Lean Equipment Design

Global Common

SD-015

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1. Introduction

1.1 Purpose

This manual is intended to provide guidelines for equipment design that will enable the implementation of the Nexteer Production System (NPS) and which are consistent with the principles outlined in the Manufacturing System Design (MSD) training.

This is accomplished by:

- Showing the Relationship in Customer Program Implementation (CPI)
- Identifying the Relationship to the elements of NPS
- Reviewing Manufacturing System Design Concepts
- Identifying Guidelines for Equipment Design Characteristics
- Providing Examples to Reinforce the Concepts
- Providing a Lean Equipment Checklist

Note: Whenever you see the symbol, it indicates an idea starter to prompt further thought or consideration.

1.1.1 Relationship of Equipment Design and CPI

Nexteer CPI includes the Nexteer Product Development Process, the Nexteer Manufacturing System Design and TS-16949 requirements. The following CPI tasks are directly supported by the guidelines contained in this manual.

Manufacturing Process Plan	Develop, analyze, and approve the manufacturing sequence to be implemented.
Co-Develop Final T-Spec	Collaborate with potential machine Suppliers to develop a machine T-Spec.
Select machine Supplier	Review the quotes and select the Supplier to build the machine.
Approve Machine Concept	Ensure that the machine concept meets all technical and manufacturing system requirements.
Approve machine Design	Ensure that the detailed machine design meets requirements and approve for build.
Prepare the Receiving Plant	Complete the layout and material handling plans to prepare the plant for the new equipment arrival
Approve Machine for Shipment (MQ1)	Verify that completed machine meets all technical requirements and is ready to ship.
Approve Machine for Production (MQ2)	Verify that machine is producing a part to print after in-Plant installation.
Release Manufacturing Systems to Operations	Ensure that the manufacturing system is in place and ready for run at rate.

1.2 Review of System / Cell Design

The Nexteer Manufacturing Engineering philosophy is to design manufacturing systems that achieve a balance between Operators, equipment and material resulting in:

- Maximum utilization of Operators' skills and attention.
- Properly sized modules.
- Smooth flow of materials (no process islands).
- Minimum Total Life Cycle Cost of the products produced.

Our goal is to provide the fastest response to the customer and build to customer demand, moving material in one piece or small lots from one value-added process to another without interruption and with the least amount of waste.

Lean Manufacturing promotes product-focused plant layout rather than traditional process-focused layout. This allows equipment to be arranged to effectively utilize floor space and people in order to be responsive to customer requirements.

A fundamental principle in the design of manufacturing systems is the elimination of waste. All people involved in the equipment design, specification, selection, or build must have an understanding of the types of waste and be involved in their reduction and elimination.

Figure 1 below shows the seven types of waste, commonly found in our manufacturing processes.

IDENTIFICATION AND ELIMINATION OF WASTE		
Types of Waste	Contributors to Waste	Ways to Reduce Waste
1. Correction 2. Overproduction 3. Movement of Material 4. Motion 5. Waiting 6. Inventory 7. Processing	1. Unevenness 2. Overburden 3. Current Process Methods	1. Simplify 2. Combine 3. Eliminate

Figure 1: Identification and Elimination of Waste

1.2.2 Process Requirements

To meet this goal, Nexteer has established eight Process Requirements for Manufacturing Systems shown in Figure 2 below. Sections 2 and 3 of this manual contain guidelines for, and examples of, equipment characteristics necessary to meet these requirements.

PROCESS REQUIREMENTS	
• Flow:	Achieve 1-piece flow. Eliminate waste of transportation.
• Pull:	Produce only what the customer orders. Eliminate waste of inventory.
• Takt Time	Produce at the rate the customer requires. Eliminate waste of over-production.
• Separation of Human and Machine	Achieve full utilization of people and machines. Eliminate waste of waiting and motion.
• Built-In Quality:	All defects prevented. Eliminate waste of defects.
• Stop and Solve:	All abnormal conditions are immediately recognized.
• Respect for People:	Develop all employees to enable their contribution to improve the business. Eliminate waste of non-utilized talent.
• Continuous Improvement:	Enabling all employees to focus daily improvement efforts towards a common goal. Eliminate waste of over-producing.

Figure 2: Process Requirements

1.2.3 System / Cell Design Goals

There are several system/cell design goals that equipment design supports. These goals are:

- Flow material through the cell
- Have the ability for one person to run the cell efficiently
- Keep material outside the cell. Parts are loaded into the cell from the back of the cell
- Locate material to minimize handling/optimize presentation to Operator
- Arrange equipment to have Operator start and finish points close together
- Size equipment to minimize Operator walk distance
- Never have an Operator wait on a machine to finish cycling
- Non-cyclical work is done outside the cell by support people
- Cells should be capable of benefiting from continuous improvement
- Utilize manual load/auto-unload to improve balance and workflow

Use a work combination table to document Operator standardized work. This is the key to continuous improvements.

1.3 Review of Manufacturing System Design (MSD) Methodology

The method for creating manufacturing systems design is documented in the Manufacturing System Design (MSD) training. The MSD methodology is a team/workshop approach, which consists of the following steps:

1.3.1 Determine Module Size

Module size is based on customer requirements. The focus is on small modules to be flexible to variation.

1.3.2 Calculate TAKT Time

TAKT Time is based on customer demand. It provides Nexteer with the target rate for material consumption.

TAKT Time per module is calculated as:

$$\text{TAKT Time per module (sec / pc)} = \frac{\text{Available Operating Time (sec / day)}}{\text{Daily Volume Required (pcs / day)}} \times \text{(No. of Modules)}$$

1.3.3 Construct a Block Diagram

Construct a sequence chart identifying all steps required to produce the part and lay them out in a process flow order.

1.3.4 Prepare a Machine Balance Chart

Utilizing the sequence chart, prepare a machine balance chart to compare the cycle time to the TAKT Time.

1.3.5 Lay Out the System

Lay out the system to optimize value added activity. Arrange equipment to facilitate material flow and support the Operator with value added motions. As machines are designed, Operator panel and control enclosure locations, material racks, and cycle initiation devices are all added to the layout.

1.3.6 Prepare an Operator Balance Chart

Prepare an Operator balance chart showing the work content of each Operator. The goal is to have the minimum number of Operators necessary to perform the activity at the customer rate.

1.3.7 Determine Buffer Sizes, Lot Sizes, and Lead Time

Once the system is laid out, buffer sizes and lot sized can be determined. With this information, lead time can be determined.

1.3.8 Determine Containerization and Packaging Requirements

Determine containerization and packaging requirements for material to flow to the point of use, from operation to operation, and to the customer.

1.3.9 Error-Proof the System

Error-proof the system by considering material movement and storage between operations, part labeling, and routing of rework and scrap.

1.4 System Simulation and Mockup

A mockup is a physical 3-D or virtual model that allows people to touch it, try it out, and play "what if?" unlike a 2-D drawing. Mockups of machines, equipment and part presentation devices allow us to validate and improve the Operator-machine interface. Mockups allow cross functional teams and vendors to eliminate potential problems before building the equipment. Our goal is to identify and eliminate sources of waste through Operator input and involvement.

2. Equipment Design Guidelines

Making the transition to lean manufacturing equipment can be difficult, for it runs counter to our tendency to improve a manufacturing system by automating as much as possible and speeding up the machinery. To move material in a continuous, "balanced" flow may mean using or developing slower, simpler, less-automated machines.

To support our manufacturing system design, goals identified in Section 1.2 must incorporate the following Lean Equipment Design Characteristics:

- Meet the Ergonomic Spec.
- Make machines easy and fast to load.
- Design machines for cellular layouts.
- Make machines flexible for changes.
- Make the machine easy to support.

