Designing, Testing & Data Validation of A MES (Manufacturing Execution System)

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Abstract **- In the edge of industry 4.0, the trend of proper resource allocation is taking its place in all kinds of industries. It includes the data regarding products, inventory used & its quantity, processes done on it, all the test data & quality check. Of course, this could not be done without an automated system. So, a system is designed to perform these tasks automatically & store the data to the database. The system is called a MES, i.e., Manufacturing Execution System which is nothing, but an automated system designed to perform the execution tasks. This paper presents the industrial approach towards implementation of MES & the tools required to design & test the execution system & also we will see how we can validate the data; we are getting from it. We will also see how the state base analysis can be used to design a system flow & PLC program. The theory of automata is going to be primary tool for this task, so we will also have a glance over it.**

Index Terms **- Automation, MES, SCADA, PLC, I/O Devices, testing, Database system.**

I.INTRODUCTION

The concept of using computers to have a traceability over manufacturing process brought us very advantageous points with the flow of raw material to finished goods. There were many flaws in the system before this concept, for example.

- Maintaining & tracking old data.
- Infeasibility of accessing such a big data.
- Rinsing out the useful information.
- Segregation of data with Accounting, MIS & Manufacturing Process.
- Segregation of data according to work type.

With this new evolving idea of MES, the management of manufacturing floor, functions, resources, and inventory became so easy and they give accounting and MIS all the information they require. The best part is this idea is being built around the manufacturing world and requires no advanced knowledge of computers. In most cases these systems run on smaller local computers and are fairly simple to use. MES is more like an online system, designed to perform & execute a predefined sequence of operations set. Execution may have a different context, like a product, machine control, measurements, inventory movements etc.

MES is a manufacturing tool designed for manufacturing process. Most manufacturing companies use a planning process (MRPII/ERP or equivalent) to determine what products are to be manufactured. Once that plan has been developed, there must be a translation of the plan that deals with real resources that are currently available. What is necessary is a method to take input from the planning system and translate that plan into a language that fits the plant floor and the resources required to execute the plan - a major role for the MES. The study of different users gives us the following benefits of MES.

- Reduced manufacturing cycle time.
- Eliminated data entry task & its time.
- Reduction in inventory requirement.
- Reduction in lead time.
- Improved product quality.
- Reduced paperwork.
- Proper track of events.
- Empowered plant operation.

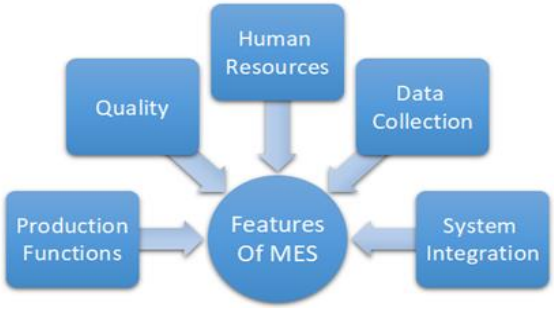


Fig. 1.1 - Features of MES

Application Areas of MES -

System Planning & Data Acquisition -

MES is designed to collect, collate & update the data in system according to the planning or schedule. According to the requirement, the planning system may vary, and its interface may be different, according to its input & output requirements. The requirements & outputs from the system are pre-planned & discussed with vendor, user & MES provider.

Inputs & receiving within MES -

The input for MES can be either I/O devices or the Bar Code over a part and this data is then processed for further operations. The display is provided to display the data & flow and it is also provided with data entry facility. In this process, the material has to gone under various quality assurance steps to fulfill the product requirement. On the failure or passing of the test over material, the decisions are made according to the MES structure & then the status and data is then uploaded to the planning system.

Routine/Time based operations -

The MES can perform routine/time-based operation as per the schedule given in the planning system. For example, the MES can routinely check the status of its I/O devices, connected to its system and give the update in data logging system.

Work Scheduling or Sequencing -

A very obvious question that should be asked frequently in manufacturing management is "What is the schedule of work to be performed?" Though it may seem obvious or intuitive, the area of schedule development probably offers the best opportunity for improving the resource management process. The issue here is not to determine production quantities (presumably, that was determined by the planning system), but rather how to rank a given list of tasks based on the resources (people, equipment, and inventory) currently available.

