Session No. 689

LeanSafe™: When Lean and Safe Principles are Applied, Productivity Improves

Roberta Nelson Shea
COO & General Manager
Pilz Automation Safety, L.P.
Canton, MI

Introduction

For more than 30 years, the author has worked with customers and standards-writing committees with the goal of improve safety in the workplace. The challenge is to minimize the productivity impact while assuring compliance with standards and best practices. Best practices have improved over the years and as such they have influenced standardization activities.

Safety has long been considered as an obstacle to lean manufacturing. Indeed many standards and regulations, whether they are in Europe, the Americas or Asia, dictate that a particular piece of manufacturing equipment MUST contain certain safety systems. Most people expect people to be protected from machinery hazards by some form of 'safeguarding'. Safeguarding is typically provided by some combination of fixed mechanical guards, with interlocking provided by guard switches, and sometimes also presence-sensing-type safeguards such as light curtains, safety mats or other devices that either detect the presence of a person or prevent a person from reaching a hazard.

This means that machine designers have to work with the 'constraints' applied to them for safety. They have to design a cell with safety in mind. In some cases, this prevents a designer from designing a truly 'lean' cell. After all, lean is the identification and elimination of waste. But the "lean team" usually views machine safety often as a type of 'waste'. Why? Safety doesn't make the part quality better, or improve the product. It adds little to the process of manufacturing except, of course, preventing people being injured. It is often tolerated as a cost of doing business, even in the most safety conscious and safety committed companies.

I often hear the term "We need to make the parts as efficiently possible…. And of course, we must be safe!" Yet few actually look at these together. Most Lean tools are applied to the 'making' of the products. The lean audits, teams and studies all focus on identifying the manufacturing! And most safety tools (audits, checklists, reviews) focus on compliance, not how to make people safe while helping them to be productive.

Very few tools focus on the combination of manufacturing AND safety. Therefore, if companies want manufacturing to perform as efficiently and safely as possible, then they must look at ways of merging lean tools to the manufacturing and the safety processes. Today, I am presenting a case study where an actual robot system was reviewed using a combination of LEAN and SAFE processes.

Integrating Lean & Safe is an Emerging Issue

Momentum is building around the integration of lean and safe. The principles were first formalized into B11 TR7 (an AMT B11 technical report) that looked at consolidating ideas and principles applied by some companies in the aerospace industry. This report primarily looked at the how to integrate the 7 (seven) forms of waste into the well known B11 TR3 risk assessment process, as well providing examples of where Lean and Safe could work well together. TR3 (currently under revision) is a task-based risk assessment model.

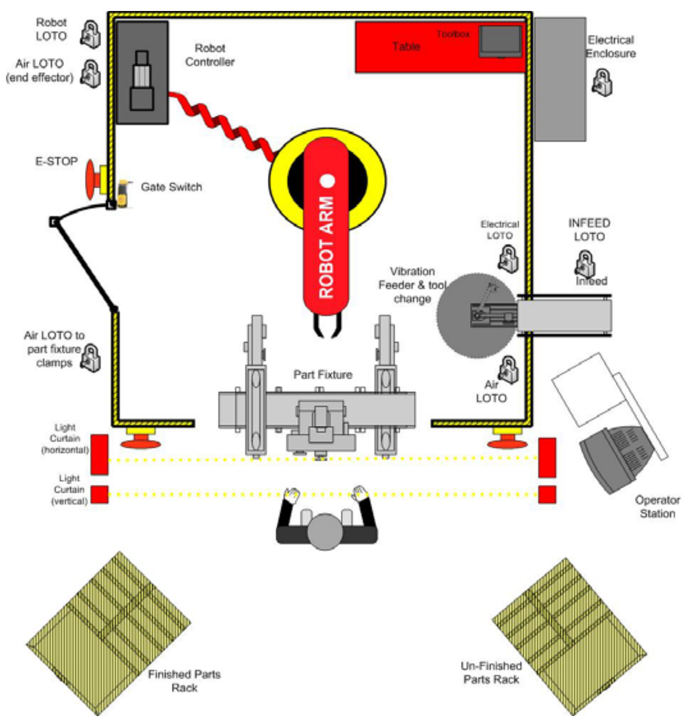
After TR7 was published, a group of interested companies set up an informal Lean and Safe Forum to share ideas on how to progress and take the concepts to the next level. This forum meets via web and teleconferences each month. This forum started with GM, Lear Corporation, Boeing, Pilz, design safe engineering, and other. It has grown to include many other companies such as Delphi, TRW, Ford, Federal Mogul as well as industry organizations like PMMI, RIA, AIAG, SAE and academic institutes like Purdue University.

Today there is an economic driver forcing companies to be lean. However, they must also be safe. The intent behind integrating lean and safety is a powerful opportunity. But the ideals are still very new and there is much work to be done.

Existing Robot System

There are several pieces of equipment in this cell; however, I have tried to limit the drawing and explanation to the main points.

1. This robot system is portable. It is on a metal floor skid, so that it can be relocated to be used elsewhere for production needs. This provides a flexible capacity to produce various parts where all they need to do is move the cell to a different production area.
   This is a great lean concept.



2. The system acts as an automated fastening system where the primary purpose is to insert fasteners into parts located in the interior dashboard.
3. There is a part fixture jig that holds the part in place. Pneumatic clamps ensure the piece is held correctly.
4. There is vibration feeder that provides the robot with a steady supply of fastener clips.
5. There is also a tool changer so the robot can change tools depending on the particular part being assembled (when it is moved around the production floor).
6. There is a table and toolset in the rear of the cell for quality checks.
7. The robot controller is located at the rear of the cell.

The operator loads Interior Parts (IP) onto a fixture. He then steps back and presses the cycle initiation start button next to the operator station. The robot then moves to the feeder, picks up the correct fasteners and then inserts them into the IP. When finished the robot moves to a 'hold' position that is safely monitored. The operator then removed the finished part, puts it on the rack, grabs another IP from the un-finished rack, loads it into the fixture and starts the cycle again. *NOTE: Two sets of light curtains ensure the operator has stepped away from any hazards before the machine runs.*

There are several safety devices on the diagram. The company safety department performed a risk assessment on this production cell. The safety team required that several safety systems be installed: LOTO (Lock-out Tag-out / Control of Hazardous Energy) system, door safety switches, a 2nd light curtain (horizontal at floor level) to prevent a person being "beyond" the first light curtain's field and not being detected. Mechanical guarding is installed to prevent unauthorized access (and make up the cell walls). There was 18'' of clearance applied from the end of the robot's end-effecter to the cell walls, in accordance with the ANSI robot safety standard (ANSI RIA R15.06). When in manual mode for teaching, the robot operates in slow speed. So the robot is moving slowly when a person is inside the cell and teaching. The light curtains are positioned using the required safety distance formula so that if a person breaks any light beam, then the robot will stop before the person can reach any hazard. These are all requirements per the current robot safety standard and are installed to prevent injury.