2.1 Meet the Ergonomic Spec

As stated in Section 1.2, it is important to maximize the utilization of Operators' skills and attention. Operators are the most important element in a lean manufacturing system. When Operator functions are value added, everyone wins. Operators should be doing value added work, not just watching equipment run. Keeping parts flowing smoothly with no interruptions is a difficult challenge. Helping the Operator meet this challenge means providing equipment with safe effective guarding and everything within arm's reach, from shoulders to waist. It also means designs that provide the Operator with immediate feedback on the status of the entire system and provide immediate knowledge of whether the work has been done right.

2.1.1 Safety and Ergonomics

In equipment design, health and safety are of primary concern. Nexteer must reduce and, if possible, eliminate ergonomic hazards in the workplace while maximizing Operator productivity. Understanding human capabilities and limitations helps us to design equipment, tools and jobs that fit the wide variety of sizes, shapes, and capabilities of our workforce. The Design-In Ergonomics Manual provides detailed guidelines for machine and tool design. Reference SD-011 (Specification for Safety Circuits), SD-012 (Design-In Health and Safety Specification, and SD-1038 (Specification for the Application of Automatic Operator-Interface Safety Design).

1. Proper Lockout Placement

   To improve productivity, safety, and serviceability, place machine lockouts together in a central location, preferably at the rear of the machine.

2. Simple but Effective Guarding

   The proper use of guarding can make both the Operator and the machine more efficient. The proper mix of hard guarding, light screens, safety floormats, sliding barriers, and shuttle mechanisms to protect, but not obstruct, the Operator during load, unload, or equipment operation is essential.

Have your equipment concept drawings include guarding, wiring, pneumatics, Operator panel, control enclosure, and cycle initiation devices to facilitate Operator interface. Equipment concepts should not be approved without these features documented.

3. Equipment Addresses All Ergonomic Issues

Equipment design can either create or solve ergonomic issues. The following list of ergonomic guidelines should be considered when designing equipment.

Selected Ergonomic Guidelines Related to Equipment:

1. Set the work height to:
   - For parts < 2 lbs. – 4" above elbow
   - For parts < 10 lbs. – level with elbow
   - For parts > 10 lbs. – 4" below elbow
2. Make reach distances within 2ft., if possible.
3. Use gravity; do not oppose it.
4. Minimize the degree of spread of parts, fixtures, and disposal points.
5. Eliminate sharp edges on work surfaces.
6. Minimize vibration levels.
7. Provide good visual access.

Consider a common work height as shown below. Using a standard workstation height often does not consider the fixture thickness. This leads to variation in work height and wasted motion in positioning parts.

Good

Bad

Design for average height in the country.

Consider other assist devices (e.g. lift tables) to position parts or containers for ease of loading / unloading.

4. Reduce Machine Noise

A lean machine needs to be a quiet machine. Operators on the plant floor need to hear and converse with each other (and with maintenance and other support staff areas) constantly to solve production problems and implement improvements in the process. Reference SL 1.0 (Sound Level Specification).

- Air / Oil is less noisy than hydraulic.
- Soundproof chutes – (part obtain / part disposal).
- Limit height of fall and angle of gravity chutes.
- Plexiglass and acoustical matting on drop shelves.
- Utilize reduced noise compressed air nozzles.
- Enclosures around part orientators / selectors.

5. Provide Necessary Visual or Audio Controls

   To maximize the use of the Operator's skills and attention, the Operator shall be kept informed. The equipment must have the necessary features to accomplish this.

- Send output of machine to an Andon System (see figure to the right). The key to an Andon System is to aid in communication and keep the line running. Operators use the system to call for help. Team Leaders, Maintenance, and Management use the system to support the Operators.

- Put cycle counters (fixed and reset-able) on machines to monitor tool changes and need for maintenance.
- Use downtime clocks and TAKT Time clocks to provide instant information and help keep the pace.
- Display fluid levels.
- Limit the size of flow-racks, or paint lines on them to indicate proper level of material, and control overstocking or overproduction.
- Use light towers on machines as another form of Andon (see figure at right). In this example, the Operator is able to call for help with a switch.
- Post simple, straightforward graphic visual instructions in front of the Operator at the workstation (see figure at right). Design a space to contain this information. Hint: posting the Standardized Work Instruction (SWI) reinforces the standardized work and supports continuous improvement.
- Use a Human Machine Interface (HMI) panel to display important information. The HMI panel is typically a touch screen used for machine control, fault diagnostics, and machine status.

2.2 Make Machines Easy and Fast to Load

Moving material in one-piece flow in smaller customer focused modules gives us both a challenge and an opportunity. One-piece flow demands higher uptime to get the needed throughput. More and smaller modules lead to greater TAKT time and the opportunity to slow machines down. Simplified equipment reduces both investment and downtime. Simplified equipment may also increase the number of suppliers.

Our thought process needs to start with an understanding of how to build just one. As we speed things up and add automation to the basic process, we add complexity. All complexity starts with air and power. Putting the complexity into the tooling, rather than the machine, can reduce cost and improve flexibility (e.g. drill, chamfer, and counterbore on one tool instead of three (3) separate machines). When automation is required, don't use excessive electronic controls when simple mechanical devices will suffice (cams, pulleys, etc.) offering less downtime and easier maintenance and trouble shooting.

2.2.1 Proper Use of Automation

Understand what needs to be controlled and how best to use people for value added tasks and automation only where necessary. An example might be in a welding operation, where an Operator may be capable of controlling the speed of the welder, but the control of the wire feed needs to be electronically monitored and controlled. To be less automated means to focus on automating the "right" things. Typically, when discussing "less automated," we are considering shifting from semi or full automation processes where there is little or no human involvement other than filling parts containers, tool changes, changeovers, etc., to more manual work where the Operator is more involved in loading, unloading, transferring, and visually inspecting parts. Minimizing the use of automation reduces capital.

1. Levels of Automation

Shigeo Shingo (one of the key architects of the Toyota Production System) in his book "A Study of the Toyota Production System" wrote about the various steps in automating equipment. Below are the six steps or stages (modified slightly) of Automation Evolution:

Stage 1 – Manual load, manual process and manual unload. An example is the tightening of a fastener with a basic wrench.

Stage 2 – Manual load, automatic process and manual unload. The Operator loads the part and initiates the cycle. The Operator stays with the machine during the cycle. Upon completion, the Operator unloads the part and monitors for defects.

Stage 3 – Manual load, automatic process and manual unload. During the process, the Operator moves and runs other equipment. The Operator loads the part and initiates cycle; the Operator does not stay with the machine during the cycle. The equipment makes the Operator aware of problems.

Stage 4 – Semi-automatic, manual load, automatic process and automatic unload. The equipment sends out a warning alarm when a defect is sensed.

Stage 5 – Pre-automation. Automatic load, automatic process and automatic unload. The equipment stops in the event of failure and the Operator corrects the fault in station.

Stage 6 – Automation. Automation includes entire automatic processing, trouble detection, and correction.

As we progress through the different stages of automation, notice how the Operator is separated from the equipment to a larger and larger degree. The transition from Stage 2 to Stage 3 frees up an Operator during a large percentage of the cycle. However, as you progress through to the other stages, your labor savings increase to a lesser degree. The figure to the left shows this relationship graphically.

Associated with moving to more automation is additional investment cost in equipment too; sense errors/defects, orient correctly, convey, engage or disengage automatically. Automation for these tasks typically adds little or no value and leads to more indirect support (Engineering, Maintenance and Training) and more potential downtime. The figure to the left shows this investment cost relationship graphically.

