IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 2 Issue 1, January 2015.
www.ijiset.com
ISSN 2348 – 7968

Mistake Proofing with Automation

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Abstract

Automation is often seen as a way to boost productivity, reducemanual labor, and increase quality. But automation alone cannot be relied on to improve quality.

The most reliable way to increase quality in a system is by mistake proofing it. That means find places where the process fails and reducing or eliminating the risk. This paper covers the basics of error proofing, the levels and types, the repercussions to not mistake proofing. It also covers check lists, fail safes, and visual controls.

1. Introduction

As machines become more advanced and as factories become leaner, it is tempting for management to replace people with machines. Automating tasks once done by a person. Machines, they reason, do not make mistakes. But anyone who has worked with machines knows that they can make the most obvious mistakes. A machine cannot spot the discoloration in a material, or a large crack running through it. A machine will use the wrong tool bit for a job if the operator put it in the wrong slot. And a machine can't notice that its cutting tool is too dull to make a clean cut.

Pure automation leads to mistakes because quality relies on a human touch and the knowledge that comes with experience. Autonomation combines the repeatability and precision of automated machines with the understanding and oversight of humans. Mistake proofing can be built into the whole process. It can be used to alert errors with the stock material, errors with the machine itself, and communicate its issues with the operator.

This paper will look into ways machines are designed to reduce or eliminate defects; sensors, processes, tool exchangers, networking systems, couplers, and more. While also looking at how machines can be design to leverage their operator's knowledge; control charts, visual inspection, checklists, and routine maintenance

2. Automation Alone ≠ Quality

It is a common reframe that machines can do any job with better quality. Automation does not naturally lead to better quality in manufactured goods. In the early 1990's MIT and Harvard conducted a study on automation within the automotive manufacturing process. With one of the thelargest sample sizes ever recorded for this type of research they were able to plot level of automation against quality of parts produced.

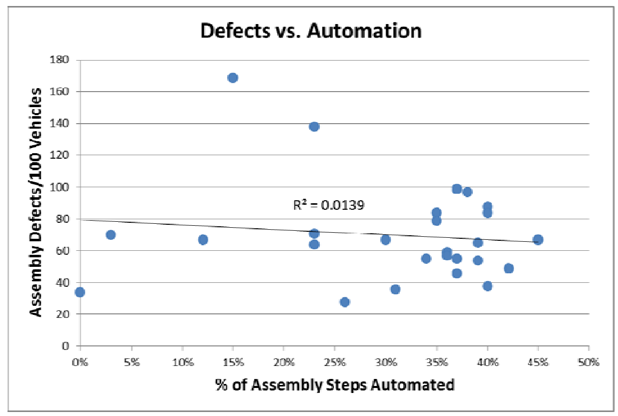

Fig 1. Assembly defects per 100 vehicles. (r2 = 0.0139)

Figure 1 shows a graph of the data collected. Each point represents the average number of defects per 100 car produced put against the percent of steps automated. As you can see the trend line for this data is almost horizontal. Automation alone does not drastically impact quality [1][2].

An example of this phenomenon is the Denver International Airport baggage handling system. The system was created to reduce the amount of manual labor that went into sorting and transporting luggage around the 17 miles of tracks and 5 miles of conveyer belts [3]. It was designed to cut out human handlers all together. The construction costs quickly ballooned to $186 million and delayed the opening of the airport for a year [4].

The conventional method of handling luggage at that time was to have workers with hand held scanners. These workers would scan tags at every junction the luggage went through, and direct them to the next junction. The system was reliable with little error. But it was laborious. BAE Automated Systems of Carrollton, Texas designed a system to make use of cutting edge computer processing and laser scanning.

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The original plan for the system quickly shrank, going from three fully automated concourses into a single concourse used by outgoing flights from a single airline. [3] Worse, the system was prone to errors. Over 100 computers were networked together. If one failed, no back up was readily available. And spread out across the complex, a failed computer could not be easily tracked down.

The system lacked a sufficient number of carts leading to bottle necks. The system was unable to detect jams and bottle necks. Causing luggage to build up on the conveyer belts without anyone being alerted [3]. The line balancing issues within the system were not addressed until roughly six months after the planned opening date [5]. BAE president Gene DiFonso said of the line balancing problems "We had bags lined up and waiting for vehicles and empty vehicles going by with no bags. The problem was that we assumed we could release empty vehicles in some arbitrary quantity. Sometimes that number coincided with the number of bags waiting, but sometimes it didn't."