System requirements for MES -

When we consider a wide operations range to be encapsulated in MES, we must consider some system design consideration for hardware & software. The system design should be done on the following basis.

Full Integration -

The exchange of information is the most important when it comes to multiuser environment. The full integration serves the access of data at any user point with a computer network system.

Scalability To Future Needs -

The software & hardware design must allow a upward scalability to meet the need of product changes & system upgradation.

Compatibility With Existing Systems -

The MES should be compatible with current system as it is the most economical factor while designing it.

Broad System Access -

System access must be easy to understand what's going on with system, when it comes to the data acquisition. It also helps to access the wide range of data over database.

Security -

To ensure the data integrity, the security of the system must be considered while designing the MES. It can be the protocol from industry or supplier itself.

The Ability to Upgrade Hardware -

The system should be flexible with any hardware integration and must perform with a stable outcome.

Easily Added Functionality Changes -

The MES system should be so flexible to add up the functional changes while testing or in a working condition. As continuous improvement takes place in a system, it must affect less with cost perspectives.

II.LITURATURE REVIEW

The main part of an automation system is a controller, and the device which is used to have the control is PLC. So, the logic designed in PLC will execute the whole process. The state base analysis is very useful while designing the logic for PLC. Some mathematical equation can be obtained for each transition & a fail proof program can be written in a proper format [1]. When it comes to the multishop floor, the tools like GPGP (Generalized Partial Global Planning) & TAEMS (Task Analysis, Environment & Simulation) helps a lot to for workshop coordination[2]. The manufacturing organization is layered with the three

basic parts & these are ERP (Enterprise Resource Planning), MES (Manufacturing Execution System) & PCS (Process Control System). To collaborate with these three layers, proper communication of these three layers with each other is most important. The system design & its implementation ideas for MES should be so that, it will run a process without any glitches & they are clearly explained [3]. Various equipment resource planning theories like Gry relation & ant colony. These theories provide the brief idea about resource allocation & its planning [4]. Distribute Numeric Control can be implemented when multishop floor industries comes into picture. The control technique gives the brief about the computer & network system & gives the idea about the software based on human interface, requests to the system, business logic & data storage [5]. As we know, software plays an important role in MES, the layering of the system must be understood clearly first. The study regarding application development had done and presented, in which flexible MES implementation has done by considering product description, business logic & enterprise structure [6]. RFID technology gained its popularity as it provides us the flexible data acquisition in real time basis. The work has done on the implementation of RFID technology for a production line which may be a single or multi-process system. Architecture & design of RFID system depends on the process flow of the system [7]. MES systems main role is to control the process, to have its traceability & conserve the data of production. To meet these roles, proper softwares & hardware tools must be understood clearly. The work is conducted on collaboration of DCS (Distributed Control System), ERP (Enterprise Resource Planning) & SCADA (Supervisory Control & Data Acquisition) system in which the contribution of the each & it's working structure [8]. While implementing a MES system, we must understand the standards used & applied. The research work has done on this. ISA-95 is an International Standard for the integration of enterprise control system & it consists of various models & terminologies. This study helps to adopt a proper system according to the product and its assembly process & helps to get maximum efficiency [9]. Management of multishop floor is a difficult task as it has number of products on the same line. The research work has done to mitigate the challenges for such systems. The technique of assigning a manufacturing process sequence is applied for each product & they are saved as an abstract. It results in the batch of part items & the corresponding workflow will be assigned to that batch particularly [10].

III.DESIGNING OF MES

MES is collaboration of different parameters like automation, electronics & computers. So, while designing the MES, we must understand these parameters first. The design is depends on the type of industry & its workflow. For example, we will consider a simple assembly line, where different child parts are assembled to have a final product. The MES system is designed with basic tools like RFID technology, PLCs, SCADA systems, Database servers & Profinet network system. Let us understand some tools briefly.

RFID Technology

RFID (Radio Frequency Identification) in MES is a new wireless technology which is implemented to store real time production data of a job. This data includes serial number, task completion, child part data. The assembly includes a RFID read-write device which reads & write data on RFID & a RFID tag on which the data is written & stored. The RFID is installed on a process line to have traceability of a product. This technology helps to grab the real time data of assembly line & to maintain the quality of product. It also helps to keep the track of the product while processing. The RFID plays a very important role in an Industrial automation.