When justifying the cost of increased automation, look at what we are really saving by doing so. The additional cost to fully automate can be very significant compared to the small percentage of an Operator's time (typically 10%) saved.

2. Manual Loading

Manually loading takes advantage of the human ability to coordinate eye / hand movement and tactile feel during part loading.

- Loading parts from part bins allows the Operator to orient them at the same time. Auto loading requires that parts be oriented before loading.
- Eliminate all obstacles between part bins and machine nest.
- Chamfer nests to allow ease of placement of parts and reduce wear.

3. Manual Unload v. Auto-Eject

Auto-eject is a machine feature that is beneficial when an Operator is running multiple processes and leads to the elimination of a handling step. When parts are large and can't be picked up with one hand, the Operator must put down the part they are attempting to load in the machine and remove the part from the fixture.

When designing a machine, we should start with a concept of a simple auto-unload. Concern over part quality/potential damage sometimes adds to the cost and complexity of auto-eject and may make it undesirable.

Design machines that include auto-eject of completed parts toward the Operator side of the Machine in the direction of part flow whenever possible.

Auto-eject devices should maintain part orientation. This helps the Operator when loading to the next machine or fixture.

2.2.2 Use Supplier Standard Machines ("Off-the-Shelf")

Purchasing Standard Machines ("off-the-shelf") can save us time and money. When equipment suppliers build custom machines, delivery times are longer, and costs are generally higher. All machines, even "off-the-shelf," must meet all local, national, and international standards.

Equipment and suppliers are often asked to "customize" machines to use a certain set of components, both mechanical and electrical. While this helps Manufacturing Plants standardize and reduce the number of spare parts inventoried and reduce training requirements, it can add significantly to machine cost and delivery times.

Continue to work with purchasing and machine Suppliers to make the Nexteer machine a shelf item. This implies Nexteer can commonize within Nexteer from Plant to Plant, and division to division.

When "off-the-shelf" is not possible, ask yourself:

- What extra is Nexteer paying for?
- Does it provide a strategic advantage?
- Will it conflict with standardization?
- Will it require additional training or service personnel?

2.2.3 Eliminate Waste in Equipment

In the Manufacturing System Design methodology, we learned to break down the Operator tasks and determine where Operators are adding value using the Operator balance chart. In the machine balance chart shown below, machine cycle time, as indicated in the green checkered highlighted area of each stacked bar, is usually assumed to be adding value. In this example, the second operation (leak test) is a very expensive machine that runs much faster than required and then waits. The Leak Test adds no value. Where possible, eliminate such testing and use process monitoring and control to produce good parts and verify with audits. If it must remain, can we use more cycle time and reduce investment? In the fifth operation (press/weld), the machine cannot produce a part fast enough to meet TAKT Time and may have to be duplicated, or split into two machines, with shorter cycle times.

Figure 3: Machine Balance Chart

Further analysis of the cycle time in the fifth operation, as shown in the expanded "machine time" stacked bar, shows waste in the machine cycle. During only 4.0 seconds of the 21 second machine cycle is the machine adding value. This value is indicated by the solid green areas in the expanded stacked bar. If the part was loaded at the point of operation and the press and spin-weld operations could take place in one position, then 9 seconds of time could be eliminated. By "eliminating" and "combining" these steps, we have reduced machine cost and complexity.

Each non-value-added machine motion adds machine costs, maintenance cost and increases downtime. Investment is higher, controls cost/complexity are greater. Examples 1 and 2, in Section 3, show further analysis of machine cycle time for value added content.

- Loading at the point of operation must be considered if it can be done safely.
- When loading cannot be performed at the point of operation, raised barrier guards eliminate pinch points. Eliminate variation due to moving critical fixturing on slides and shuttles.
- Small, 2-position rotary dials can act as an auto-eject mechanism while separating the Operator from hazardous areas. Use of this added mechanism must be balanced against the benefits of auto-eject.

2.2.4 Select Proper Cycle Initiation

To make the Operators more efficient, they must be able to initiate the cycle and move to the next operation with minimal or no wasted motion. Equipment can safely be started with a variety of devices, in many configurations, when done in conjunction with guarding. Some of the devices used include whisker switches, palm buttons, opto-touch switches, light curtains, and safety floor mats. Reference SD-007 (Approved Components List).

Whisker Switch

Palm Button

Light Curtain

Two (2)-hand control is a configuration where an Operator must use both hands simultaneously to operate buttons or switches continuously to maintain motion until a hazardous condition is eliminated. An example of this type of design is a mechanical power press.

Two (2)-hand cycle start initiation is a configuration where an Operator must use both hands simultaneously to operate buttons or switches momentarily to initiate machine motion when a secondary safety system is present. An example of this type of design is any machine required to meet Brazilian NR12 specifications.

One (1)-hand cycle start initiation is a configuration where an Operator, in conjunction with a primary safeguard, can hit a button or switch while walking away from the machine. Opto-touch buttons are typically used in these applications.

Presence Sensing Device Initiation (PSDI) is a configuration that uses part presence and the light curtain to initiate machine cycle. With this configuration, the Operators simply exit the light curtain or close an interlocking door and the machine cycle is automatically initiated.

Another configuration uses an interlock device in conjunction with a slide or door. With this configuration, the Operator pushes a slide into the machine, or closes the door. The closure of the device with the interlock initiates the machine cycle.

- Place cycle initiation switching devices along Operator walk paths and within reach.
- If cycle time is less than 3 seconds, the Operator(s) will not be able to run multiple machines. In this case, two-hand control may be more cost effective.

Continuous improvement activities or changing volume requirements will often drive changes to cell designs. Initiation methods should be designed to be easily movable to accommodate changes.

2.2.5 Support Standardized Work

The equipment design should make it difficult to deviate from standardized work. For example, when operations require parts to be picked from a container, don't allow space for parts to be stockpiled, mixed with other parts during changeover, and/or dropped or damaged.

Have machine design include a location to post standardized work.

Avoid areas which might accumulate "extra" inventory or other materials contributing waste and poor workplace organization. The figure on the right shows no room for defective parts, pop cans, or other waste.

2.3 Design Machines for Cellular Layouts

The benefits of one-piece small lot flow are:

- Faster lead time (customer responsive)
- Lower inventory (improves cash flow)
- Higher quality (quicker error detection)
- Shorter Operator walking distances
- Easier visual management

To support one-piece flow, machines must be close together so that Operator walk distances are minimized. If walk distances are large, Operators will be tempted to batch parts and store extra inventory between machines.

2.3.1 Narrow Effective Width Machines

The machine should be kept to a width slightly larger than the width of the smallest part dimension. This reduces walking distances and material movement as well as allowing material to be moved to the point of use from behind the machine. Keeping the control enclosure low at the rear helps keep the center of gravity low which helps in machine relocation and allows space to move parts into the work area from behind the machine.

Pull down (below left image) or slide out (below right image) Operator panes can reduce effective machine width.

Service areas should be at the back or front of the machine with no side access required. Side access requirements force machines further apart, increasing effective width.

Some machine suppliers are beginning to make trapezoidal (⏢) shaped machines to reduce effective width to the Operator interface. This is effective at the curve in a U-sell.

2.3.2 Machine is Open on the Sides

The use of C-Frames eliminates wasted motion of moving parts around posts and reduces possible part damage due to added part handling.

2.3.3 Avoid Large Batch Type Off-Line Equipment

Try to utilize multiple smaller machines incorporated within the cell (e.g. painting, washing, heat treating etc.) when possible. This eliminates waste in excess inventory, travel distance and facilitates one-piece/smaller lot flow. Large batch processing equipment, often referred to as monuments, are typically inflexible, lengthy to change over and difficult, if not impossible, to move or relocate. Furthermore, material does not flow well through this equipment.