There are more safety principles installed in this cell. However, remember that this cell went through a safety review, such that many hazards have been addressed. Although the system is not totally compliant, it can be reasonably argued that with the existing safety systems, the existing cell is already pretty safe!!!

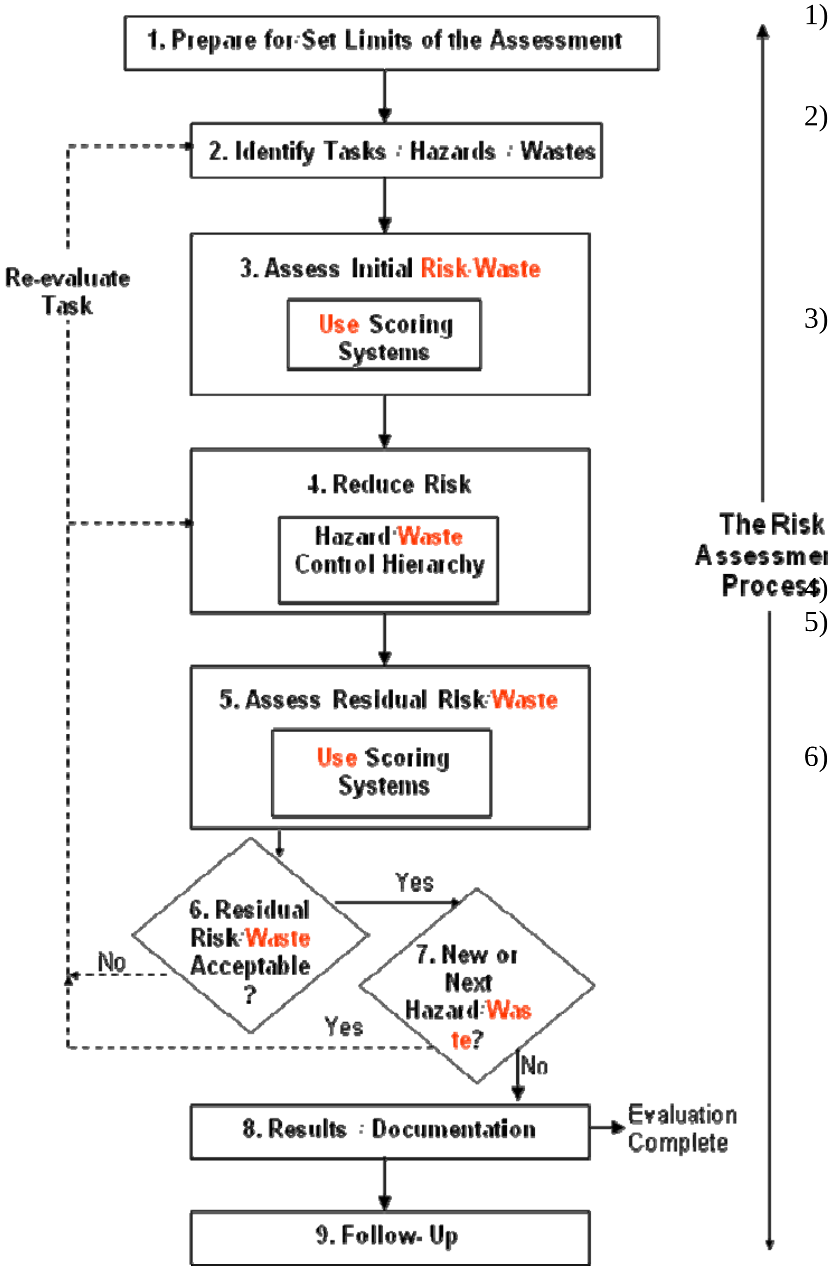
But is it Lean and Safe?

Without considering lean principles at the time of doing the risk assessment, it becomes very easy to simply install safety devices, systems or principles that are not very lean. The results may be safe, but they may also include waste: wasted space, devices, time (cycle time, time to do maintenance and therefore downtime, etc) or in terms of the 7 forms of waste - COMMWIP

The Goal of the LeanSAFE™ Process is to Achieve Acceptable Risk with Minimized Waste

From the drawing, risk assessment is an iterative process that is designed to look at hazards AND tasks with a view to achieving acceptable risks. B11 TR7 took the existing risk assessment methodology TR3 and integrated the 7 forms of waste – COMMWIP. In other words, achieving acceptable risk with minimized waste means that the system is acceptably safe and lean!

This is the iterative approach that was taken. The flowchart details a systematic identification and analysis of every task, hazard and source of waste. Shown on the right is an example.



1) What is the task – i.e. loading the part

2) What is the hazard(s) – pinch points from the pneumatic clamps, ergonomics (twisting, leaning, over reach)

3) What is the waste associated with this task – part doesn't easily fit into fixture sometimes resulting in the operator having to lean over fixture to adjust. This increases time to load and exerts strain on operator.

4)

5) Score the risk and the waste (is it high risk but results in low waste? Is it low risk and low waste?)

6) Identify possible risk reduction solutions – such as should we redesign the fixture jig? Should we improve operator training? Job rotation, etc. the scoring of risk and waste (step 4) helps to assess these solutions. If there is low risk and low waste, then Job rotation maybe the best solution. However, if there is low risk and high waste then possibly redesign the jig!

6) Assess the residual risk/waste and if acceptable, move onto the next hazard…

Remember, that adding a safety solution may add waste. So it is important to re-assess every task/hazard/waste again AFTER you have come up with a solution. **The main point is that we now have a defined PROCESS for integrating lean and safe ideas.** It is not just a theory. It is a defined process that can be applied to any piece of equipment, process or system!

LeanSAFE™ Issue #1

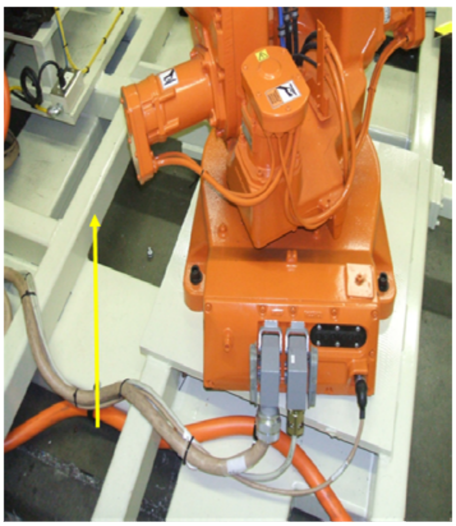
As you can see from the picture, the main robot cable from the robot controller is run along the steel floor beams. This robot cell is designed to be movable so that it can be moved to areas where there is a greater production need. Therefore, the cell is constructed on a steel floor so that it can be easily lifted and moved by a forklift/crane.
Safety Issue: The cable causes an obvious trip hazard!
Lean Issue: The cable is subject to mechanical damage as it is unprotected. It is easy for people to stand on the cable (pressing it against the steel beam edges) or for tools/objects to be dropped on the cable. This results in damage and the need to replace the cable more frequently than if it was protected.