SCADA System

The SCADA system is a process automation system, which gathers data from various I/O devices like sensors, actuators & instruments placed at remote location to store it, display, and process it for other remote operations. The SCADA system can process the data of hundreds or thousands of I/O devices in a real time basis. The input to the SCADA system may be a digital, e.g., switch, read sensors, relays & motor, or an analog input, e.g., level, temperature, pressure, voltage, current, intensity. Between the SCADA & remote devices, the process & computer system is encapsulated to perform various operations defined by the user. This encapsulated system actually connects the all the remote devices to the SCADA. As the data

may be in the form of analog signals or digital, it cannot be used or transmitted directly over system. Data conversion equipment like DAC & amplifiers are used to digitize the data, which can be easily transmitted to a long distance with the help of communication devices that follows Industrial Communication Protocol. Typical field devices that can handle such operations are PLCs, RTUs & IEDs. These devices are designed with the standard which follows the Industrial Communication Protocol like Modbus, AB-DF1, DNP3.0, Bell 202, RS-485 & RS-232.

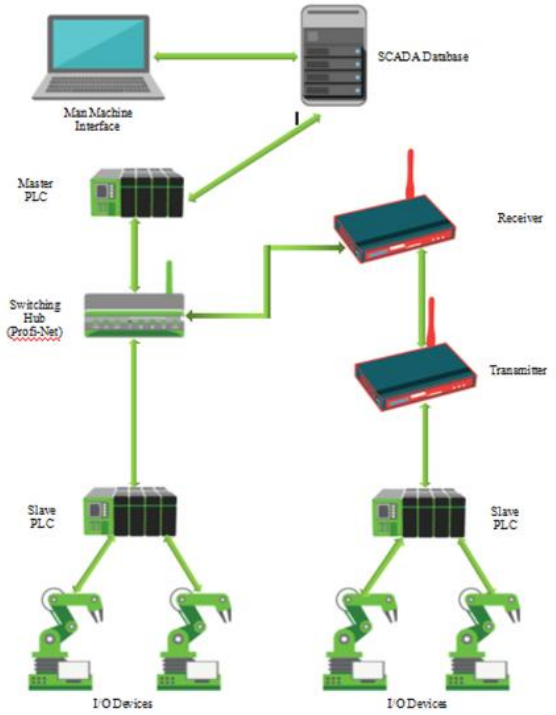


Fig. 2.1 SCADA System

PLCs & State Base Analysis

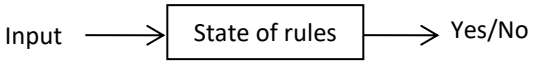
Before going in the depth of this analysis, we must first understand what is actually a state base analysis & to which this relates? The answer is 'The Theory of Automata'. Automata theory is a study of machines & the computation & their collaboration to perform various tasks. An automata can be considered as a computing device that can be programmed with a predefined sequence of operations. The device will perform these operations automatically. So, to understand automata, we must understand the theory of computation which is nothing but a mathematical study of things that can be computed mechanically.

Let us consider, we need to program a machine which will accept the binary data that ends with zero only.

e.g - 0110010 → Accepted

0100001 → Rejected

Or we need to design a machine that accepts only particular programming language like java, python, C, C#, C++ etc. So, how we can achieve this? That is where the compilers come into the picture. Compilers helps to write a program & compile it to the code that can be accepted & understood by a machine. It is the compiler that tells us what errors there in program are. So, we can say that the theory of computation is nothing but designing a system that gives you a desirable output.



The Theory of computation has some layers in it & it contains the following points to study.