Good Bad

2.3.4 Review Multiple Operation Equipment

Typically, simple workstations are often linked into large dial machines or transfer lines. The linking of these "stations" with automatic material handling is often done to save material handling labor and to meet short cycle times. As we move to smaller manufacturing cells with greater TAKT times and as we prepare machine and Operator balance charts, we must review the value-added workstations to see if they should be combined or kept separate to better utilize the Operator. Linking these stations together would not be an issue if uptime and change over time were 95% and 10 minutes, respectively.

Example 5, in Section 3, shows where a two (2) operation workstation was split into two separate workstations.

Example 10, in Section 3, illustrates a case where five (5) complex machines (each having one value added station) linked by conveyors were combined into one machine with multiple stations. To accomplish this and still meet our reliability goals, one operation was eliminated, and others were simplified.

2.3.5 Manual Backup

The viewpoint of production and the machine's uptime must be considered when selecting and designing equipment. When an automated system or an automated load and unload device is used, design the machine or system so it can be operated manually. When designing the machine for manual operation, ensure the Machine Risk Assessment is properly documented.

Determine during the design phase how the automated portion can safely be by-passed, if necessary, and what additional tools are required to perform the operation manually. Make sure that the workplace is designed to include the manual back up tools. It is also important to document the manual method with set-up instructions, process checks, preventative maintenance plans, and Operator instructions. The backup method must be maintained and checked periodically to ensure that it will function if required.

Back up robotic welding equipment with semi-automated MIG welders that trained Operators within the cell can use.

Hang manual screw / rivet guns on an automatic station so Operators can manually drive screws / rivets if the automatic station experiences problems.

2.3.6 Pacing Mechanism

A pacing mechanism is required to let the Operator know whether the rate of production is being maintained or not. Letting the Operator set the pace is the least favorable method of pacing, since they don't have an actual indication of how well they are doing, and other cells may be held up waiting for parts. A better pacing method would be a display counter. This can be a real time display of parts produced vs. required. Another method is with a TAKT time

countdown timer allowing Operators to pace their work throughout the cell, like the 24-second shot clock in the NBA. A method without a counter would be to automate the final machine in the cell, so it controls the pace. In all cases, it is important to tie the pacing mechanism to the Andon Board to allow real time monitoring of the system.

2.3.7 Distance Between Machines

Machines should be placed less than 12" apart or as close to each other as practical to minimize walk distances and the use of floor space. Over the course of an 8-hour shift, walking distance adds up as shown in Table below.

WALKING TIME-TABLE			
Steps	Feet	Seconds	Miles / 8 hr. Shift (@ 30 sec Cycle Times)
1	2.5	0.6	0.43
2	5.0	1.2	0.85
3	7.5	1.8	1.28
4	10.0	2.4	1.70
5	12.5	3.0	2.13
6	15.0	3.6	2.55
7	17.5	4.2	2.98
8	20.0	4.8	3.40
9	22.5	5.4	3.84

Cell width should be a maximum of 4 feet as shown below.

Good Bad

2.3.8 Right-Size Electrical / Mechanical Components

Design to meet the requirements (no-overkill). Don't pay extra for what we don't need. It drives equipment size larger and cost higher. For example, purchasing a larger size control enclosure to have "spare space" may make it more difficult to bring material in from behind the machine because now the control enclosure is in the way.

- Use appropriately sized PLC Controllers for the application.
- Use Remote I/O where practical.
- Wire directly in I/O modules to eliminate redundant terminal strip.
- Use IEC components properly sized to help reduce control enclosure / Operator panel size.
- Keep the spare control enclosure space less than 10%.
- Limit position sensors to only what is required for proper machine function.
- Consider right sizing the hydraulic system to minimize floor space, actuator size, and utility usage understanding Nexteer's 3000 PSI maximum pressure limit.
- Use pneumatics rather than hydraulics whenever possible.
- Use an arbor press instead of pneumatics if deemed necessary.
- Use a 2hp motor instead of a 5hp motor if that is all that is needed.

2.3.9 Minimize Use of Conveyance

Conveyors must be used carefully, or they can be a source of much waste. Our first choice for moving parts between operations within a cell is manually by the Operator. In cases where parts are heavy and Operators need an assist device, non-powered conveyors should be considered to avoid cost, complexity and potential downtime. There are cases, such as vehicle assembly, where motor driven conveyors must be used.

- Use standard modular conveyors when they are required. End flanges that can accept sprockets, or be bolted to the next section, add flexibility in conveyor length and layout.
- If powered conveyors are used, consider variable speed to adjust for demand (TAKT Time) changes. This allows a way to pace operation.
- Powered conveyors can be continuous motion. This allows the Operator to continue working on a part and not have to hurry when a part is about to "index" out of the workstation.

Non-powered conveyors can use gravity to assist in part movement as shown in the figure below.

2.3.10 Simple Part Presentation Devices

Part presentation devices should be reusable, re-configurable and/or flexible. The illustration at right shows a part presentation rack reconfigured to present fewer parts with a chute to dispose of empty containers. Part presentations devises should stand-alone so they can be moved to get access to the sides of machines. Part presentation devices should be designed to get parts to point of use from behind the machine, as well as get empty containers out of the cell.

Integration of part presentation devices with machine base and tooling should occur before guarding, piping, wiring, Operator panel, and control enclosure location are finalized.

Part presentation devices should provide FIFO (first in / first out).

2.4 Make Machines Flexible for Changes

Equipment must be as portable and flexible as possible. A goal in flexibility is to be "in sync" with the customer, able to react to changes in volume, product design or delivery timing. Remember, we want the ability to run "every part every day" if the customer requires it. Portable equipment makes relocation possible with minimum cost, allowing for continuous improvement in manufacturing system design. All equipment will be moved at least once in its lifetime (when relocated from the machine builder to the production area). The goal of machine relocation is good part to good part in 4 hours or less. These efforts will also make installation and qualification easier (quicker to market).

2.4.1 Design Equipment to be Self-Contained

Self-contained equipment has control enclosures, hydraulics, cooling systems, chip collection, leveling, vibration isolation, etc. all on one base. Self-contained equipment is easier to move because no rewiring or piping is required.

A next best alternative to having the control enclosure on the same base is temporary control enclosure mounting points for moving. See figure below.

2.4.2 Provide for Flat Floor Mounting

Equipment should not require any floor preparation such as pits, foundations or catch basins. Relocating equipment that is part of the building is difficult and expensive, if not virtually impossible. The elimination of pits has an added environmental advantage. Pits can fill with hazardous material and leak through the slab into the ground. Since these leaks are not visible, they are often not repaired immediately.

2.4.3 Avoid Fastening to Floors

To reduce relocation time, do not fasten equipment to floors unless it is necessary. (e.g. tight tolerance, vibration, narrow footprint, top heavy conditions, etc.). Lockable wheels or Teflon footpads may be evaluated to make it easier to reconfigure machines that are not lagged down.

2.4.4 Use of Fork Pockets and Casters

Design equipment with fork pockets or casters for ease of relocation. When using casters, use lockable wheels to keep machine in position.

Fork Pockets

2.4.5 Use Flexible Drops and Quick Disconnect Utility and Ventilation Connections

Keep utilities and ventilation above ground using flexible drops and quick disconnects where possible. Avoid steam and natural gas. Flexible electrical connections will be done only as allowed by local applicable standards.