Waste:

- Correction (we need to repair the cable or replace it – which means we need to keep spare cables in stock!) and
- Waiting (the machine would be unavailable for 2 hours. That is 2 hours of production and 2 hours of an electrician's time!!)

Solution: Run the cable under the steel beams. There is space under the cross-beams where the cable would fit and still not be in contact with the floor and protected from the fork lift tines. This simple change makes the machine SAFER and LEANER!!

LeanSAFE™ Issue #2



You can see the skid construction of the cell. However, it also a good example of what happens when the lean team and the safety team worked, but not together! The cell floor is very uneven with various beams and pieces of equipment. This makes it very difficult to stand solidly or maneuver safely across the floor!

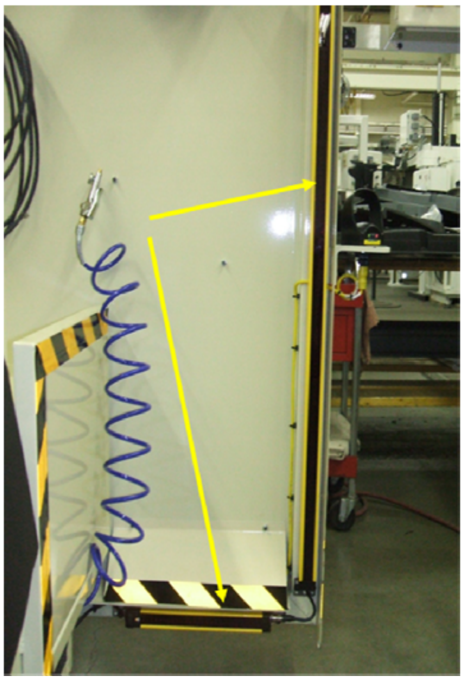
Safety Issue: There are very obvious slip/trip hazards with, at a minimum, the potential for ankle/foot injuries.

Lean Issue: The floor allows the cell to be moved easily and still retain its strength… but it doesn't allow people to move easily within the cell! The team found it very difficult to stand or move around in the cell. We had to be VERY careful, and had to hold onto to other pieces of equipment for stability.

Waste: Waiting. Obviously, any task needed to be performed within the cell took longer because of the amount of time required to slowly move around. This was especially true for maintenance tasks where the maintenance person had to carry spare parts and tools into the cell.

Solution: Level the floor with lift-off grating. This would mean much quicker maneuvering (resulting in faster uptime) and a decreased less risk of injury. Again a good example of the cell being Leaner AND Safer!!!

LeanSAFE™ Issue #3



This shows the area in front of the machine where the operator loads the part. The tall light curtain issues a stop command to the robot and fixturing. The safety team had asked for a 2nd light curtain to be installed to prevent the issue where the operator stands 'beyond' the first light curtain and having the potential of the system starting while they are in the hazard area. You may ask, WHY don't they just move the first light curtain closer to the hazard? Due to safety distance calculations, the light curtain must be at least this far from the closest hazard. If only one light curtain were installed this way, there is a potential for a person walk through the light curtain and be an undetected location that is close to the hazard area. This is why the smaller 2nd light curtain (horizontal at floor height) was installed.

Safety Issue: This is a common problem. However there are a few ways to solve this problem, of which installing a 2nd light curtain is only one method.

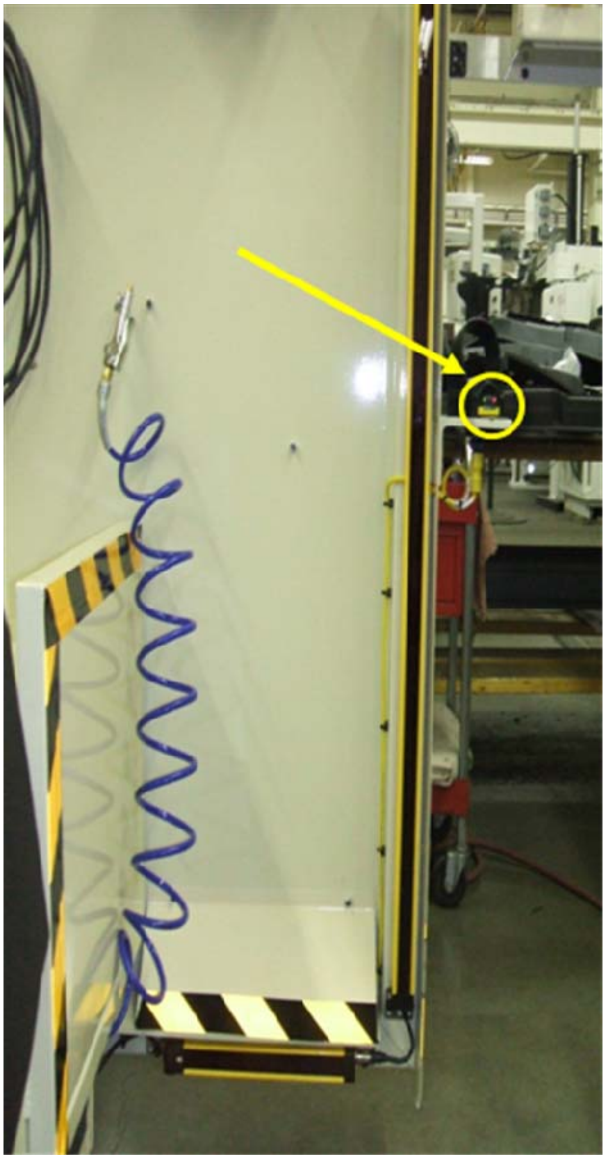
Lean Issue: By adding a 2nd curtain we have increased capital costs (we need to buy another light curtain), we have increased installation costs (wiring, set-up, etc) and we now need to stock another size of light curtain in case of the need of emergency replacement.

Waste: Inventory

Solution: Another solution is to replace the two light curtains with a large light curtain at a 60 degree angle. This will prevent a person from being behind the 1st light curtain and yet still meet the minimum safety distance. *NOTE: This solution depends on the safe distance calculations.* This is a great example where the level (compliance) of safety remained the same (it was already sufficient), but the cell became leaner. It is not necessary to make the cell leaner and safer in every case. Sometime a LeanSAFE™ audit will keep the safety at the same level, but safety may be implemented differently so that the result is a leaner cell.

Remember – there are a lot of cells out there that are SAFE right now… however, doing it differently might make the cell LEANER!