1. Finite state machines
2. Context free languages
3. Turing machine

& We will focus only on finite state machines as it is a very simple computational method & very flexible too. Finite State Machines or sometimes also called as a 'Finite Automata' is divided into two parts according to its output i.e., Deterministic Finite Automata & Non-Deterministic Finite Automata. For this study, we are going to use Deterministic Finite Automata theory. Consider the following state diagram for understanding of DFA (Deterministic finite Automata);

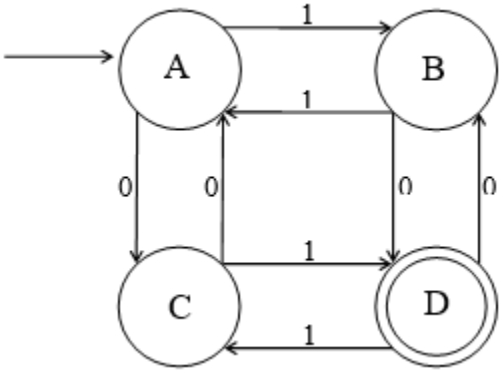


Fig. 2.2 State base analysis for DFA

In the above figure, {A, B, C, D} are the states, arrows are the transitions that shows the jumping of states from one to the other with the input over each i.e. (0,1). In above diagram, A is a starting state & D is an ending

state. Every DFA can be defined using a set of 5-Tupple.

M = {Q, ∑, q0, F, δ }

Where, M - Finite Automata

Q - set of all states

∑ - inputs

q0 - starting state

F - set of final states

δ - transition function that maps Q * ∑→ Q

So, by referring the Fig. 2.2, we can rewrite the tupple;

Q = {A, B, C, D}

∑ = {0,1}

q0 = {A}

F = {D}

Now, as the δ is the transition function, it should be represented in a chart, as δ = Q * ∑,

States Inputs	Next State With input 0	Next state with input 1
A	C	B
B	D	A
C	A	D
D	B	C

Table 2.1 Table of states for inputs

Above theory of DFA is used to determine the sequence of operations that a machine has to follow. This makes programming easy & makes a readable machine code that can be debugged very easily in a fault condition. But due to the technical advance, the human have become successful to make such devices like PLC, DCS, Controllers etc. which are easy to program & the state transition will only be a matter of interlocks. We can write a ladder logic in PLC by considering every output as a state which will be switched only for a particular input set string.

State base analysis is done when there is a process includes a process flow for assembly. Because, each assembly unit is installed or assembled at different level & hence the flow of the child parts must be cleared with a systematic process. State base analysis helps to design such flow in a simple form & can be implemented for multiple of lines & stations at the same time. Let's understand how the state base analysis can be applied to an example. The following figure shows an assembly station states where a product is assembled with a child part;

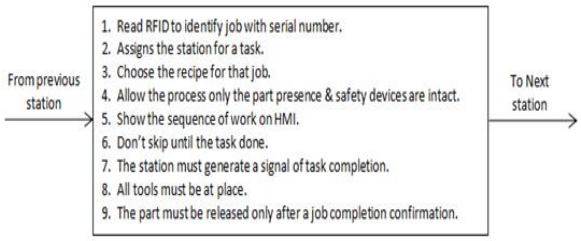


Fig. 2.2 State base of a station

For above figure, we can say that the jump to the next station, we must fulfil all the conditions for current station. To achieve this, the I/O devices like sensors, readers, scanners, printers & digital tools are used and implemented. These I/O devices keeps the track of job process & allow the process to complete in systematic manner. The control over these devices is obtained with the help of PLC which is programmed to perform tasks as per the given steps in a particular state. Each step can be written as a state of condition which will either trigger the next state or create a desired output. Let us apply this technique to the above-mentioned state. Each operation will trigger the next operation when it gets done in a PLC logic. Let us write a logic for the first condition, where the reader will read the data in RFID & store it in its temporary memory to burn the new data of current station. The data read by the reader is the data of previous station & the tasks have performed in it. The logic will be like this.

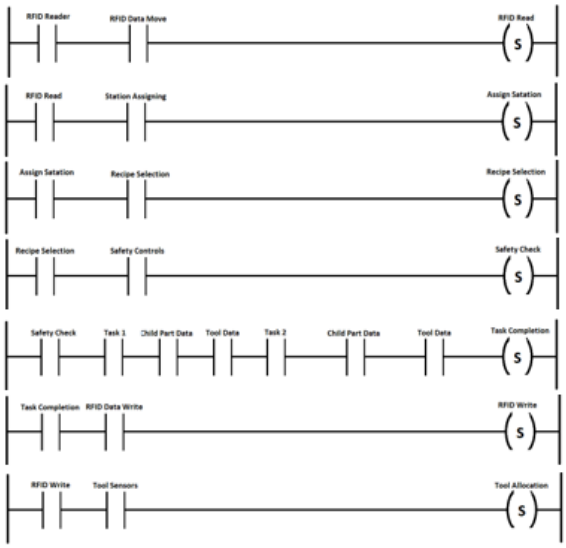


Fig. 2.3 PLC Logic for State Base Analysis

The logic written above is for the first line & for given state base shown in Fig. 2.1. Each state is triggered by previous state & its confirmation is given to the next state. The set bit of the PLC is used while writing the