Another issue came from bar codes printed on the luggage tags. Laser scanning equipment installed on the conveyer belts had difficulty reading the tags; causing around 70% of luggage cars to be sent to manual sorting stations. Investigations into the issue shows that the label printers were faulty, printing out poor quality labels. Causing them to be misread or not read at all. Upgrading the printers reduced the error rate to around 5% [5]. Still the lasers could be foiled by hidden tags, tags remaining on luggage from previous flights, or scanners knocked out of alignment by operators.

Another issue came from photo sensors placed along the track to detect jams with the luggage cars. Over time some photocells were knocked out of alignment, moved to the wrong position of the track, or even painted over. The caused the system to think the track was jammed even if it was not [5].

In 2005 it was announced that the baggage system would be retired; saving the airport $1 million a month in maintenance costs. The system had been plagued with troubles, from overconfidence in technology, to a lack of training, to not fully understanding the scope of the challenge. But a contributing factor to the failures of the system came from a lack of error proofing. The system lacked redundancies, had too many single points of failure, did not control the environment well enough, and did not integrate people into the system in a meaningful way.

3. Types of Error Proofing

Shigeo Shingo was born in Saga City Japan 1909. After World War II ended, he began working at the Japan Management Association as a consultant. He focused primarily on improving factory management. His work with the Toyota Production System leads him to recognize three types of error proofing within a mass production system [6].

- Contact method - identify defects by whether or not contact is established between the device and some feature of the product's shape or dimension.
- Fixed value method - determines whether a given number of movements have been made.
- Motion step method - determines whether the established steps or motions of a procedure are followed.

The contact method is one most people are familiar with. It is used often in consumer products. From the plug that only fits into the outlet one way, to the USB connector that can only fit into the port with the correct orientation. Using the shape of the product as a way to prevent its misuse is an absolute way to keep the error from happening. An electrical plug would need to be damaged or modified to fit incorrectly into an outlet.

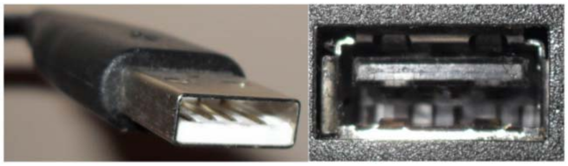

Fig2. USB Plug and Socket. (Shape of the parts mean it can only fit in one orientation.)

In manufacturing contact methods are used as well. Go / No go gauges allow operators to quickly test the dimensions of a part. For example, to test the diameter of a cylinder part a gauge could be created with a hole the size of the maximum diameter of the cylinder. After producing a part the operator could slide the gauge down the shaft to ensure that no part of it is wider than the maximum allowed diameter.

Fixed value method is used in error proofing operations with a fixed number of steps. For example welding operations or progressive stamping. This system monitors the steps taken by the machine. If it detects that a step has been missed, or the machine hasn't moved far enough it stops the line and alerts the operator. The idea is that the machine has a fixed value of steps or distance it has to perform or travel and if it does not do that, there is anerror. Other fixed values often monitored are pressure, temperature, current, flow, light, etc.

A variation of the fixed value method is the odd part out method [7]. This method can be used with automatic placing machines. For examples those used to assemble circuit boards. In this method the machine takes parts from a bin or tray with an exact number of parts in it. After it has completed a run the container is checked. If any parts remain, the operator knows the machine missed a step, and can take steps to rectify this.

Shigeo Shingo last method of error proofing a manufacturing system is the motion step method. This method ensures that the correct steps were taken for each operation. This ensures that the correct parts are used in the correct steps. For example, all the parts for a particular component may be color coded so that only parts of a particular color are used in the manufacture of an assembly.

These methods of error proofing allow for automated operations without cutting out the operator. With the go/no go gauge the operator must still check for good parts, with the fixed value method the operator must monitor the fixed value for discrepancies, and with the motion step method the operator must make sure the operation is done using the correct steps.

The advantage to these systems is their visual nature. It breaks quality down in a way that is easy for an operator to judge quickly. Are there any parts left in the bin after a odd part out operation? Does this part fit into this gauge? Are there any off-colored parts in this motion step assembly? It empowers the operators to make decisions on quality that otherwise would have to be determined by a quality technician. Allowing for instant feedback and correction.

