

# Lean Manufacturing: Principles, Tools and Methods

Version **2.0**

Improve productivity and increase profits through lean manufacturing



## Introduction: The 9 Principles of Lean Manufacturing

In today's manufacturing environment, assembly work is routinely characterized by short production cycles and constantly diminishing batch sizes, while the variety of product types and models continues to increase. Constant pressure to shorten lead times adds to these demands and makes the mix truly challenging, even for the most innovative manufacturers.

The ability to respond quickly to rapidly changing customer demands requires the use of manufacturing systems that can be re-configured and expanded on the fly, and which can accommodate advances in assembly techniques without making any initial manufacturing investments obsolete.

Lean manufacturing, an approach that depends greatly on flexibility and workplace organization, is an excellent starting point for companies wanting to take a fresh look at their current manufacturing methods. Lean techniques are also worthy of investigation because they eliminate large capital outlays for dedicated machinery until automation becomes absolutely necessary.

Indeed, the concept of lean manufacturing represents a significant departure from the automated factory so popular in recent years. The "less is better" approach to manufacturing leads to a vastly simplified, remarkably uncluttered environment that is carefully tuned to the manufacturer's demands. Products are manufactured one at a time in response to the customer's requirements rather than batch manufactured for stock. The goal is to produce only the quantity required and no more. And since limited numbers of parts are produced, it may be necessary to change processes during the day--to accommodate different parts and to make maximum

use of personnel, equipment and floor space. The flexibility inherent in manual assembly cells is therefore preferable to automated assembly. This requirement for maximum flexibility creates unique demands on the lean workcell and the components that make up the lean workcell.

Granted, the lean approach is not the solution for all manufacturing problems. But it does offer a uniquely flexible solution for assembling more complex products. This guide describes 9 basic lean manufacturing principles that should help you evaluate lean manufacturing solutions for your own applications.

The 9 principles discussed are: Continuous Flow, Lean Machines/Simplicity, Workplace Organization, Parts Presentation, Reconfigurability, Product Quality, Maintainability, Ease of Access, and Ergonomics.

