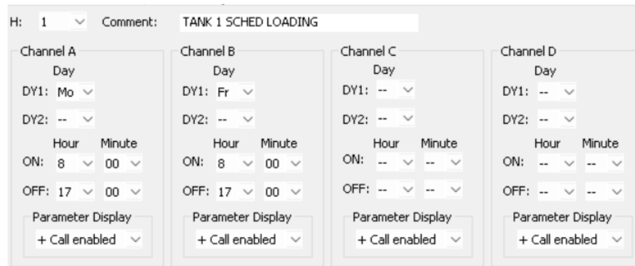


Figure 11 7-Day Time SwitchExample for Tank Process

Table 2 7-Day Time Switches Schedule for Truck Loading and Tank Filling

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<tr><td>0:00</td><td rowspan="7">Tank Fill (H05)</td><td></td><td rowspan="7">Tank Fill (H05)</td><td></td><td rowspan="7">Tank Fill (H05)</td><td></td><td rowspan="7">Tank Fill (H05)</td></tr>
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<tr><td>8:00</td><td rowspan="9">Tank 1 Truck Load (H01)</td><td rowspan="9">Tank 2 Truck Load (H02)</td><td rowspan="9">Tank 3 Truck Load (H03)</td><td rowspan="9">Tank 4 Truck Load (H04)</td><td rowspan="9">Tank 1 Truck Load (H01)</td><td rowspan="9">Tank 2 Truck Load (H02)</td><td rowspan="9">Tank 3 Truck Load (H03)</td></tr>
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3.2. Ladder Diagram Programming

The ladder program shown in Appendix A employed for the tank and leak automation has a total of 97 rungs and denoted by 10 subsections to easily identify the process being taken. The 1st subsection is the tank availability automation where the tank is deemed unavailable when the tank level is high-high (A01-A04), flammable gas is detected (N05-N08), and the outlet valve is open (S01-S04). The 2nd subsection is the tank filling automation where the tank is filled either by the 7-day time switch (H05) or a manual input from the controller (R09). The tank filling automation shown shows that when the inlet valve from the transfer pump is open or the tank is unavailable the tank filling transfers to the next tank available. The 3rd section is for the storage tank truck loading initiation where the truck loading process is initialized (SM09-SM12) by a push button or a 7-day time switch (H01-H04). The 4th section is the automation for the tank's outlet valve (S01-S04) where it is opened when the truck loading is initiated (M09-M12), or a tank leak is detected (N01-N04). The 5th section is for leak detection automation where the leak detection automation is energized (R10). The flammable gas detectors input (I01-I04) sets the leak automation (SN01-SN04) and the tank unavailability due to flammable gas detected (SN05-SN08). The 6th section is for the transfer pump outlet valve (Q05-Q08) automation where it can be shown that the program picks the available tank to transfer the product from the tank with the leak. The 7th section is for the automation on the transfer pump (S08) and its inlet valve (S07) which was initialized by the leak detection (N01-N04). A 10 sec timer (T01) starts the transfer pump to allow the valves some time to fully open. The 8th section is the automation for the truck loading arm (S06) and its valve (S05) where the truck is filled when it is detected by the sensor (I05). This section is utilized for leak automation only when the product transfer is not available (S07). The 9th section is for the low-low level liquid level (A05-A08) where it resets the truck load automation (RM09-RM12) or leak automation (RN01-RN04) when the tanks have a low-low liquid level. The 10th section resets (R05-R08) the flammable gas detectors (RN05-RN08) by the operator when the tanks are fixed and can be filled again.

3.3. Ladder Diagram Scenarios

This section shows the simulation scenarios of the ladder program show in Appendix A and proves that the programming in the Picosoft software performs the intended outcome and automation problem of the paper. The "Tank Availability Automation" section of the ladder program simulates the tanks availability based on the tank availability process shown on Figure 6 with the markers M01 to M04. The availability of markers depends on the high levels of the tanks (A01-A04), the flammable gas detected marker (N05-N08), and the status of the outlet valve of the tank (S01-S04).