- Strain relief devices should be used to tie hose and cable to machine to prevent accidental strain on them.
- Enough extra line for movement of equipment realignment of service without disconnecting shall be provided. (Note: In the United States, National Electric Code requires vertical flexible drops).
- Only qualified personnel shall install or move equipment, and all power shall be shut off to avoid equipment damage or personal injury.
- Refer to local equipment controls group for further details and examples of Flexible Utility connections.

Figure 4: United States Flexible Electrical Power Drop Example

Figure 5: United States Flexible Pneumatic (Air) Drop Example

2.4.6 Support Quick Change-Over

Machines need to be capable of changing over rapidly from part-to-part in order to meet dynamic daily customer demands.

Changeovers steps are sometimes called elements. Internal elements are those steps performed while the machine is down. External elements are those steps performed before stopping the machine and after starting it back up. Rapid changeover is accomplished by transferring all internal setup elements possible to external setup elements and by standardization and elimination of waste. Quick change is extremely important to system flow in batch processes in order to fill downstream pull signals while holding low inventory levels. Changeover participants must have responsible and standardized tasks. Standardized tasks support continuous improvement.

The cell or process must have the ability to run every part every day and quick changeovers help to make this realistic. Tooling and fixtures shall be designed to provide minimal downtime, tool setup, required adjustments and have all dimensions on mean or at new tool starting dimension points. Fixtures shall have clearly indicated and positively located setup positions and enable changing equipment over without the use of hand tools. This is possible through workplace organization and the use of clamps, toggles, lock pins, etc. Model changeover should be less than the cycle time. The NPS Benchmark for model changeover is less than the cycle time for assembly lines and less than 5 minutes for machining processes.

Use rollover or interchangeable fixturing.

2.4.7 Avoid Adjustments

Design controls, tooling and fixturing with no adjustments or "fine-tuning" required. Create pre-determined locations or settings with fixed positions. Don't require Operator judgment and trial runs to see if parts are good. This saves setup time (increasing machine operating time), reduces or eliminates buffers of inventory (cost) and eliminates scrap (cost).

Typically, few machine builders know how often or how many different tools or dies a manufacturer plans to change, so little effort is put into simplifying the process.

Shigeo Shingo in his discussion of Single Minute Exchange of Dies (SMED) provides the following examples of ways to avoid adjustments:

- Least common multiple system – If a process requires adjustment with a limit switch at any one of several settings, place a switch at each position connected to its own power switch. Then, when a different setting is required, only that switch is activated.
- Drilling – When drilling to multiple depths for different part sizes requires different stop settings, provide pre-set stops for each depth.
- Machining – When multiple jigs are required to position parts for different tooling, rather than adjusting each time one is needed, put all jigs on a common rotating fixture with an insert pin or locking device to locate the required position.
- Fabricating – When fabricating different sized parts is based on the setting of a stopper positioned by an adjustable guide screw, replace it with a fixed stopper and multiple positioning jigs.

2.4.8 Design for Flexibility to Future Changes

Product designs change. Schedules change. Similar products are often introduced so now, instead of one part, there is a "family of parts" to run. The equipment must be designed to anticipate all of these situations. Some of the ways to achieve this were discussed earlier in this Section, such as quick change over and eliminating adjustments. Another example, for a part that has two or more distinct components or operations in the "family", would be to add extra machines that can be quickly moved in and out of the cell during change over. They could also be left in place, assuming this does not disrupt the flow in the cell and turned on or off as required. The goal of flexibility is to have level operating costs with any size family of parts and at any volume level.

2.5 Make the Machines Easy to Support

Equipment designed to have zero defects supports one-piece flow by reducing variation in the system. One-piece flow also aids visual inspection. Try to detect a defect before adding additional value that will be wasted.

2.5.1 Provide Simplified, Built-In Error Proofing

Error proofing methods must be utilized to eliminate potential sources of failure found in Failure Mode Effects Analysis (FMEA). Error preventive fixturing and color coding (not always as effective) are preferred over functional testing.

Design fixtures and machines to detect abnormalities (such as incorrect orientation or mixed parts) and to stop and signal automatically whenever they occur. Part presentation could also be utilized to assist in error proofing. The system should be designed to assure bad parts do not flow down the good part path. This will prevent the waste that would result downstream by working on the defective part.

2.5.2 Workplace Organization

A place for tools, gages, etc., should be established for easy Operator access. Searching through a drawer full of tools wastes time and reduces productivity.

Good Bad

Use an outline of each tool or gage to make it obvious when one is missing.

2.5.3 Consider Whether to Have machine Detect Error, Reject Part and Alert Operator

Design equipment to detect errors and ensure that machine rejected parts are contained properly and removed from the process. The equipment must alert the Operator when this occurs and require a “non-normal” activity such as releasing the rejected part.

Sometimes a chute with a switch is used to ensure the rejected part is not passed forward.

2.5.4 Boundary Samples

Boundary Samples must be provided with machines. "Known Bad Master" parts must be provided to allow the Operator to verify that all test or verification systems are functioning properly at an interval specified by the Manufacturing/Quality Organization.

- "Known Bad Master" parts should be readily identifiable (i.e. RED in color or identified in some manner such that they will not be inadvertently shipped to the customer).
- "Known Bad Master" parts should have a permanent storage location along with instructions for the proper sequence of operations to perform verification steps.

2.5.5 Reliable and Maintainable

In order to support one-piece flow, equipment must be reliable and maintainable. Slower, simpler machines designed to module TAKT times should be more reliable and therefore have less down time. Should the equipment fail; however, it must be designed such that recovery from failure can be rapidly accomplished. Equipment must be designed for quick diagnosis and fast repair

MACHINE P.M. SCHEDULE	1	2	3	4	5	6	7	8
CHANGE AIR FILTER		✓						
CHANGE LIGHT BULBS					✓			
CHANGE BELT			✓					
CHANGE COOLANT					✓			
CHANGE OIL FILTER					✓			
CLEAN OUT SUMP		✓		✓				
ADJUST TENSION				✓				
TIGHTEN GIBBS		✓						
INSPECT WAYS								
MOTOR SIGNATURE			✓					

2.5.6 Equipment Designed for Planned Maintenance

The goal of Planned Maintenance is to ensure equipment and tools are ready and able to run when needed, which in turn lowers plant costs. It includes scheduled and unscheduled maintenance programs with strategies for responding to machinery and equipment failures. Design the machine so scheduled maintenance can be performed at a time specifically planned to minimize interruptions in manufacturing and assembly (e.g. during lunches or breaks). The planned maintenance should cover daily, weekly, monthly, quarterly, and annual tasks as required.

Design equipment with the owner / operator concept in mind. Owner / operator is a concept whereby the Operator of the machine assumes the role of owner with responsibility for the condition of the equipment. At a minimum, equipment should be designed so that Operators can identify problems such as noises, vibrations, oil leaks, and low fluid levels and notify maintenance prior to negative impact on uptime.

2.5.7 Equipment Designed for Accessibility

Design the machine for easy access to control enclosures, hydraulic units, and pneumatic valves by providing:

- Easily removable guarding with a tool.
- Place all serviceable components behind machine for unobstructed entry after installation.
- Clearance for tools.
- Unobstructed view of components.

2.5.8 Equipment Designed for Maintenance Diagnostics

If diagnostic devices are required, they should be kept simple to reduce complexity and controls requirements, be built into the equipment, and include:

- Visible and/or audible indication of maintenance required.
- Self-diagnosis and correction instructions.
- Identification of faults to component/module level.
- Capability for storing performance data.
- Output format compatible with “off-the-shelf” software.

Plexiglass cover or housings on components permit quick visual check without disassembly.

Use LED’s whenever possible to help keep the diagnostic display small and simplistic.