### The 9 Principles

#### 1. Continuous Flow



#### 2. Lean Machines Simplicity



#### 3. Workplace Organization



#### 4. Parts Presentation



#### 5. Reconfigurability



#### 6. Product Quality



#### 7. Maintainability



#### 8. Ease of Access

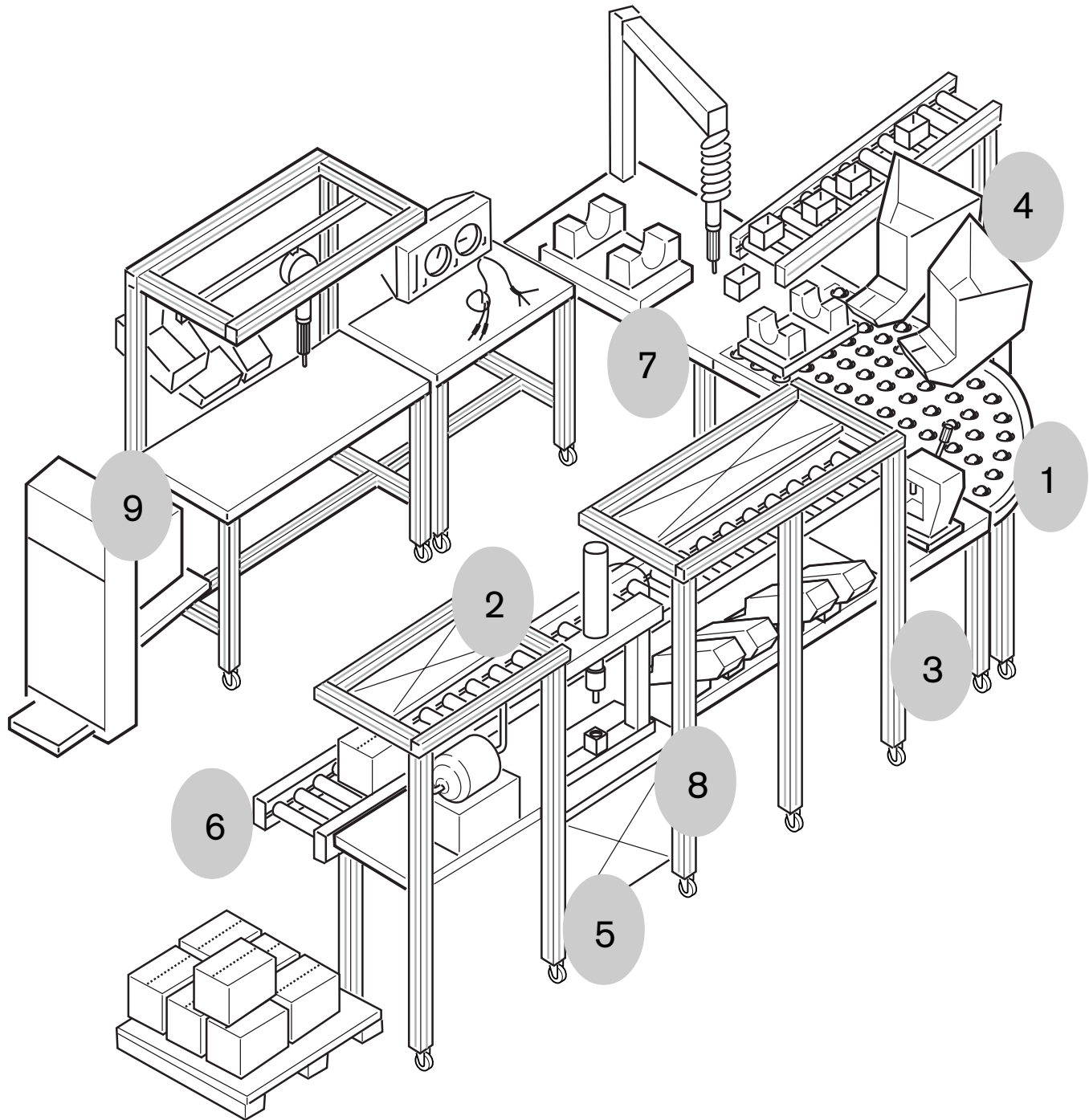


#### 9. Ergonomics



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# A Typical U-Shaped Cell for Lean Manufacturing



# 1. Continuous Flow

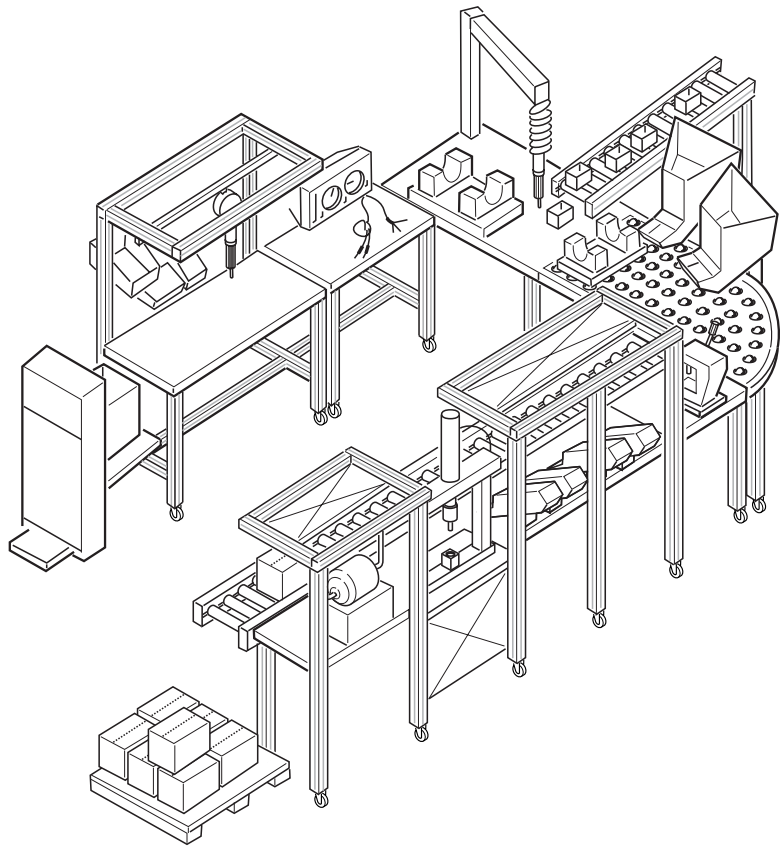
The preferred shape of the lean workcell is U-shaped. Each subprocess is connected to the next in order of process. With the worker in the interior of the U, minimum movement is required to move the workpiece or assembly from one workstation to the next.