LeanSAFE™ Issue #4



In this picture, notice the cycle initiation push-button shown by the arrow and circle. After the operator has inserted a part, they have to turn around and press the cycle initiation button (located 4 feet away). This button was changed to an ergonomically friendly inductive-type switch.

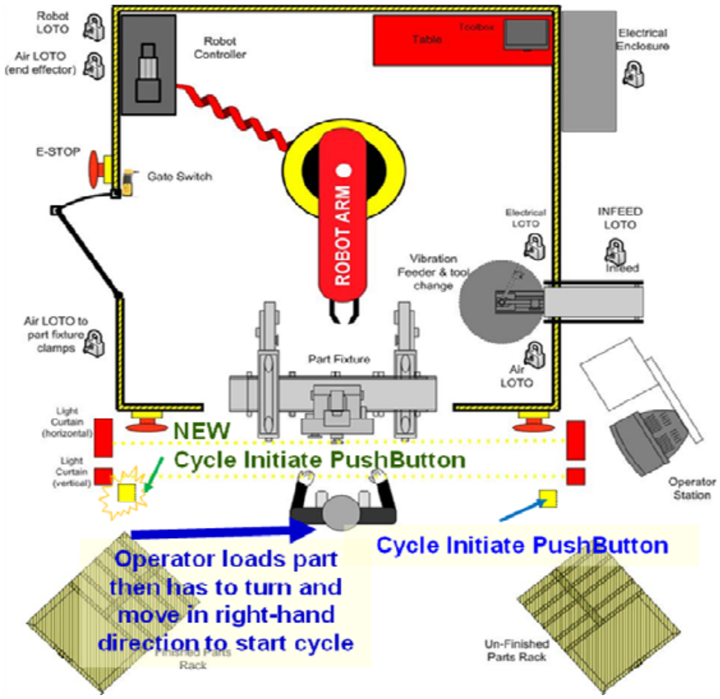
Safety Issue: Before the cycle starts (robot starts moving and clamps engage), then the operator must be safe. The operator protective devices are the light curtains. If either light curtain detects a person, then the cycle will not start. *NOTE: Cycle initiation is not a safety function.*

Lean Issue: There are a few issues with this.

1. The operator takes 3 footsteps, and adds an additional 2 seconds due to the time to walk to and press the pushbutton.
2. The cycle initiation pushbutton is only on the right hand side of the machine, so when the finished parts rack is on the left side, the operator has even more steps.
3. The operator has other tasks to perform in between cycles. So, they usually try to 'brush' the switch as they walk past to perform other task. Several times, I observed the operator having to return to re-press the button because the cycle had not started. I learned that this is typical and the operator handles hundreds of parts daily.

Waste: Overproduction (re-pressing the cycle button) and movement (extra steps).

The next drawing shows the existing cycle start pushbutton and the part racks. It should explain the operation logistics (process steps to perform the tasks) which have non-value added aspects.



Solution: (1) One possibility is to use PSDI (Presence Sensing Device Initiation). PSDI is where unobstructing the light curtain causes the control system to initiate the cycle start. Once the operator has loaded the part (and the sensor on the fixture jog confirm it is in place) and the operator steps back out of the light curtain, then the cycle begins. There is no safety risk because the light curtain ensures that the cycle will not start until the operator is clear. This means that the cycle initiation button would no longer be needed. If there is no need to press this button, all the extra steps and time are eliminated. *NOTE: LCI is not suitable for all applications and may not be allowed for some applications.*

(2) If PSDI is not a suitable or allowed by company policy or standards, then another possibility would be installing a 2nd cycle initiation button on the left-hand side of the machine (shown as a possibility in the drawing above). This would help make the system leaner, but not as lean as if PSDI were used.

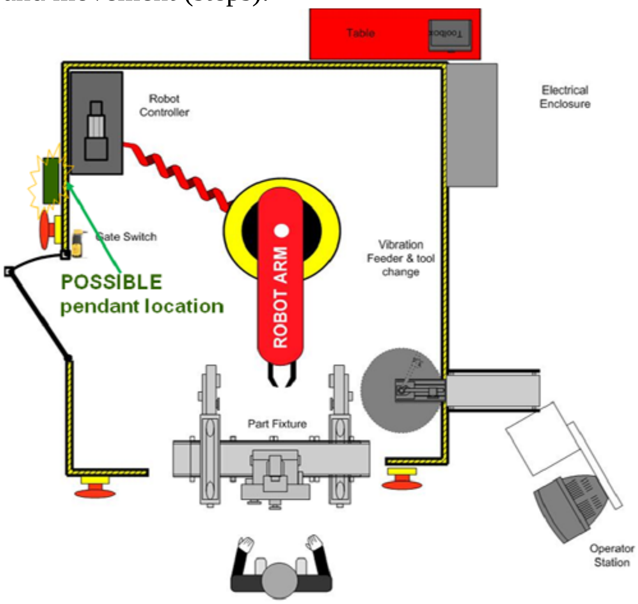
LeanSAFE™ Issue #5

In this picture, you can clearly see the robot teach pendent. This pendent needs to be accessible from both outside and inside of the cell.

Safety Issue: There is always an inherent risk with an operator being inside the cell while teaching (operating at reduced speed in manual mode). However in this case, the operator also has to lean over some equipment to reach the pendent after entering the cell – all while being on a very uneven floor. The robot controller is inside the cell, which is non-compliant with the robot safety standard.

Lean Issue: In order to enter and teach the robot or doing minor robot maintenance (that requires power on), the person walks around the system, enters at the door, carefully wobbles their way to the robot controller to change the mode to slow speed manual mode. The person then wobbles to get the teach pendant which is located outside the cell (a long, non-ergonomic reach). This takes 30 seconds to 2 minutes.

Waste: There is obvious waste from correction (moving the pendent to a more accessible place) and movement (steps).



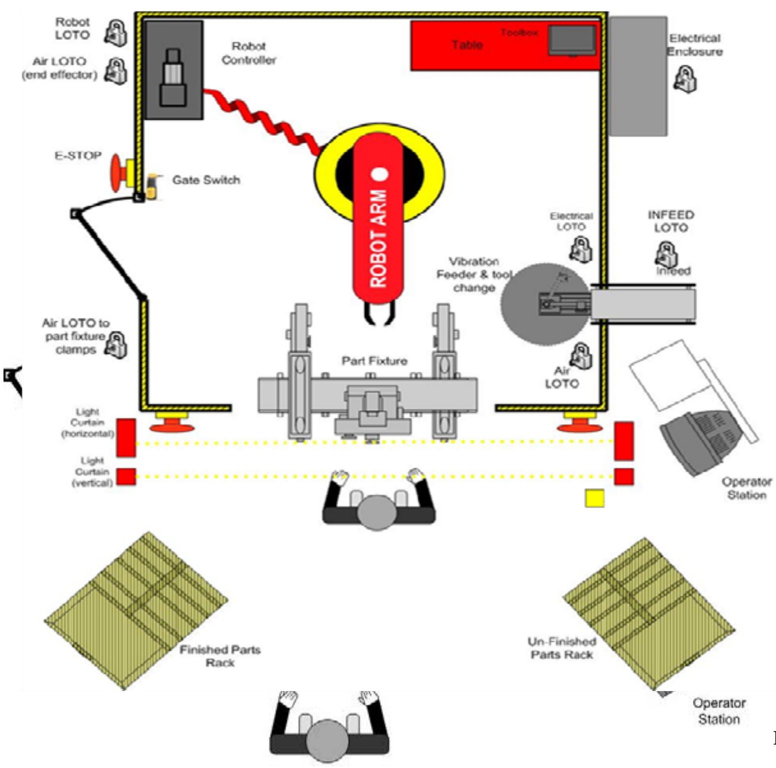
Solution: The pendent could have been located more conveniently or placed on a swing arm (with pull cords) that would allow the operator to reach the pendent from inside and outside the cell.