4. Levels of Error Proofing

Not all error proofing is equal. There is a hierarchy of devices from least to most desirable [8].

- Level 1 device -- A device that prevents a mistake or eliminates the error
- Level 2 device -- A device that detects a mistake or error after it occurs, but before it turns into a defect
- Level 3 device -- A device that detects a defect

A level 3 device detects the creation of a defect after it is made. This can be an inspector looking at a machined part, a visual inspection system that check the alignments of parts after soldering, or a scale used to weight candy bars in a chocolate factory. This level prevents the defects from reaching the customer but doesn't stop the products from being scrapped or reworked.

This is also the least reactive level as parts are only inspected and rejected after they have been created. Sometimes hours or days later. In the meantime whole batches may need to be scraped.

Level 3 is also the most laborious level. Requiring secondary inspection, as well as labor for reworking or replacing defective parts.

Level 2 error proofing defects a mistake after it occurs but before it ruins a part. For example, a five axis CNC machine may check its tool before it begins using it. If it finds it lacks the tool, or that the improper tool was put into a slot, it will shut down the line. This prevents the system from producing a bad part.

This level is superior to level 3 as it doesn't produce defective parts. The line is shut down the problem is taken care of before bad parts are produced. The issue with this method is that it shuts down the assembly line. The system can be expensive to produce as it requires an array of sensors to function.

Level 1 mistake proofing is the most desirable. At this level mistakes are prevented from happening in the first place. Use part geometry, sensors, or other means the operation is set up to eliminate a defect from being made. For example, a round part could be put into a die at any angle. There are 360 degrees of variation from one part to the next. But if a key was cut into the disk and a matching pin put in the holder the part could be aligned quickly and accurately every time.

Level 1 mistake proofing is the best. Once implemented there are no defective parts being created, and the assembly line does not need to be shut down to fix problems.

An example of the difference between the levels is a carpenter cutting boards on a table saw. She could estimate where to cut each board, and then measure the resulting length to see how close she is to the target dimension. Or she could set up a stop at the end of the table to butt the board up against. Ensuring that the same cut is made every time.

5. The Value of Mistake Proofing

It is readily apparent that reducing errors saves money. You create less scrape, waste less time reworking parts, and can cut back on inspection. While these savings are the most direct, mistake proofing has other benefits. Higher quality parts improve a manufacturer's reputation. It is possible to charge a premium for quality. The operator's focus and attention can be directed towards value added operations, rather than wasting time and effort aligning parts.

Another value for mistake proofing is in safety. Especially when dealing with large machines, the dangers presented to the operators is real. A drop press can crush hands, exploding boilers can maim, and gas explosions can kill.

A common method of error proofing for large machines is to have the start switch operated with two hands. Pushing two buttons insures that the operator's hands are away from the machine. Steve Glass took this idea for error proofing to the next level. Modifying a table saw, he created a breaking system for the blade. The system monitors the blade looking for the change in electrical current that happens when a person touches it. If that occurs, an aluminum block is forced into the blade within five milliseconds, stopping it and preventing an amputation. The stop saw is an ingenious method of mistake proofing a table saw, making it far safer to use [9].

6. Fail-Safes

It is inevitable that whatever you build will one day break. Be it a turbine, a car, or a sink. Depending on the application a failure could be catastrophic.

On the night of December 3rd 1984 a systems failure at the Union Carbide India Limited pesticide plant in Bhopal, Madhya Pradesh created one of the world's worst industrial accidents.

That night, water seeped into the pipes of a tank holding 42 tons of methyl isocyanate. The water reacted with the methyl isocyanate exothermally, heating the tank to over 200°C. The pressure build up forced the tank to vent, releasing around 30 tons of noxious gas into the air, and the surrounding city [10].

It is estimated that up to 8000 people died within two weeks of the gas leak [10]. And countless more have
Suffered from exposure. If the methyl isocyanate tank had a failsafe that prevented the venting, or neutralized the reaction then the Bhopal accident would not have occurred.

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Fail safes do more than protect lives. A fail safe can be utilized to protect people, machines, and systems. A common example of this is a shear pin.