program & each beat is reset in the next State of station. The data taken or recorded like serial number scanned, tool data like torque & angle are saved on data base like SQL server & this data is displayed on SCADA system. The final completion of work is done with the conjugate previous bits & a work completion bit is set at the end as shown in Fig. 2.3. This bit will be the input to the next state & as soon as PLC enters into the next state of station, it will reset all the bits from previous station. The data like serial number & task completion will be available in RFID to read it in the new station, so that the system will acknowledge that the part is successfully assembled at previous station. If some tasks on the job are missed, then it will show the fail signal in current station. This process allows to maintain a fail proof system as well as the quality.

Fig. 2.4 State Completion bit set

Database Server

Database management is an information management system which is designed to store the large data in a multiuser environment. Multiuser environment gives the access of the data to number of users in the same environment. A database server is a network-based application which maintains the database files e.g., Microsoft SQL server. SQL is a very powerful & high-performance database server. It is used for data storage & data analysis over a wide range of storage options. SQL comes up with a highly secured environment, so that the data can be accessed securely & rapidly. User interface is required to access such a wide range of data. So, user can design a web application. The user will access the data through the application, but the data taken on the application will be from the database server itself.

Profinet Communication Network -

Profinet is an industrial ethernet communication system developed by PROFI-BUS Organization. It is a complete ethernet standard which serves with IEEE802.3. It follows the TCP/IP protocol of Information Technology. While setting up the MES system, selection of a proper communication network plays an important role. Profinet serves some good advantages for MES design & they are as follows.

- High Speed data transfer (over 100mbps)
- Difficult Motion control application control
- Easy installation & access
- Easy integration with LAN supported devices.

As shown in Fig. 2.1, various devices are connected to each other with profinet. Profinet allows the devices connected to it communicate fast & maintain the production flow with proper traceability. Profinet is capable of handling various I/O devices like PLCs, DCS, IPC, Sensors & Actuators. Fast data exchange capability allows these devices to transfer bulk amount of data with a fast transfer rate. Apart from the automation system, profinet plays a very important role while transferring the data to the database server. It contains a bulk data which has to be stored & accessed as well.

IV. PROPOSED WORK

MES is a collaboration of various sectors, like automation, electronics, computers & electrical. So, having basic knowledge about these sectors is must. To fulfill the requirement, this basic knowledge we'll need is;

1. PLC programming
2. Relay logic & logic building
3. Computer Networking
4. Computer languages - C & Python
5. Electronic Circuit Analysis - Sensors & Actuators
6. SCADA Communication & Database

With this set of knowledge, the defined work area can be operated & the knowledge can be applied to improve the current system as well as to implement a new system. With the reference of the figure above, the work area is highlighted with the set of things to work on. Fig. 4.1 shows the block diagram & Fig. 4.2 shows the work areas for the proposed work.

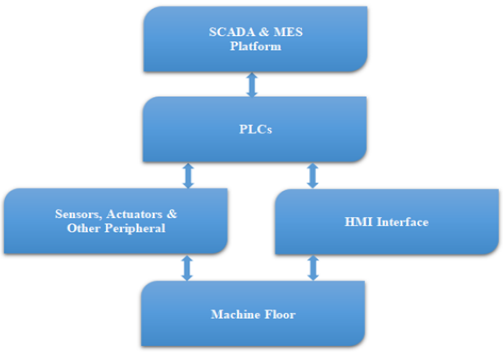


Fig. 4.1 Block Diagram for proposed work

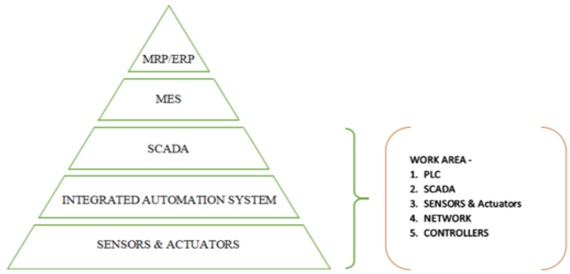


Fig. 4.2 Work areas for proposed work

The work is divided into three phases, that is design, test & validation. The design part is already explained in section III.