When more complex diagnostics is required, utilize human machine interface for diagnostics.

2.5.9 Consider Proper Use of Standardization

Design equipment to use components that are commercially standard, readily available, and common from machine to machine. This includes the use of commonized fasteners and tools. This will also greatly reduce spare parts inventories and associated carrying costs.

Pay attention to final destination of machine and what components are available there.

1. Information Management

A key to equipment maintainability is the availability and understanding of the necessary information. Once a master set of operating parameters is established, one needs to be quickly informed of an abnormal condition and be able to return it to normal. This can be facilitated through:

- Match marking fasteners.
- Marking directions of rotation and flow.
- Contents of cabinets and control enclosure labeled.
- Dirty filter indication and replacement part number labeled.
- Put a machine Manual on the machine.
- Identify mechanical and electrical home position for diagnostics troubleshooting.

2. Use of Modular Components

Equipment should be designed into physically and functionally distinct units to facilitate their removal and replacement (e.g. gear box, circuit board, drive unit). Although typically thought of in terms of electrical components, this can be applied to mechanical elements as well. Fixing circuit boards, gearboxes, etc. often requires specialized skills, tools, and training. Replacing an entire unit or module saves time and reduces the need for special training.

Use quick disconnects for utilities whenever removal or replacement will be facilitated. Also, use standard vs. specialized electrical connectors. Be careful not to “overkill” the use of quick disconnection and waste money.

2.5.10 Simplify Gaging

Keep gaging simple and flexible (e.g. surface plates, dial indicators, etc.). Try to incorporate gaging into the downstream operation fixturing.

3. Equipment Design Examples

The examples of equipment provided in this Section reflect the areas discussed in Section 2. Some examples show violation of the principals outlined in the guidelines and are marked as a (-). Other examples show areas of conformance (+) with the guidelines. A (?) indicates questions that cannot be answered with the information available.

Examples ToC

- Example 1: Value Added Analysis of a Sixteen Station Rotary Table Welding Machine
- Example 2: Value Added Analysis of a Two Operation Press/Weld Machine
- Example 3: Analysis of a Small Lot Size Wash Operation.
- Example 4: Analysis of a Flexible Weld Station
- Example 5: Analysis of a Workstation Replaced by Two Separate Stations
- Example 6: Analysis of an Assembly Machine
- Example 7: Analysis of a Mold Machine
- Example 8: Analysis of a Stake and Grease Machine
- Example 9: Analysis of a Bearing Press Machine
- Example 10A: Analysis of Five Separate Final Assembly Operations (Before)
- Example 10B: Analysis of Combined Final Assembly Operations (After)

3.1 Example 1: Value Added Analysis of a Sixteen Station Rotary Table Welding Machine

Description: Platinum Center-wire welding machine in Spark Plugs at Nexteer-E. This machine is a bowl fed rotary table that runs at 40 parts/minute. The Operator stocks and tends two machines. Parts are loaded to the nest at Station 1. Parts are lifted from the nest in Stations 4, 6, 8, 10 for processing and then dropped back into the nest. Only stations 6 and 8 add value to the product.

VALUE ADDED ANALYSIS:

$$\frac{.6 \text{ sec}}{1.5 \text{ sec x 13 stations}} = 3\ \%\ \text{of time in machine is value added}$$

$$\frac{\$62\text{ k}}{\$318\text{ k}} = 19.5\ \%\ \text{of machine cost is value added}$$

3.2 Example 2: Value Added Analysis of a Two Operation Press / Weld Machine

Description: Press/Spin Weld operation in Modular Fuel Assembly at Nexteer-E. The Operator pre-assembles parts while the machine is running, unloads the complete part, loads the nest with next assembly, and initiates the cycle. The Operator stays at this station. The breakdown of the machine cycle is shown below. The value-added portion of the machine cycle is shown in green.

3.3 Example 3: Analysis of a Small Lot Size Wash Operation

Description: Washer used in manufacturing of Monotube Dampers. Part of the Monotube Damper Tube Cell at Nexteer-C in Dayton. In this operation the Operator walks between 8 machines. The TAKT Time is 35 sec. The wash time is 240 sec. The washer cleans both the OD and the ID of the tubing. This is a modified version of a washer that is used in the baking industry to clean bread pans. Operator manually slides basket, containing 10 tubes, into the washer and initiates cycle. Door closes and parts are washed and dried. Wash cycle will not start if basket is not properly located (error proofing).

+ Manual load & unload
+ 10 pc flow
+ High uptime
+ Replaced 3 washers
+ Self contained
+ Flex drops

Washer Station – Monotube Damper Tube Cell

Layout:

Part Drawing:

3.4 Example 4: Analysis of a Flexible Weld Station

Description: Welder used in manufacturing of Monotube Dampers. Part of the Monotube Damper Tube Cell at Nexteer-C in Dayton. In this operation the Operator removes the previous part, places the tube and ring in the fixture and initiates cycle while walking to the next machine. The TAKT time is 35 sec. The cycle time is 5 sec. The welder can weld either the ring (as shown) or a bracket. The tube rotates into the welder. The weld occurs. The tube ring assembly then rotates back to the load/unload position.

Weld Station – Monotube Damper Tube Cell

+ Flex drop/quick connect
+ Easy initiated cycle start (whisker switch in direction travel)
- Operator panel adds to effective width
+ Mounting Ring is loaded at point of operation
- Tube is loaded onto a sleeve that rotates automatically to point of operation
- TAKT Time >> cycle time

Layout:

Part Drawing:

3.5 Example 5: Analysis of a Workstation Replaced by Two Separate Stations

Description: Liquid Cooled Generator Assembly Cell. Original workplace has two fixtures on single base. Stake Station has shuttle to move part under stake head. Parts are placed at the workstation as shown in the original layout. Revised concept allows for material delivery from behind the workplace, out of the Operator walk path.

3.6 Example 6: Analysis of an Assembly Machine

Description: Steering Upper Head assembly machine at Nexteer-S, Plant 6 in Saginaw. In this operation, the Operator walks between three machines. The TAKT time is 59.2 sec. In this workstation, the Operator places the yoke assembly from the previous operation on the fixture, places the housing over the yoke assembly, and places the inner race, inner race seat, upper bearing spring, spring retainer, and retaining ring. The Operator then places a thimble over the yoke assembly. The press is cycle started and the Operator waits three seconds, unloads, and places the part to the conveyor which feeds the next operation.

- Operator panel adds to width
+ Narrow base
+ Load at point of operation
- Wide control enclosure
- Position of valves on side. May be OK in this application if part rack is moveable
- Small parts containers can't be supplied from behind due to control enclosure size/placement
- Machine base wider just to hold small parts

Layout:

Part Drawing:

3.7 Example 7: Analysis of a Mold Machine

Description: Overmold machine molds plastic onto solid shaft and yoke assembly. Part of the Intermediate Shaft Cell at Nexteer-S, Plant 7 in Saginaw. In this operation, the Operator walks between two machines. The TAKT time is 15.0 sec. At this workstation, the Operator unloads the previous part, loads the part, initiates cycle by a wobble stick, and moves to the next machine. The machine cycle is 8.0 seconds including load time.

+ Cycle initiated by wobble stick
+ Load at point of operation
± Slide out operator panel adds some width but is better than turning the operator panel 90°
+ Narrow effective width (narrow end faces operator)
+ Control enclosure located at back

Layout:

Part Drawing:

Plastic To Completely Cover Splines Of Steel 10 Tooth Solid Shaft.