The idea of the shear pin is straight forward. It is a pin that is placed at the junction between a shaft and an engine or gear box. The pin is designed to have a lower shear stress than either the shaft or the machine it's attached to. That way if a sudden extreme torque load is applied to the shaft the pin will be the first to break, saving the rest of the machine from damage. It is far cheaper to replace a shear pin than to replace an engine.

Fuses work in a similar manner. Put between a power source and a machine the fuse is designed to fail in the event of a power surge. This prevents the power from flowing through the system potentially causing a fire.

The shear pin illuminates an engineering issue with fail safe mechanisms. They should be simple and reliable enough to work 100% of the time. As these are the things we trust with our lives. On the other hand if the fail safe is too sensitive it will trip constantly. This is dangerous because people will attempt to bypass the safety systems entirely. Perhaps using a nail instead of a shear pin, or bypassing a fuse socket with cable.

An excellent example of a fail-safe mechanism is the fire door. A fire door is a heavy metal door that is used in larger buildings. When shut it hinders the spread of fire through the structure. Fire doors are generally held open through an electro mechanical lock. When the fire alarm sounds, the lock disengages and the doors shut. The advantage to using this type of lock is that if the power goes out, the locks would automatically disengage and the doors would close. Even if the lock failed to deactivate, the fire door has a secondary fail safe. Many doors have a fusible link built into the arm holding it open. This link is designed to melt at high temperatures. Meaning that even if the alarms are not triggered the presence of fire near the door will be enough to cause it to close.

The railroad industry has a history of accidents. In the early days of steam locomotion trains would often derail due to poor tracks. Faulty or non-existent pressure release valves would lead to boiler explosions, and poorly trained engineers taking turns too fast could cause the train to tumble off the tracks. Even today, train safety is paramount. On July 6th 2013 an oil filled train was parked on the edge of the town of Lac-Mégantic, Canada. The train was on a downhill grade, and insufficient braking was applied to it. The train began to roll downhill, picking up speed until it hit a sharp bend, derailed, and ignited the

ISSN 2348 – 7968

oil in its tanks. The resulting inferno killed forty two people.

Tragedies like the one in Lac-Mégantic are fortunately rare. The train industry has worked hard over the years to improve train safety. They have accomplished this through better designs, stronger materials, better standards and practices, and better automation.

The dead man's switch is a common fail safe mechanism that is familiar to anyone who uses a lawn mower. An operator running a machine must apply pressure to a switch, if she fails to do so the machine will turn itself off or enter a safe mode. For lawnmowers this prevents the operator from getting close to the blade while it is running. Trains also had dead man switches, where the loss of pressure would activate the train's breaks automatically. Modern day trains use a different style fail-safe. Instead of holding down a lever, the operator is prompted to press a button every few minutes. If she fails to do so the train applies its breaks [11]. In this way the operator must be vigilant as well as present.

Signaling is another major area of concern. A train operator must know if the track ahead of her is safe or not. If a train has stalled unexpectedly or derailed, the train behind it must be stopped as well. Relying on an operator alone to put on the brakes is dangerous. Slow reaction time, adverse weather, and the physical distance needed for a train to come to a complete stop means that a there may not be enough time between when the hazard is spotted and the train stopped.

Modern trains get around this using relays. Using a relay, the train track will be broken up into different "blocks". These blocks are electrically isolated from each other. A battery is hooked up to the two rails at one end of the track and a relay is attached to the other. This completes the circuit and will signal a train that it is safe to move through the block. As the train travels along the track it acts as a bridge between the two rail lines. Shorting out the power from the battery. This means that while the train is in the block no power reaches the relay. Any other trains that pass through while the relay is off will receive a brake signal [11].

The relay is an excellent fail safe because the train only gets a green light if the signal is present. This means that if the battery dies, or a connection to the rail is broken, or if the relay burns out, the train will be stopped. In this way failure of the mechanism will not result in a crash. Street crossings use the same mechanism for stopping traffic [12]. It furthermore has a battery backup in case of power failure so that the signs stay down and the lights continue to flash.

An additional layer of safety is applied to this mechanism through the use of automatic train stops [11][12]. Developed in the turn of the century these are bars affixed to the outside of the rails. Capable of being raised and lowered. When the stop signal is triggered the bar rises. If a train conductor fails to stop his train the automatic train stops will trigger the train's breaking system; causing it to stop without the conductor's input. Furthermore, most trains require that the drive climb out of the cabin to reset the air valves manually.