The robot controller also needs to be relocated to be external, in order to be in compliance with the standard.

NOTE: Point of operation safeguarding and suggestions from the last LeanSafe™ issue are not shown in this drawing. Please refer to earlier drawings which show light curtain(s), cycle initiation pushbuttons, teach pendants, and parts racks.

LeanSAFE™ Issue #6

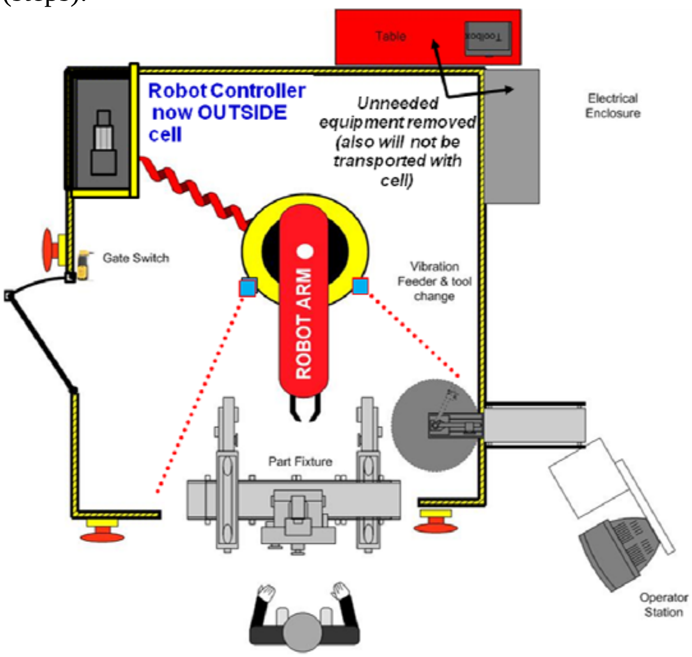
This robot had no means by which to restrict the robot's motion. This means that the actual robot cell size is smaller than the reach of the robot (including the end-effector and part).



Safety Issue: The robot safety standard requires that perimeter safeguarding be NO closer than the restricted space of the robot. So the robot's space must be limited (restricted) in accordance with the standard. In addition, there is another safety standard requirement of providing 18 inches clearance, which was not done with this system.

Lean Issue: The cell contained the robot controller and some other equipment which was not needed inside the cell. If the cell were simply made larger to comply with the standard, then the cell would become too large to be easy to transport / relocate.

Waste: If brought into compliance without use of limiting the robot's motion, space would be wasted. Having additional, un-needed equipment in the cell is another form of waste. There is obvious waste from correction (moving the pendent to a more accessible place) and movement (steps).

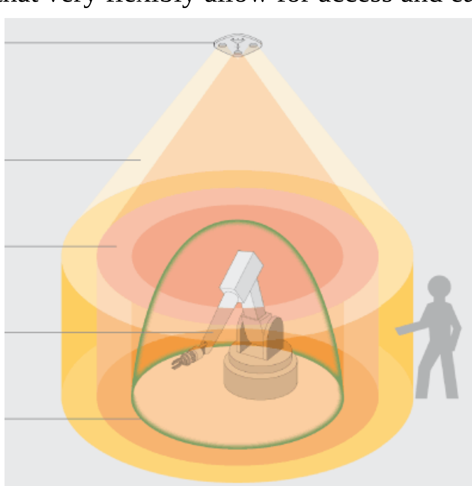


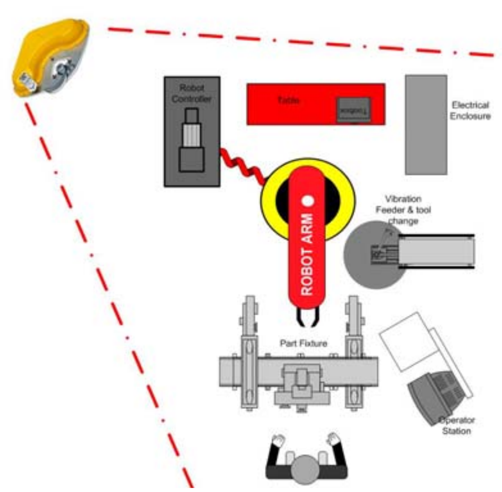
Solution: The robot only needs about 60 degrees of base rotation to do any of its required work. By limiting the movement of the base axis, we can comply with the standard AND we can also make the cell smaller than it was installed. In this application, 2 hard stops were recommended for the primary axis. Non-essential equipment (table, toolset) is removed to reduce the cell footprint.

NOTE: Some new robots may have safe motion and speed control features such that limiting is done safely within the robot system. This safety feature is only possible with some new model robots.

By limiting the motion and removing non-essential equipment, the entire cell can be made smaller. This makes it even easier to move and relocate.

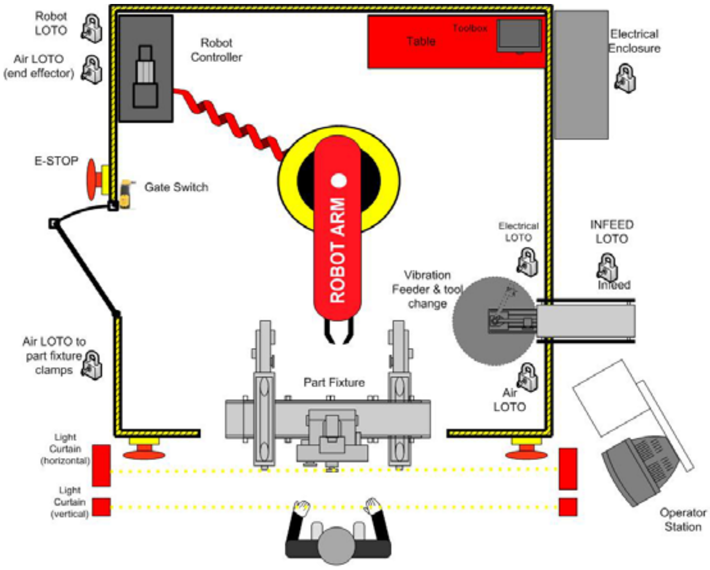
If this system were NOT transportable, there would be another possibility: remove all the mechanical guarding and instead use a safe vision system. The safe vision system sets the perimeter safeguarding, however the vision sensor must be installed. Since this system moves, there is no place to install the sensor and have it move with the system. If the robot cell were not regularly transported to new locations, use of a safe vision system would allow developing small cells that very flexibly allow for access and ease of re-deployment.