Ultimately, one of the goals of the lean workcell is to eliminate all non-value-added movement; hence its U-shape. When the worker has finished the process, he simply turns around and is back at step one.

The workpiece may be carried from one value-added operation to the next. However, there are times when the workpiece or the fixture holding the workpiece is too heavy and must be transferred mechanically between workstations.

Although very heavy parts may be transported on belt conveyors, manual push or gravity conveyors are ideal for moving parts between workstations. Their minimum complexity makes them easy to service and minimizes down time. In addition, they are easy to connect end-to-end, which makes it easy to move workstations within a workcell.

The curved “corners” of the U-shaped workcell can pose a problem. As potential dead space, they may act as a mini storage area, thereby encouraging a return to batch processing. Instead, the use of a ball roller transfer should facilitate part movement through the corners of the U-shape.



*Fig. 1a: Simple roller conveyor for movement of heavy parts.*



*Fig. 1b: Ball roller transfer*

## Continuous Flow:

- U-shaped cell
- Connect sub-processes
- Value-add-to-value-add operation
- Machines in order of process
- Parts arrive as needed
- Counterclockwise flow
- One-piece flow (small lot flow)
- Non-cyclical work done outside cell by support people

## Benefits:

Elimination of non-value added movements, work in process, and inventory.

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## 2. Lean Machines/Simplicity

Since continuous-flow, one-at-a-time manufacturing is another goal of lean manufacturing, it is important that each workstation or machine be designed to fit within a minimal envelope. The minimal envelope ensures the elimination of excess flat space at the workstation or machine. This is done to avoid the possibility of storing parts or subassemblies at the machine. Storing parts increases work in process and results in “batch” processing, which subsequently defeats the purpose of lean manufacturing. In addition, smaller, minimal size workstations and machines eliminate unnecessary steps taken by the worker between subprocesses.

Finally, significant floor space may be saved by properly sizing workstations and machines. Although tempting for the sake of conformity and standardization, the deployment of standardized machine bases or workstations for all processes should be avoided. Each machine base or workstation should be designed to optimize assembly subprocesses, which in most cases will vary from workstation to workstation. This customization can be achieved with virtually any structural material. To save on cost, however, as well as to minimize the environmental considerations related to disposing of inflexible welded steel structures, preference should be given to material that is reconfigurable and reusable. The modular characteristics of extruded aluminum, bolt-together systems make them perfect for the implementation of lean manufacturing concepts.

Moreover, in a continuous improvement environment, all workstations and workcells must be easy to modify as process improvements are identified. In addition to their superior flexibility in layout and design, lightweight aluminum structures are easier to move when re-configuration is necessary. Casters may be quickly mounted to the T-slotted profiles to allow movement without the use of fork trucks or other lifting equipment.

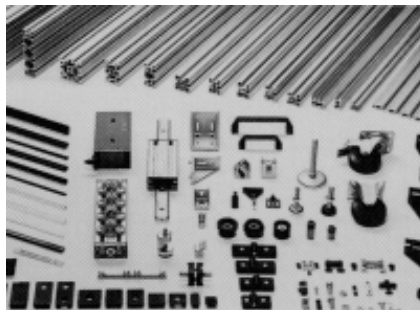
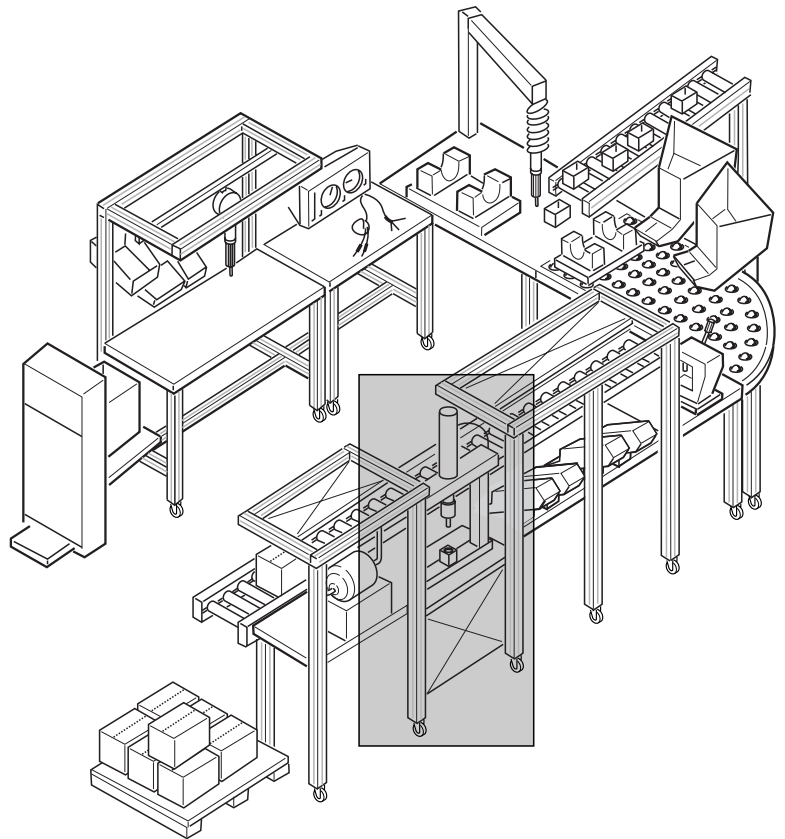