7. Checklists

Documentation is the life blood of a consistent procedure. Having a set of standard work instructions is vital to creating a repeatable, trainable operation. One of the most useful of these documents is a checklist.

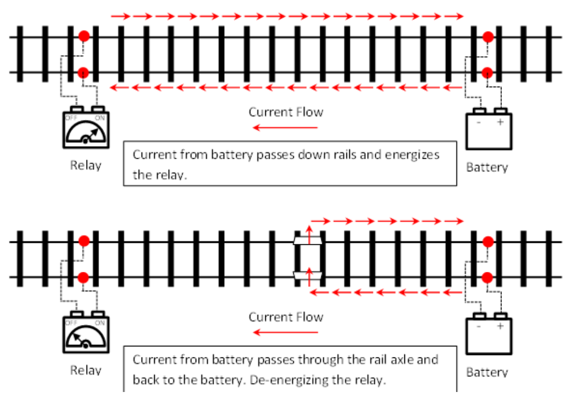

Fig. 3: Relay Fail-Safe System

A checklist are distilled down from larger documents. They reference the key points of the document while leaving the details out. They are used to remind the operator of all the key points from that larger document without forcing them to reread it each time.

Checklists can be used in many different applications. A materials checklist may outline every item needed to produce a part. A common example of this is the page that comes with furniture that comes un-assembled. Often these will include a checklist of all materials needed. A checklist will also often include all the machines and tools required to do a job.
Procedural checklists lay out the steps one has to do in order to finish a job. For example, a computer assembler may have a checklist of every step needed to build a computer. After each step, he check off and signs it verifying it was accomplished. In this way he, and his supervisor can verify that every step was done in proper order.

Safety and maintenance checklists are another common sight. They are used before an operation or after an operation to ensure the health of the operator and the machine.

In 2008 the World Health Organization published guidelines for best surgical practices. These procedures would help protect the safety of patients. A research team took those guidelines and turned them into a 20 point checklist [13][See Appendi]. Between 2007 and 2008 the team studied eight hospitals across eight cities. Getting post-operative data on patients from each. After a large enough sample size was gathered, the team then implemented the checklist before, during, and after each non-cardiac procedure.

The team collected data on 3733 patient outcomes before the checklist was implemented and data for 3955 after implementation. They found that the mortality rate dropped from 1.5% pre-checklist to 0.8% after the checklist. Furthermore the rate of inpatient complication dropped from 11.0% to 7.0% [13].

Furthermore, they found improvement in all hospitals regardless of location. Rich and middle income. All hospitals improved patient safety by implementing the checklist.

The checklist caused both institutional changes, as well as behavior changes with the procedures. Each site had to adopt policies that they were not doing normally. These include pre-operation and post-operation briefings. Confirming identity, as well as marking operation sites.

In addition, the checklist forced changes in when steps were carried out. Antibiotics were administered in the operating room instead of in post-care wards. Antibiotic treatments are often delayed there. This increased adherence to them from 56% to 83%.

Checklists force operators to take a more active role in their duties. It gives them a structured guideline to use as a basis of their job. Distilling the essential information into one easy to read list. But, it can profoundly affect the success and reliability of the procedures it is applied to.

8. Visual Controls in Error Proofing

One of the key aspects to good error proofing is ease of use. And one of the easiest was of conveying message is through visual indicators.

For instance, on the Toyota assembly lines every operator has to ability to stop the line. When the line is stopped a red light above the station turns on. Indicating where in the assembly line the problem occurred [6]. As machines take over the jobs once done by humans, they carry on this system. Often when a machine detects an error it will shut itself off and signal a problem.

Ventilator associated pneumonia is an often fatal condition for people who are on ventilators. The Institute for Healthcare Improvement's in their “100000 Lives Campaign” give recommendations on ways to reduce Ventilator associated pneumonia. One recommendation is for ventilated patients to have their heads elevated at between 30 and 45 degrees.

The Patient Safety Improvement Corps is an organization out of Mississippi focused on improving the patient safety in hospitals. It wanted to find a visual method of helping error proof patient’s beds.

The old style was a simple sign that said “HOB 30”. There was no indication of what 30 degrees should be. The Patient Safety Improving Corps redesigned the sign to make is more visual. Their goal was to be able to determine the angle of the bed from the hallway.