LeanSAFE™ Issue #7

In this picture you can clearly see all the different types of LOTO devices utilized in this cell.



There are

1) Lock out valves for air (End effector, part fixture jig, regular cell air)
2) Electrical lock out
3) Lock-out points for the robot controller, vibration and tool changer, infeed conveyor, and regular electrical enclosure.

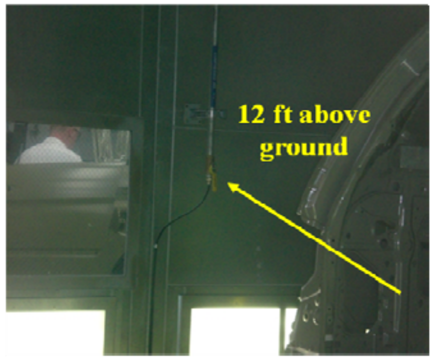
There are **7 different points** that must be isolated before a person enters the cell. These lock-out points are not well located. For example, the infeed conveyor LO point is on the rear wall of the building! It takes an average of 3 minutes to lock out all 7 points.

Safety Issues: The safety department required full lock-out for all tasks except teaching the robot. So anytime someone had to enter the cell, then full LOTO was performed.

Lean Issues: The time to do this is around 3 minutes (the same for the reverse of the process), making the total system downtime approximately 7 minutes not counting the time to perform the task. This is waste due to waiting and unnecessary movement (walking around to perform the lockout process). The cell was designed for relocating. However the lockout implementation requires electrician's time whenever the system is moved.

Solution: (1) It may not be necessary to lock-out each time. If the task is routine, repetitive and integral to production then lock-out is NOT required if alternate effective safeguarding is provided (the safeguarding system must be designed to a suitable safety integrity). This is sometime called the alternative measure (see ANSI Z244.1) In the future a new standard UL 6420 may help with electronic systems such as SLS-type system that electronically perform the lock-out. (2) Also, consolidating the isolation points into 1 area that is placarded will reduce the time to lock-out and recover from lock-out. (3) Designing the lock-out system into quick connects for all possible cell locations will speed the re-deployment of the cell.

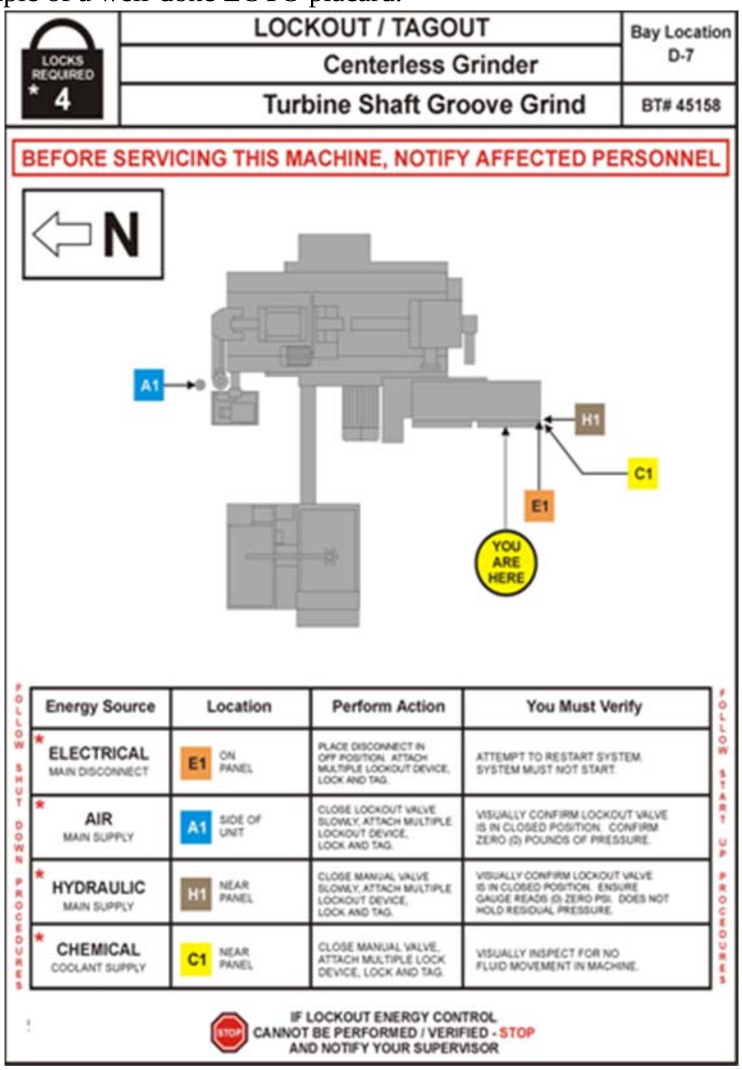
Having an isolation point that is 12 feet above the cell is not easy to isolate. And the reality is that it is likely to be forgotten or not done due to the difficulty.



Even if it this lock-out point is used properly (12 foot in the air), then doing so adds significant time.

NOT LeanSAFE™!

Below is an example of a well-done LOTO placard.