V.OUTCOME & RESULTS

Testing is nothing but checking the system for its desired output. Particularly for a production line, the testing is done with the number of products under supervision. Scanning data, tool data, inventory data & the final product data is checked against the batch & glitches are found. For data validation, BOM (Bill of Material) checklist could be used, and cross checked with the data of the product batch under observations.

The work has been conducted on different lines for different outcomes. The testing has been done for two lines. For the first line, the MES system is tested for its desired outcomes. While testing, it is found that, the data is not appearing properly on a SCADA system & it is missing. The root cause for it was, there was a bypass in a PLC logic which was done due to the improper communication of the tools used to tighten the bolts. The PLC program was initially designed to record the torque data of that particular station, but the digital torque wrench was getting failed to transmit the data to the PLC. Wireless digital torque wrenches are then integrated with the system for that station. The PLC logic is so designed to transmit the data to the PLC, then only the process completion signal will be generated & the product can be sent to the next station.

Fig. 5.1 Wireless Torque Wrench & Transmitter

OP20 DP2 Status	OP20 Bolt 1 Torqu	OP20 Bolt 1 Angle	OP20 Bolt 1 Status	OP20 Bolt 2 Torqu	OP20 Bolt 2 Angle	OP20 Bolt 2 Status	OP20 Status
OK	(null)	(null)	(null)	(null)	(null)	(null)	OK
(null)	(null)	(null)	(null)	(null)	(null)	(null)	(null)
OK	(null)	(null)	(null)	(null)	(null)	(null)	OK
OK	(null)	(null)	(null)	(null)	(null)	(null)	OK
OK	(null)	(null)	(null)	(null)	(null)	(null)	OK
OK	(null)	(null)	(null)	(null)	(null)	(null)	OK
OK	(null)	(null)	(null)	(null)	(null)	(null)	OK
OK	(null)	(null)	(null)	(null)	(null)	(null)	OK
OK	(null)	(null)	(null)	(null)	(null)	(null)	OK
OK	(null)	(null)	(null)	(null)	(null)	(null)	OK
OK	(null)	(null)	(null)	(null)	(null)	(null)	OK
OK	(null)	(null)	(null)	(null)	(null)	(null)	OK
(null)	(null)	(null)	(null)	(null)	(null)	(null)	(null)
OK	(null)	(null)	(null)	(null)	(null)	(null)	OK
OK	(null)	(null)	(null)	(null)	(null)	(null)	OK
OK	(null)	(null)	(null)	(null)	(null)	(null)	OK
OK	(null)	(null)	(null)	(null)	(null)	(null)	OK
OK	(null)	(null)	(null)	(null)	(null)	(null)	OK
OK	(null)	(null)	(null)	(null)	(null)	(null)	OK
OK	(null)	(null)	(null)	(null)	(null)	(null)	OK
OK	(null)	(null)	(null)	(null)	(null)	(null)	OK
OK	(null)	(null)	(null)	(null)	(null)	(null)	OK
OK	(null)	(null)	(null)	(null)	(null)	(null)	OK

Fig. 5.2 Outcome for first line(before)

OP20 DP2 Status	OP20 Bolt 1 Torqu	OP20 Bolt 1 Angle	OP20 Bolt 1 Status	OP20 Bolt 2 Torqu	OP20 Bolt 2 Angle	OP20 Bolt 2 Status	OP20 Status
OK	28.2	0	1	30.2	0	1	OK
OK	30.2	0	1	32.6	0	1	OK
OK	29.2	0	1	28.2	0	1	OK
OK	28.6	0	1	27.6	0	1	OK
OK	28.4	0	1	28.8	0	1	OK
OK	29.6	0	1	28	0	1	OK
OK	31.6	0	1	30.6	0	1	OK
OK	28.8	0	1	30.2	0	1	OK
OK	33	0	1	31.4	0	1	OK
OK	29.2	0	1	32.4	0	1	OK
OK	30.8	0	1	32.2	0	1	OK
OK	29.6	0	1	28.8	0	1	OK
OK	30.4	0	1	32	0	1	OK
OK	28.2	0	1	29	0	1	OK
OK	29.2	0	1	29.4	0	1	OK
OK	27.4	0	1	32.4	0	1	OK
OK	31	0	1	30.8	0	1	OK
OK	31	0	1	32.8	0	1	OK