From the process flow of Figure 7, the process for tank filling is shown at the ladder program entitled "Tank Filling Automation". It is shown that the tank filling automation starts from the tank fill push button R09 and will open the motor-operated valve of tank 01 (Q01) until it is full. When tank 01 is full, the "Tank Availability Automation" would then automatically transfer the filling to tank 02 and would energize its valve of Q02 and so on until the filling is stopped or the rest of the tanks are full. Due to the limited spacing of the rung, markers were used to transfer the filling from one tank to the other.

Figure 12 shows the process sequence for truck loading of the product in tank 04. From the ladder program, the truck loading starts either by the 7-day switch (H04) or the push button with spring-return (R04) and depends on the status of the flammable gas detector (I04). The two inputs start the initialization where the output valve of tank 4 and the inlet of the loading arm (S05) is opened. The proximity sensor (I05) detects the truck and opens or closes the loading arm. The tank loading continues this process until tank 04 is low-low liquid level which resets the truck loading automation.

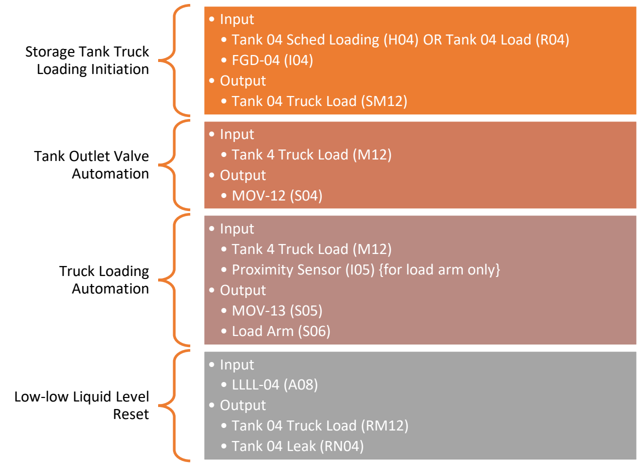

Figure 12 Truck Loading Automation Process

With regards to the main topic of this paper, the scenario described here is a simulation on when a leak is detected on tank 01 and wherein the contents are transferred to the other tanks. The automation starts with a push button that latches to start the leak detection automation (R10). When a leak is detected on tank 01 which is signified by an energized I01 input, this in turn will energize the markers SN01 to start the other processes and SN05 to mark that tank 01 is unavailable for further use. The leak automation process starts with opening the outlet valve of tank 01. Assuming the tank 02 is unavailable, tank 03 opens its transfer inlet valve (Q07) instead of tank 02 inlet valve (Q06). The inlet valve (S07) for the transfer pump (S08) is also opened and a 10 sec delay is assumed to ensure that the valves are fully opened. The transfer pump continues this process until tank 01 is low-low liquid level which resets the leak automation of tank 01. A push button with spring-return (R05) resets the flammable gas detection initiation (RN05) until the tank is filled and would be available for use once again.

Lastly, a situation can arise when there are no available tanks to be utilized as can be shown on the "TANK AVAILABILITY AUTOMATION" of the ladder program. This unavailability can be because of high-high liquid level of the other tanks (A02-A04), a flammable gas has been detected in one of them (N05-N08), and/or an outlet motor operated valve is open (S01-S04). When that happens, the truck loading automation will take into effect when the inlet valve for the transfer pump (S07) closes. The resets of the low-low liquid level and the flammable gas detector marker are still the same process from the previous examples.

3.4. Cost-Benefit Analysis

In addition to the programming and simulation, a cost-benefit analysis is also employed in this paper to showcase the minimum number of barrels of oil saved in achieving a return on the investment of introducing the automation to the designed tank farm system. Since the tanks are comprised already with the certain equipment for instrumentation such as the radar transmitters, valves, pumps, and flammable gas detectors, this study focuses only on the type of PLC used for this automation which is the Allen-Bradley/Rockwell Automation 1760-L18NWN-EX [22]. The tabulated cost of the PLC excluding the shipping fee plus the installation costs, which also includes the labor and construction expenses, is shown in Table 3.