Their solution was to place the sign the sign on the bed at a 30 degree angle. This way the text will be level when the bed is properly angled [14].

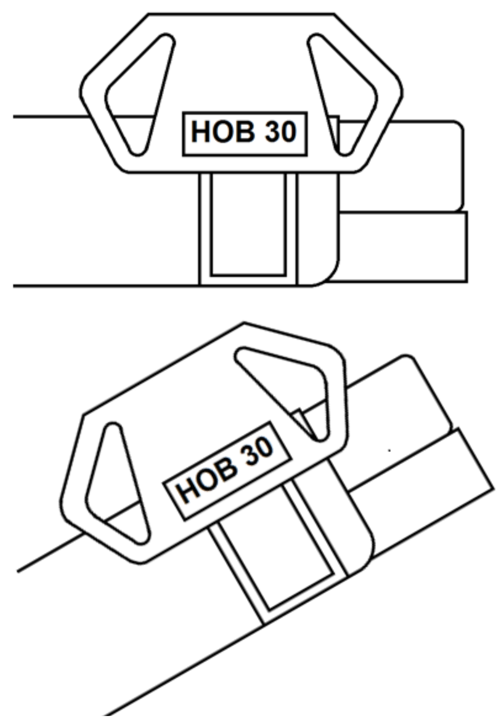

Fig 4. Bed sign before error proofing

ISSN 2348 – 7968

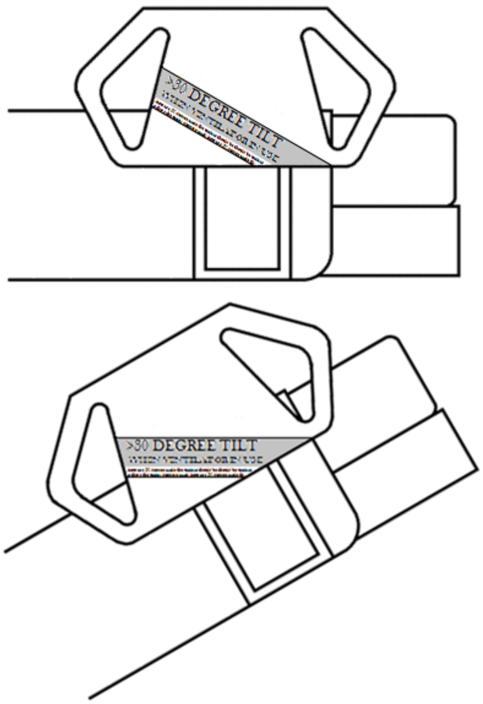

Fig 5. Bed Sign after Error Proofing

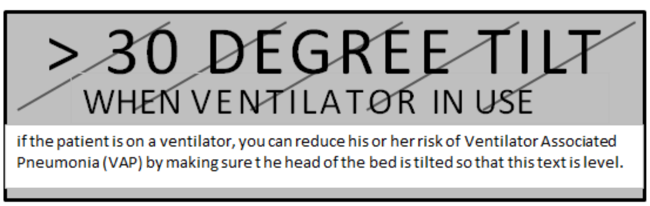

Fig 6. Close Up of Error Proofing Sign

The new sign is a visual aid to nurses setting up the bed, and is a good tool for doctors to judge whether a bed is positioned correctly [14].

9. Conclusion

Quality cannot be left up to machines alone. Without human involvement, any automated system will fail to produce high quality results without a human touch.

The design of a system can greatly impact the quality of work it produced. When automating a system, using basic mistake proofing methodologies can eliminate preventable errors from damaging the product. Whether that part is a flange being machined, or a patient's life in the operating room.

The most effective methods of mistake proofing are often the simplest. A sign on a hospital bed shows everyone at a glance whether a bed is at the right angle. A shear pin on a snow blower means a rock caught in the blades won't wreck the drive train. A check list before surgery reduces the risk of complications to patients.

The tools of error proofing are numerous. They are visual, electronic, and physical. A well designed system, automated or manual will incorporate as many means of reducing errors as possible.

10. Recommendations

This paper only scratches the surface of mistake proofing when it comes to automation. Further research into the following areas would be enlightening:

- Mistake proofing die exchanges
- Mistake proofing in visual inspection systems
- Mistake proofing before and after automation.

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