Fig. 5.3 Outcome for first line(after)

For second line, the MES is newly designed and implemented. The main purpose of the system is to record the leak test data of the system & save it to the database for quality and future record purposes. For a single job, three leak tests are conducted and saved to the SQL database. Barcode stickers are used to scan it against the SCADA system, so that it'll record the data for that particular serial number. Primarily, the bar codes are generated by SCADA itself. Whenever the cycle gets completed in previous station, it will give signal to the SCADA & generate a bar code in its sequence & gives a command to the printer.

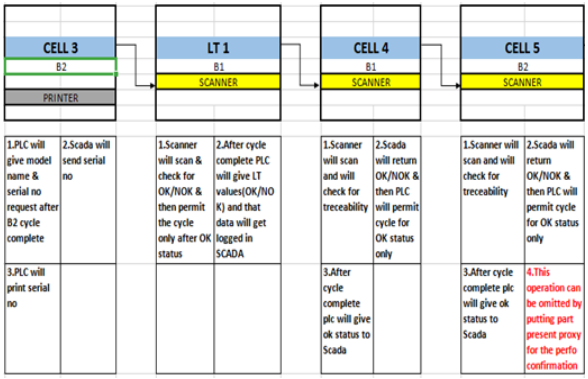


Fig 5.4 Process flow 1

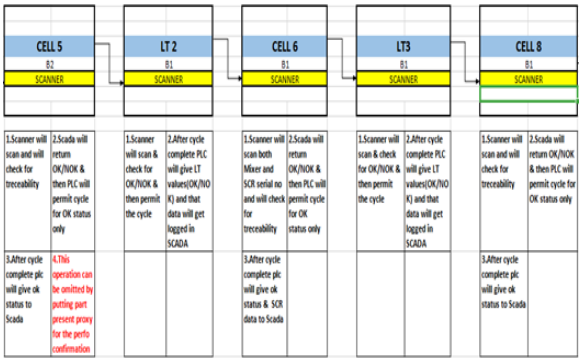
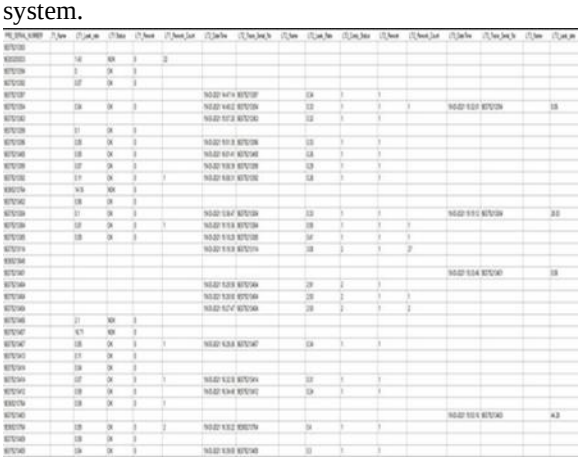


Fig 5.5 Process flow 2

At each leak test station, the code is scanned through a scanner. Each leak test cell has a leak tester unit which will perform a leak test & gives it leak rate data to the PLC. It is temporarily saved to the data block of PLC & after that it send to the SCADA system. Microsoft SQL server is compiled with SCADA system, and it will process the data regarding all the leak test stations. SQL query is written so that it will give all the three leak tests data on the sheet. As the results are arriving at the SCADA end, this is the confirmation of Successful implementation of MES system.



5.4 Leak Test data at the SCADA end.

VI.CONCLUSION

MES is great tool to have a traceability & records of a production line, which is the primary need of the industry. With the above-mentioned study & information we can conclude that, with a proper tools & resources, we can implement the system with a optimal cost saving. Each tool mentioned above contribute to the system with its advantages & helps the system to operate at optimal & desired level. Data obtained at the user end is correct & satisfactory.

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