Table 3 Estimated Costs of Automation Equipment

Equipment/Expenses	Cost
Allen-Bradley/Rockwell Automation 1760-L18NWN-EX	$ 789.00
Installation Expenses (Including labour and construction expenses)	$ 100.00
Total Cost	$ 889.00

Figure 13 shows the progression at which the dollar saved is dependent on the number of saved barrels of oil. Say that the system was not installed and an estimated volume of 15 barrels of oil was leaked from the tank, the cost of the oil lost would be $1,500.00 as per oil prices of June 2022 [5]. It is then worth noting that this system proposed by the authors could save $611.00 based on the costs stated at Table 3 and could be concluded that $40.7 per barrel of oil can be saved by the proposed automation. As seen on the graph, the proposed automation would be breakeven at 8.89 barrels of oil. The dollar saved by the automation follows a linear relationship with the number of barrels. The dollar saved per barrel of oil on the other hand follows a exponential increase then steadily settles to around $80-90 dollars per barrel after its breakeven point.

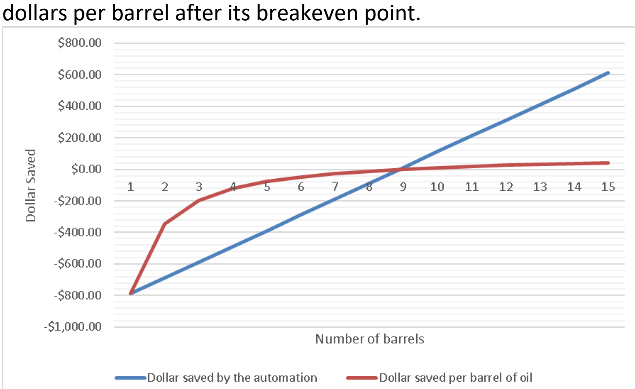

Figure 13 Dollars saved by the automation

4.0 CONCLUSION

An automation control system is proposed in this study that aims to transfer products in the storage tanks to the next available tank to save the oil from leaking and being unusable. This also reduces the risk of escalated consequences in case of leakage leading to fire and explosion scenario. Additionally, the proposed automation model also demonstrates a control system for storage tank unloading schedule to truck facility. The proposed control system utilizes the existing instrumentations facility such as level indicator transmitters and motor-operated control valves. Lastly, it was estimated that the proposed automation could save around $80-90 per barrel of oil.

Future work can include other parameters such as the application of this automation with different storage tank services with consideration of the product impurities. Furthermore, although a thorough study has been made on the use of flammable gas detectors [16], it is worth noting that the conclusion of the study is that wind plays an important role in the detection of the leakage. Thus, it is suggested that the use of multiple gas detectors and their location should be determined to provide a more precise detection which could easily start the system. Future studies can also be conducted on using level indicators or sensors that could detect the rate at which the liquid level is dropping that could replace or would be in addition to flammable gas detectors as a source of detecting leakage.