3.8 Example 8: Analysis of a Stake and Grease Machine

Description: Intermediate Shaft Stake torsion assembly and Grease operation. Part of intermediate shaft cell at Nexteer-S, Plant 7 in Saginaw. In this operation the Operator walks between two machines. At this workstation, the Operator unloads the previous part, loads the next part, initiates the cycle via the light curtain, and moves to the next machine. The TAKT time is 15.0. The machine cycle is 3.0 seconds including load time.

+ Light curtain initiates cycle
+ Load at point of operation
- Operator panel adds to effective width
+ Control enclosure in rear
- Control enclosure adds to width
+ Right amount of information for operator/maintenance on operator panel, specific faults listed
+ Disposal chute is interlocked
- Hard wired
+ Self-contained machine
- Not C-Frame

Layout:

Part Drawing:

3.9 Example 9: Analysis of a Bearing Press Machine

Description: Press Bearing onto Drive Shaft. Part of Pump Assembly Cell at Nexteer-S, Plant 3 in Saginaw. In this operation, the Operator walks between 10 machines. The TAKT time is 78 sec. The machine cycle time is 5.9 sec. The Operator manual loads a drive shaft and bearing, picks up a completed assembly from the previous cycle and hits the whisker switch. The part is automatically unloaded. The bearing is fed to the Operator from the back of the machine. The Operator is protected by a light screen.

+ Narrow effective width (small operator panel within width)
+ Flex drops for both electric and air
  The part is automatically unloaded
+ The bearing is fed to the operator from the back of the machine to the point of use
+ Control enclosure in rear
+ Self contained
+ Fork pockets
+ No side access required
- TAKT Time >> cycle time

Layout:

Part Drawing:

3.10 Example 10A: Analysis of Five Separate Final Assembly Operations (Before)

Description: Original design of Hydraulic Element Assembly/ Follower (HEA) Cell. Part of the Hydraulic Valve Lifter process at Nexteer-E in Grand Rapids. TAKT time is 1.97 sec. Machine cycle times are shown below. After the clipper operation, the cell contained five (5) separate machines for final assembly, ultrasonic inspection (2), gage checks, and oil fill. The parts flow between machines was performed by utilizing tracking and rotary storage tables. Inherent in this process was a majority of the test and inspection being done on a finished assembly.

3.11 Example 10B: Analysis of Combined Final Assembly Operations (After)

Description: The new design for the Hydraulic Element Assembly (HEA) Follower cell replaced five (5) separate machines with one (1) machine that combined component gaging, final assembly, assembly inspection, and eliminates oil fill as a separate operation by doing all of these functions while the assembly is submerged in oil.

Components gaging and assembly of the Hydraulic Element Assembly Follower is 50% of the new machine's functionality, with ultrasonic inspection at 15% and final assembly gaging being the remaining 35%. The combining of the machines, and revolution in parts conveyance and storage systems has reduced Operator requirements by 50% floor space utilization by 60%, and investment by 88%.

CURRENT LAYOUT

DATA SUMMARY

Investment*	$ 350 K
In Process Inv.	13,800 pcs
Leadtime	98 min
Headcount	1.5/shift
Takt Time	1.97 sec/pc
Total Machines	3
Delivery	6 mo.
Part Travel:	
Follower	20 ft.
HEA	35 ft.

APPENDIX A. Lean Equipment Checklist

A.1 System Design

A.2 Meets the Ergonomic Spec

A.3 Easy and Fast to Load

A.4 Designed for Cellular Layout

A.5 Flexible for Changes

A.6 Easy to Support

LEAN EQUIPMENT CHECKLIST

1. SYSTEM DESIGN

DESCRIPTION	REFERENCE	ANSWERS			COMMENTS
1.3 Has a Lean Manufacturing Workshop been performed on this process? Date completed? _____	May be called Manufacturing System Design Workshop. Frequent use of full scale workstation models.	Yes		No	
1.3.2 What is the TAKT Time (seconds)?	Scheduled Time (Available Time) / Customer Requirements (LCR)	>30	15-30	<15	
1.3.4 What is your machine cycle time vs. TAKT time?		80% - 85%	85% - 95% 70% - 80%	> 95% <70%	
1.3.5 What kind of plant layout will you have for your product?		Product Focused		Process Focused	
1.3.5 How are raw materials and other parts brought into the cell?		One Piece Flow	Small Lot (Pushcart)	Batch (Fork trucks)	
1.3.5 Does the layout/machine design allow for empty containers and finished parts to be removed from the cell?		Yes		No	
1.3.6 Who is responsible for audit type gaging and testing, not included in operators standardized work?_____		Team Leader	Advisor	Operator	
1.3.7 Have bottleneck operations within a cell been identified?		Yes		No	
1.3.7 Will buffers be used at these bottleneck operations?		Yes		No	
1.3.7 Within a cell, what is the maximum number of machines between buffers?		7-8		>10 < 5	
1.3.7 Has the size and necessity of buffers between cells been determined?		Yes		No	
1.4 Has the size and necessity of all buffers been validated by a simulation model?		Yes		No	
1.4 Was an approved simulation package used? Specify _____		Yes		No	
Does your equipment/tooling conform to the Bill of Process (Manufacturing Footprint)?	Delphi Automotive Systems -- *Bill of Process Reference Guide*	Yes		No	
Has a DFM (Product) Workshop been done?	Delphi DFM COE; GM KnowledgeCenter	Yes		No	

NOTE: This Checklist Section, System Design, duplicates the one found in MSD Methodology. Skip to the Next Section if this was completed as part of the MSD Activity.

Figure 6: System Design

LEAN EQUIPMENT CHECKLIST

MEET THE ERGONOMIC SPEC

DESCRIPTION	REFERENCE	ANSWERS			COMMENTS
2.1.1 SAFETY & ERGONOMICS					
2.1.1.1 Are lockouts/disconnects in one location?		Yes		No	
2.1.1.2 Has guarding been considered in the design of the machine?		Yes		No	
2.1.1.3 Have safety and ergonomic guidelines been reviewed and met?		Yes		No	
2.1.1.3 How are ergonomic issues addressed? (i.e. repetitive motion)		Standardized Work	Job Rotation	Automation Complexity	
2.1.1.3 Is there a common work (part) height between stations?		Yes		No	
2.1.2 How is the cycle started?		Automatic (Light Screen)	Whisker Switch / Touch Sensor	Push / Palm Button	
2.1.3 Have efforts been made to reduce machine noise?		Yes		No	
2.1.4 Are storage racks and material handling devices reusable, reconfigurable, or flexible? (ex. Creform)		Yes		No	
2.1.4 Are storage racks/containers sized to optimize inventory at machine/cell and to provide FIFO?		Yes		No	
2.1.5 Are buffer sizes visually displayed?		Yes		No	

Figure 7: Meet the Ergonomic Spec (1)

LEAN EQUIPMENT CHECKLIST

MEET THE ERGONOMIC SPEC Continued

DESCRIPTION	REFERENCE	ANSWERS			COMMENTS
2.1.5 VISUAL AND AUDIO CONTROLS					
2.1.5 Has an Andon system been utilized or incorporated in machine design or cell design to display machine/system status?		Yes		No	
2.1.5 Are cycle counters or an Andon board being utilized to alert operator to make scheduled tool changes (equipment stops if this is not done)?		Yes		No	
2.1.5 Are cycle counters or an Andon board being utilized to alert operator to make scheduled gage checks?		Yes		No	
2.1.5 Are ranges for gages and fluid levels clearly identified?		Yes		No	
2.1.6 Has a place for tools, gages, etc. been established and is it easily accessible to operator?		Yes		No	
2.1.7 What is the pacing mechanism in this cell?	If a conveyor or other automation is required, use it to start and pace the cell.	Machine Controlled	Visual or Audio Alert (Timer)	Operator Controlled	
2.1.8 What is the distance between machines in a cell?		< 12 in.	12-24 in.	>24 in.	