LOCKS REQUIRED * 4

LOCKOUT / TAGOUT

Centerless Grinder

Turbine Shaft Groove Grind

Bay Location D-7

BT# 45158

BEFORE SERVICING THIS MACHINE, NOTIFY AFFECTED PERSONNEL

N

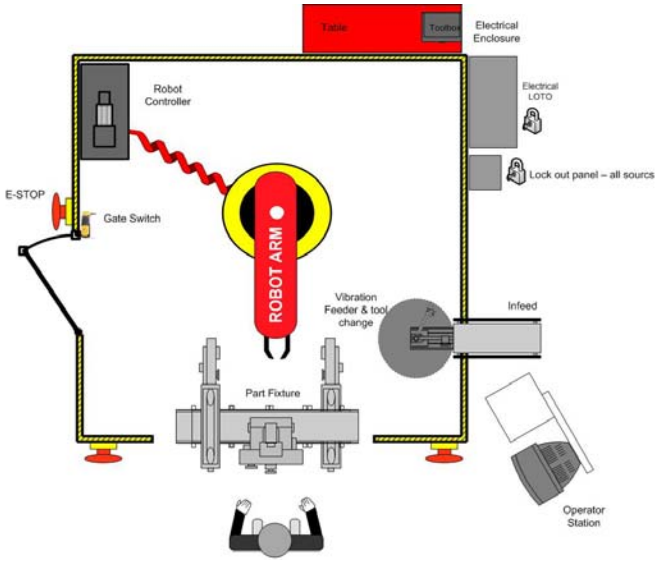
A1 H1 C1 E1 YOU ARE HERE

FOLLOW SHUT DOWN PROCEDURES

Energy Source	Location	Perform Action	You Must Verify
* ELECTRICAL MAIN DISCONNECT	E1 ON PANEL	PLACE DISCONNECT IN OFF POSITION. ATTACH MULTIPLE LOCKOUT DEVICE, LOCK AND TAG.	ATTEMPT TO RESTART SYSTEM. SYSTEM MUST NOT START.
* AIR MAIN SUPPLY	A1 SIDE OF UNIT	CLOSE LOCKOUT VALVE SLOWLY, ATTACH MULTIPLE LOCKOUT DEVICE, LOCK AND TAG.	VISUALLY CONFIRM LOCKOUT VALVE IS IN CLOSED POSITION. CONFIRM ZERO (0) POUNDS OF PRESSURE.
* HYDRAULIC MAIN SUPPLY	H1 NEAR PANEL	CLOSE MANUAL VALVE SLOWLY, ATTACH MULTIPLE LOCKOUT DEVICE, LOCK AND TAG.	VISUALLY CONFIRM LOCKOUT VALVE IS IN CLOSED POSITION. ENSURE GAUGE READS (0) ZERO PSI. DOES NOT HOLD RESIDUAL PRESSURE.
* CHEMICAL COOLANT SUPPLY	C1 NEAR PANEL	CLOSE MANUAL VALVE, ATTACH MULTIPLE LOCK DEVICE, LOCK AND TAG.	VISUALLY INSPECT FOR NO FLUID MOVEMENT IN MACHINE.

FOLLOW START UP PROCEDURES

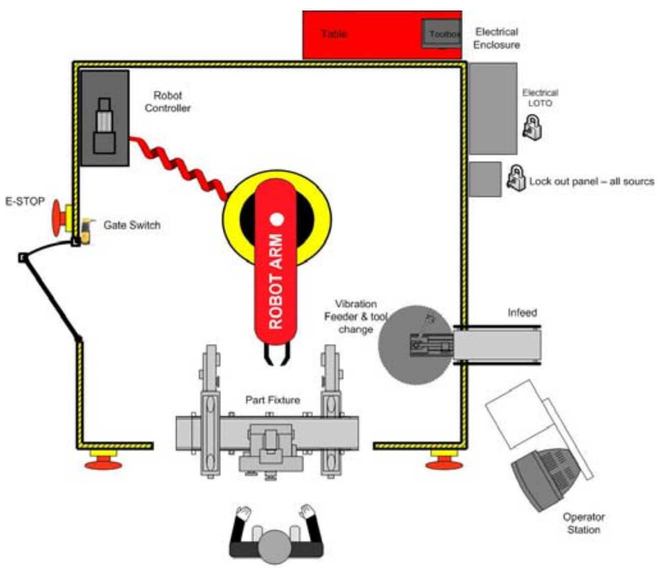
STOP IF LOCKOUT ENERGY CONTROL CANNOT BE PERFORMED / VERIFIED - STOP AND NOTIFY YOUR SUPERVISOR



Look at our robot cell now. All the air and electrical lock-outs are on a small panel next to the main electrical enclosure. This means the operator only needs to go to this panel with 7 locks, rather than walk around the cell.

LeanSAFE™ Issue #8

If you remember, there was originally only 1 door (left hand side) to enter this cell.



Safety Issue: The operator has most nuisance issues with the feeder. For feeder problems, he enters on the left hand side of the cell, passes by the robot and pneumatic part fixture to get to the problem. There is increased risk because the operator is in proximity to more hazards.

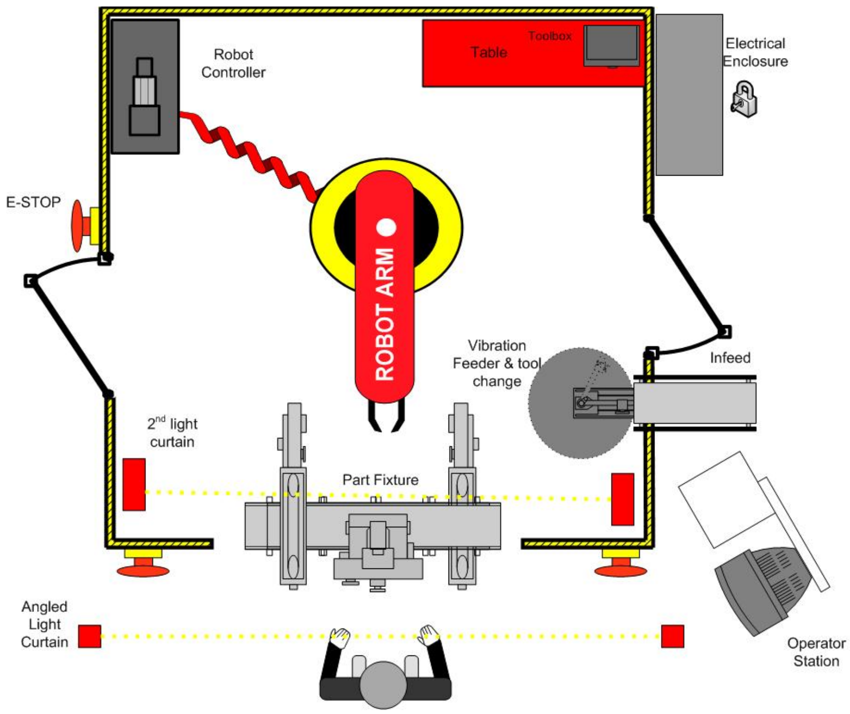
Lean Issue: This increases machine downtime, because each time the operator needs to tend to the feeder, they must access at the opposite side of the cell from where the problem is AND perform lockout.

Solution: (1) fix/ replace the feeder so that there are not these problems (eliminate first). (2) install a second guard door next to the feeder bowl (see next drawing). Installing a 2nd guard door can reduce downtime. Operator access door sometimes 5 or 6 times per shift. An extra door could reduce downtime by about 10 minutes per day and reduce exposure to hazards. Eliminating the need, would further improve productivity.

NOTE: If you cannot eliminate the feeder issue, then this is a good example where ADDING safety devices can make the cell leaner. Be careful not to think that LeanSAFE™ studies are only about reducing the number and/or cost of safety products/ techniques used on a cell.