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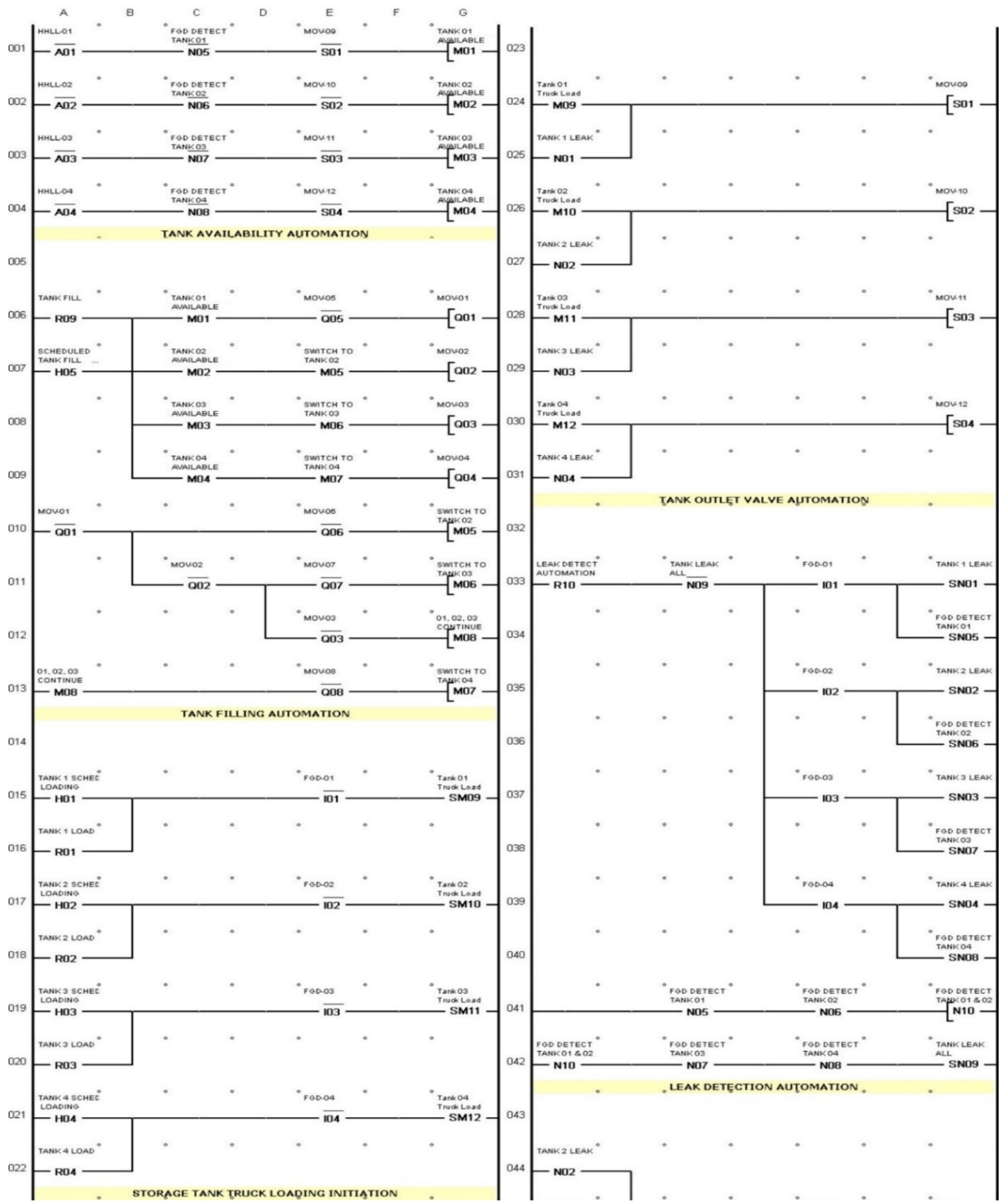