Figure 8: Meet the Ergonomic Spec (2)

LEAN EQUIPMENT CHECKLIST

MAKE MACHINES EASY & FAST TO LOAD

DESCRIPTION	REFERENCE	ANSWERS			COMMENTS
2.2.1 PROPER USE OF AUTOMATION					
2.2.1.2 How are parts loaded in the machine(s)?		Manual	Low Cost Automation	Automatic	
2.2.1.3 How are parts unloaded from the machine(s)?	Use simple automation to remove the part from the load fixture so it is empty for the next part.	Low Cost Automation	Automatic	Manual	
2.2.1.3 When parts are unloaded from the machine, are they oriented for the next operation?		Yes		No	
2.2.2 Is this equipment "off-the shelf"?		Yes	Modification Required	No	
2.2.2 If modifications are required to the "off-the-shelf" equipment, how much additional cost has been added?		0-15%	15-30%	>30%	
2.2.2 If special built, is it a proprietary design that gives us a strategic advantage?		Yes		No	
2.2.3 Are electrical/mechanical components sized only to meet requirements?		Yes		No	
2.2.3 Is 110 VAC source power being utilized whenever possible?		Yes		No	
2.2.4 Has gravity been considered as a potential transfer mechanism?		Yes		No	
2.2.5 What percentage of the equipment cycle time is value added?	(value added time / total time) x 100	> 50%	30 - 50%	<30%	
2.2.5 What percentage of the total equipment cost is value added?	(value added cost / total cost) x 100	> 50%	30 - 50 %	< 30%	
2.2.5 Where are parts loaded into the machine?		Point of Operation		On To Shuttle	
2.2.6 Have steps been taken to reduce the machined surfaces on the equipment?	DFM-MTD – GM Knowledge Center	Yes		No	
Has a DFM - Machine & Tool Design (DFM-MTD) workshop been completed?	Delphi DFM COE; GM KnowledgeCenter	Yes		No	
What is the equipment/system projected Uptime?	(Actual Units / Planned Units) x 100 Where Planned Units =Sch. Run Time / Takt Time	90-100%	80-90%	<80%	
How is material moved within the cell?		By Hand	Manual Conveyor	Powered Conveyor	

Figure 9: Make Machines Easy and Fast to Load

LEAN EQUIPMENT CHECKLIST

DESIGN MACHINES FOR CELLULAR LAYOUT

DESCRIPTION	REFERENCE	ANSWERS			COMMENTS
2.3.1 What is the width of your machine?	12 inch minimum. Design to minimize operator walking.	Equal to part size. (Smallest Dimension)	2X Part Size (Smallest Dimension)	3X Part Size (Smallest Dimension)	
2.3.1 Is the operator control panel positioned in the front of the machine and not interfering with the path of the operator?	Minimize walk time and footprint.	Yes		No	
2.3.2 Is the machine open on the sides? (Including guarding.)		C-Frame		4 Post	
2.3.3 How is material brought into the cell from machine to machine?		One Piece Flow	Small Lot (Pushcart)	Batch (Fork trucks)	
2.3.3 Have batch type machines been replaced by multiple smaller machine and incorporated into a cell? (ex: paint systems, washers, platers)		Yes		No	
2.3.4 Have smaller machines been utilized to replace a multiple spindle machine?		Yes		No	
2.3.5 Can the system be run manually if the automation goes down?		Yes		No	
What is the lot size being processed?		1 pc.	Smallest Lot Container	Batch	

Figure 10: Design Machines for Cellular Layout

LEAN EQUIPMENT CHECKLIST

MAKE MACHINES FLEXIBLE FOR CHANGES

DESCRIPTION	REFERENCE	ANSWERS			COMMENTS
2.4 How long does it take to move the equipment, good part to good part?		0-4 hrs.	4-8 hrs.	>8 hrs.	
2.4.1 Is machine self contained? (control panels, hydraulics, coolant systems, chip systems, leveling method, vibration isolators, etc.)	Integral frame with all auxiliaries attached.	Yes		No	
2.4.2 Is this a "flat floor" installation?	No pits!	Yes		No	
2.4.3 Can the machine be installed without fastening to the floor?		Yes		No	
2.4.4 Are fork pockets and/or casters included in equipment?		Yes		No	
2.4.5 Are utilities and ventilation systems connected with flexible drops and quick disconnects?	Delphi Controls COE	Yes		No	
2.4.6 Have rollover or interchangeable fixtures been incorporated in the design?		Yes		No	
2.4.6 How long does it take to changeover? (Good part to good part.)		<10 min.	10-15 min.	>15 min	
2.4.7 Have adjustments been eliminated for set-ups and changeovers?		Yes		No	
2.4.8 Is the machine design flexible enough to accommodate potential product design changes or new products?		Yes		No	

Figure 11: Make Machines Flexible for Changes

LEAN EQUIPMENT CHECKLIST

MAKE MACHINES EASY TO SUPPORT

DESCRIPTION	REFERENCE	ANSWERS			COMMENTS
2.6.1 Has a PM Program been identified and initial spare parts been identified? (Standard format required.)		Yes		No	
2.6.1 Has a Total Productive Maintenance (TPM) Program been identified?		Yes		No	
2.6.1 Has the machine been designed to allow the operator to perform routine maintenance? (Including tool changes.)		Yes		No	
2.6.1 Has the machine been designed to allow the routine maintenance to be done in the following time frames?	Use scheduled downtime (lunch, breaks, etc) for maintenance activities.	0-10 min	10-30 min	>30 min.	
2.6.2 How long does it take to remove and replace barrier guards?		0-30 sec	30-60 sec	>60 sec	
2.6.2 Are all pneumatics, hydraulics, and control panels accessible from back of machine?		Yes		No	
2.6.3 Has the machine been designed with simple diagnostics?		Yes		No	
2.6.4 Have fasteners on the equipment been commonized?		Yes		No	
2.6.5 Has information management been considered in the machine design?		Yes		No	
2.6.6 Are quick release fittings incorporated in high maintenance hydraulic connections and flex drops?		Yes		No	
2.6.6 Are quick release fittings incorporated in high maintenance pneumatic connections and flex drops?		Yes		No	
2.6.6 Are quick release fittings incorporated in high maintenance electrical connections and flex drops?		Yes		No	

Figure 12: Make Machines Easy to Support

APPENDIX B. Flexible Drops

Figure 13: United States Flexible Electric Drop Example

Figure 14: United States Flexible Air Drop Example

APPENDIX C. References and Suggested Readings

Internal References

Nexteer Production System (NPS) Compass Site

Manufacturing Engineering Compass Site for Manufacturing System Design (MSD) Reference Documents

SD-004 – Electrical Specification for Industrial Machinery Addendum

SD-012 – Design-In Health & Safety Specification

SD-017 – Design-In Ergonomics Guidelines

SL 1.0 – Sound Level Specification

Suggested Readings

A Study of the Toyota Production System, Shigeo Shingo, Productivity Press, 1989

A Revolution in Manufacturing; The SMED System, Shigeo Shingo, Productivity Press, 1985

Poke-Yoke Improving Production Quality by Preventing Defects, Nikkan Kogoya, Productivity Press, 1988

RECORD OF REVISIONS

Revision No	Date	Section	Description
001	27MY98	ALL	Initial Release.
002	01MY20	1, 2, B, C	Reformatted document to align with Global SD Specifications. Updated Sections as indicated. All changes highlighted.
003	14DE20	2.4.6	Updated to align with other specifications.
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