LeanSAFE™ Issue #9

The final issue is to look at what happens when the operator unloads a finished part. Currently, when the part is finished the operator reaches in to remove it and interrupts the first light curtain field (see picture). The robot goes into a stop mode immediately (no matter where it is in its cycle). When the new part is loaded and the operator presses the cycle start pushbutton, then the robot resumes operation.

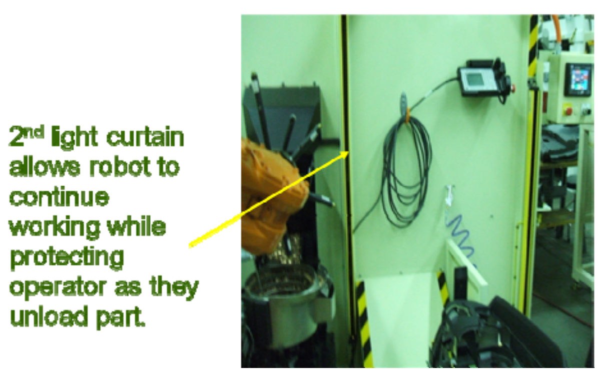


Safety Issue: The light curtain is preventing the robot and the part fixture from moving. Therefore, an acceptable level of safety is achieved.

Lean Issue: The time while the robot is 'holding' is time that it is not productive! This is time that the robot could be doing another task.

Waste: Waiting until the operator initiates the cycle.

Solution: Install a 2nd light curtain behind the part fixture. When the operator is unloading a part, then the robot can continue to work (as long as it is BEHIND the 2nd light curtain). This means the robot can go to the feeder bowl and re-load fasteners for the next part or do a tool change WHILE the operator is unloading a part. The 1st light curtain only stops the part fixture pneumatic clamps and not the robot. The only time that the 1st light curtain will stop the robot, is IF the operator were to break the first light curtain while the robot was installing fasteners – i.e. the robot is in interrupting the field of the 2nd light curtain. This will save about 5 seconds on every cycle (the time the robot is currently not working).



Summary of the LeanSAFE™ Study

The goal was to **achieve acceptable risk with minimized waste!**

If about $20,000 is spent, then the following benefits would be realized:

- $2200 in annual savings due to maintenance costs
- Increase productivity 1.2% when performing maintenance
- Improved cycle time from 45 seconds per part to 31 seconds per part
- 7% reduction in downtime when performing teach
- Reduced downtime by 15 minutes per shift = increase of 19 parts per shift
- Reduction in floor space by 18 square feet
- Easier transportability of the robot cell
- Improved (and easier) safety compliance: OSHA 1910.147 Control of Hazardous Energy (LOTO) and ANSI RIA R15.06,

Recommendation	**Implementation**	**Cost to make change** *These are simple, reasonable estimates for comparison only.*	**Results Annually** *unless otherwise specified*
1) Relocating robot cables to underneath the structure	a) 4 hours to install cable within cell structure, in a manner that allows replacement if needed.	Approximately $500	$1200 in cables + value of reducing slips, trips and falls
2) Evening the cell's floor and relocating robot cables to underneath the structure	b) Design, fabricate, and install lift-up flooring panels with slip resistant surface.	Approximately $2500	+ value of increasing productivity by 1.2% + value of labor that can be re-deployed for the time they would have spent in the cell + value of reducing slips, trips and falls
3) Angling one light curtain and removing the smaller horizontal light curtain	c) 4 hours to install (mechanical and electrical) includes removal of surplus light curtain.	Approximately $500 Savings of 1 light curtain (cannot measure this as a savings as it is already owned by company). Possible re-deployment of light curtain.	$1000 Assumes replacing light curtains on average of once every 3 years (cost of all light curtains divided by 3 years).

4) Improve cycle initiation *Note: PSDI has rigorous installation requirements.*	d) Add additional cycle initiation pushbutton (cost for parts, mechanical and electrical install)	Approximately $200	20% reduction in cycle time (from 45 seconds to 36 seconds) = 25% increase in productivity when operating
5) Decrease time to perform teach function	e) Move teach pendant to be easily accessible f) Move perimeter guard so that robot controller is external (or all selectors are only accessible externally. g) Remove unnecessary equipment	Approximately $1000	7% reduction in downtime for teach task. Compliance with robot standard (non-compliant now)
6) Limit robot movement to decrease robot cell	h) Add hard stops (from robot manufacturer)	Approximately $250 for hard stops Approximately $3000 for new perimeter modularized guarding with multiple openings to allow ease of maintenance tasks	Compliance with Robot Standard (non-compliant now) by limiting motion. Save at least 18 sq ft if perimeter guarding were re-done (k) below.
7) Decrease LO time and improve LO ease (which also makes successful completion more likely.	i) Consolidation of LOTO points j) Manifold and quick disconnect design for quick redeployment	Approximately $5000 for parts, assembly, re-routing, installation time, development of procedures, training materials, and placarding	Improved compliance (LO is procedural, so improving ease and instructions greatly affects success) Reduction of at least 5 minutes of downtime per shift = increase of 6 parts per shift
8) Increased productivity by improving feeder productivity.	k) Add interlocked door for feeder access, with mode selection, and personal control at the door	Included in (h) above	Reduce downtime by 10 minutes per shift = Increase of approximately 13 extra parts per shift.
9) Improve efficiency of unloading	l) Add another light curtain to allow robot to function when it would otherwise be idle	Approximately $2000	Reduce cycle time by 5 seconds (from 36 to 31 seconds).= additional 16% productivity increase while operating

Summary results are based on the following outcomes from Issues 1 through 9:

1)

- Robot cable – Cost of cable approx $600, time to replace: 2 hours

2)

- Evening the floor would improve all work times by approximately 5 to 10% for tasks performed inside cell.
  - Cell is currently working at around 88% production (annual).
  - Most downtime involves people inside cell.
  - A 10% improvement on 12% downtime will reduce overall downtime by 1.2%

3)

- Angled light curtain – reduction of inventory of small light curtain - $1000

4)

- Cycle Initiation – add cycle initiation pushbutton to the left side of the fixture or use PSDI to reduce cycle time by 1 second, if applicable and allowed.

5)

- Move teach pendent – saves about 30 to 40 seconds while teaching. Total teach time is about 10 minutes. Meaning downtime whilst teaching is reduced by 7%

6)

- Clearance (1) - 18’’ x 12’ = 18 sq feet of cell space recovered
- Clearance (2) – mechanical fencing eliminated, guard switches, cabling, …

7)

- Consolidation of LOTO points means time to lock out is reduced from 3 minutes to 35 seconds. Cell is locked out on average 2 times per shift = approx 5 min of downtime / shift.

8)

- Access to feeder – extra door can reduce downtime by up to 10 minutes per shift. Part cycle time is about 45 seconds meaning a potential extra 13 parts per shift.

9)

- Unloading – extra light curtain would allow robot to continue working – reducing cycle time by 5 seconds