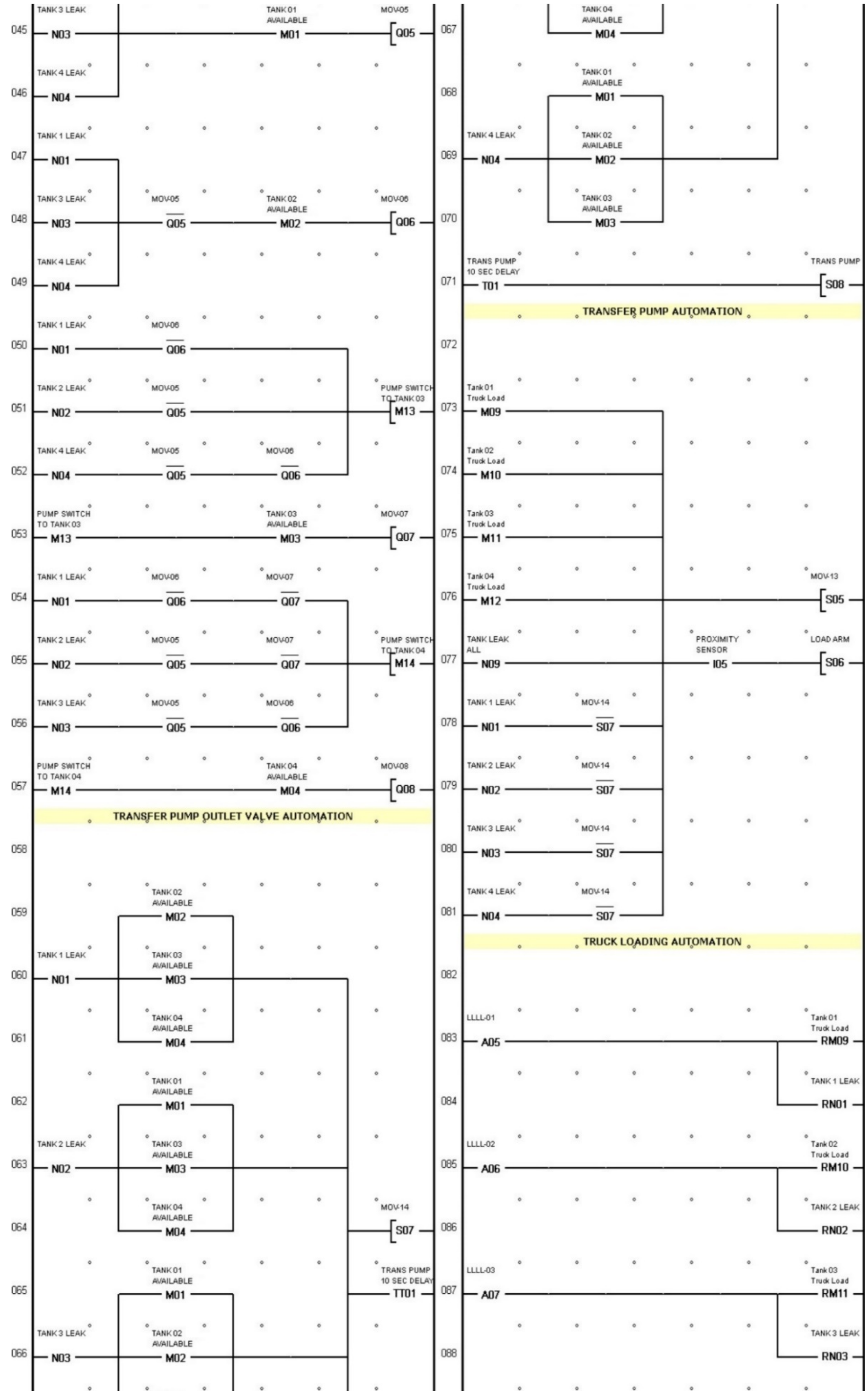
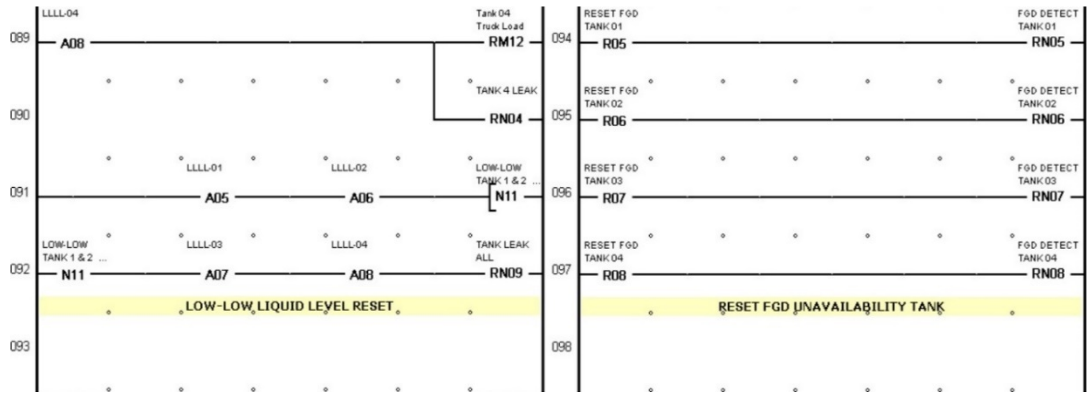
Appendix A

Overall Tank Automation Ladder Programming at Picosoft Software





045 TANK 3 LEAK N03 TANK 01 AVAILABLE M01 MOV-05 Q05
046 TANK 4 LEAK N04
047 TANK 1 LEAK N01
048 TANK 3 LEAK N03 MOV-05 Q05 TANK 02 AVAILABLE M02 MOV-06 Q06
049 TANK 4 LEAK N04
050 TANK 1 LEAK N01 MOV-06 Q06
051 TANK 2 LEAK N02 MOV-05 Q05 PUMP SWITCH TO TANK 03 M13
052 TANK 4 LEAK N04 MOV-05 Q05 MOV-06 Q06
053 PUMP SWITCH TO TANK 03 M13 TANK 03 AVAILABLE M03 MOV-07 Q07
054 TANK 1 LEAK N01 MOV-06 Q06 MOV-07 Q07
055 TANK 2 LEAK N02 MOV-05 Q05 MOV-07 Q07 PUMP SWITCH TO TANK 04 M14
056 TANK 3 LEAK N03 MOV-05 Q05 MOV-06 Q06
057 PUMP SWITCH TO TANK 04 M14 TANK 04 AVAILABLE M04 MOV-08 Q08
TRANSFER PUMP OUTLET VALVE AUTOMATION
058
059 TANK 02 AVAILABLE M02
060 TANK 1 LEAK N01 TANK 03 AVAILABLE M03
061 TANK 04 AVAILABLE M04
062 TANK 01 AVAILABLE M01
063 TANK 2 LEAK N02 TANK 03 AVAILABLE M03
064 TANK 04 AVAILABLE M04 MOV-14 S07
065 TANK 01 AVAILABLE M01 TRANS PUMP 10 SEC DELAY TT01
066 TANK 3 LEAK N03 TANK 02 AVAILABLE M02
067 TANK 04 AVAILABLE M04
068 TANK 01 AVAILABLE M01
069 TANK 4 LEAK N04 TANK 02 AVAILABLE M02
070 TANK 03 AVAILABLE M03
071 TRANS PUMP 10 SEC DELAY T01 TRANS PUMP S08
TRANSFER PUMP AUTOMATION
072
073 Tank 01 Truck Load M09
074 Tank 02 Truck Load M10
075 Tank 03 Truck Load M11
076 Tank 04 Truck Load M12 MOV-13 S05
077 TANK LEAK ALL N09 PROXIMITY SENSOR I05 LOAD ARM S06
078 TANK 1 LEAK N01 MOV-14 S07
079 TANK 2 LEAK N02 MOV-14 S07
080 TANK 3 LEAK N03 MOV-14 S07
081 TANK 4 LEAK N04 MOV-14 S07
TRUCK LOADING AUTOMATION
082
083 LLLL-01 A05 Tank 01 Truck Load RM09
084 TANK 1 LEAK RN01
085 LLLL-02 A06 Tank 02 Truck Load RM10
086 TANK 2 LEAK RN02
087 LLLL-03 A07 Tank 03 Truck Load RM11
088 TANK 3 LEAK RN03


LLLL-04
A08
Tank 04 Truck Load
RM12
TANK 4 LEAK
RN04
LLLL-01
A05
LLLL-02
A06
LOW-LOW TANK 1 & 2 ...
N11
LOW-LOW TANK 1 & 2 ...
N11
LLLL-03
A07
LLLL-04
A08
TANK LEAK ALL
RN09
LOW-LOW LIQUID LEVEL RESET
RESET FGD TANK 01
R05
FGD DETECT TANK 01
RN05
RESET FGD TANK 02
R06
FGD DETECT TANK 02
RN06
RESET FGD TANK 03
R07
FGD DETECT TANK 03
RN07
RESET FGD TANK 04
R08
FGD DETECT TANK 04
RN08
RESET FGD UNAVAILABILITY TANK