Fig. 2a: Bolt-together structural framing system

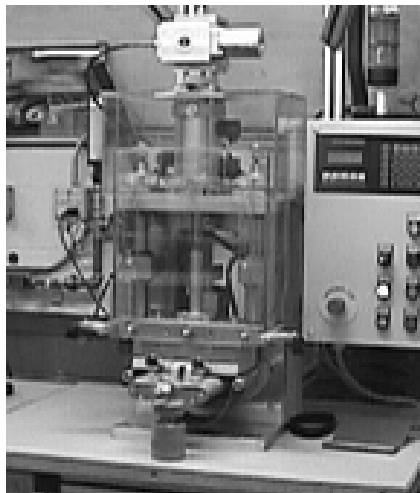


Fig. 2b: Belt welding station in minimal envelope

### Lean Machine Basics:

- Continuous flow
- Save factory floor space
- No excess production
- No extra shelf/drawer space

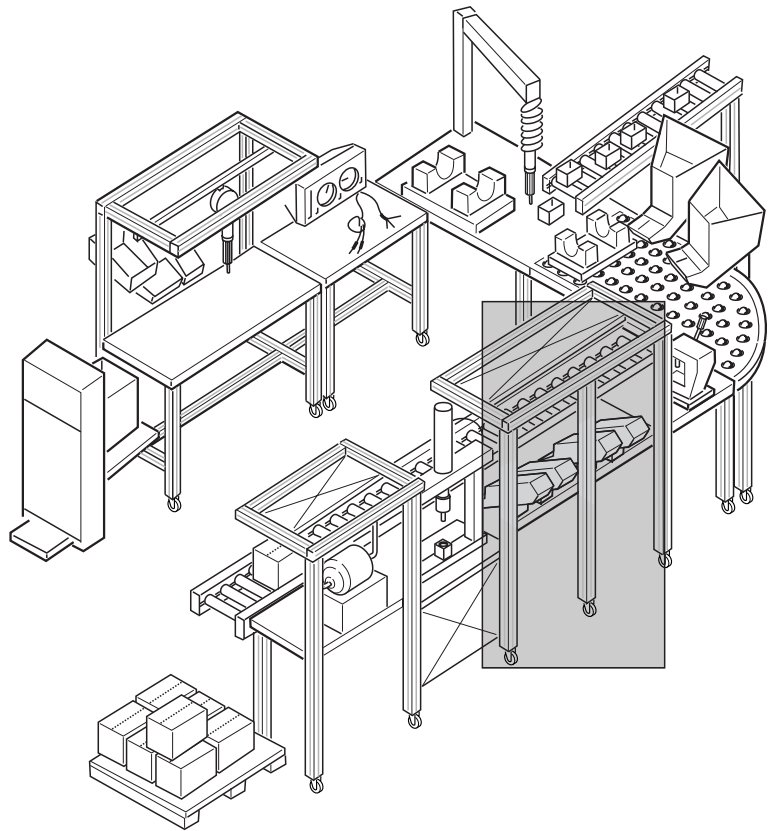
### Benefits:

One-at-a-time manufacture, quick production changeover, reduced WIP, easily modified, customizable production

## 3. Workplace Organization

### Tool holders

A smooth, uninterrupted flow of completed workpieces is the desired result of a properly designed lean workcell. Nothing can slow or stop this flow faster than the loss or misplacement of tools. Thus, all tools used at a workstation should have their own holder. There should be exactly as many holders as there are tools so that the absence of a tool is quickly noticed. Using a modular tool holder system with a specific holder for each tool is ideal. If holders can easily be added to or taken away from a workstation, this simply adds to the flexibility of the workstation and increases its usefulness in a lean manufacturing process.



To minimize downtime, backup tools should also be available at any automated workstations. These tools should be out of the worker's way until a failure occurs at the automated workstation. Of maximum benefit are tool holding structures that allow tools to be swung or slid into the work space and easily returned to the storage position when no longer needed.

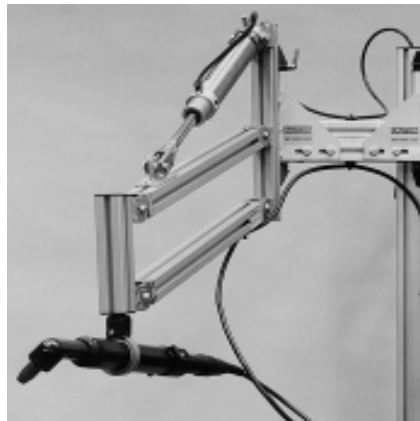


Fig. 3a: Mount for backup tool

### Information Boards

Naturally, the ready availability of work-critical information also adds to efficiency in a workcell. Supplying the right information at the workplace, such as assembly processes, work instructions, repair procedures, or even production targets, allows workers to make the right decisions and act on them on the spot, limiting downtime often spent chasing down a busy supervisor.

As with everything in a lean workcell, the information board should be simple, easy to reposition, and reusable.

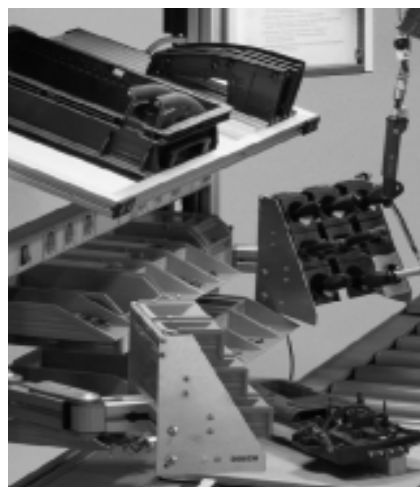


Fig. 3b: Modular tool holders

### Workplace Organization Basics:

- Organize tools with appropriate tool holders
- Provide back-up tools at automatic stations
- Insist on flexible tool mounting structures
- Put the right information where it's needed

### Benefits:

Minimize downtime, reduce wasted motion, uninterrupted workpiece flow, improve quality

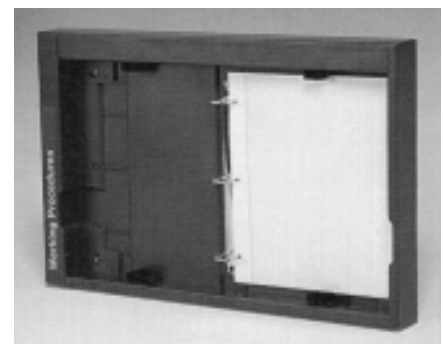


Fig. 3c: Information Board

## 4. Parts Presentation

Naturally, during the average work shift, additional parts will be required for the workcell. Traditional methods of resupplying workstations are not useful in a lean workcell. Each worker should go about his work with the minimum number of interruptions. Therefore, all parts should be supplied to each workstation from outside the workcell. The use of gravity feed conveyors or bins fits the simplified design of the lean workcell.

Parts bins should load from behind (outside the working area of the workcell) so that the worker may continue production without interruption. Gravity carries the parts to the worker's reach area. Bins should also be reconfigurable. The bins in the photo use a key stud to lock them in position. Bins are easily stackable and provide the ultimate in flexibility when reconfiguring the workplace.

Although bins are ideal for small parts, many assemblies require larger parts. These may be delivered in bins or boxes. Again the parts should be delivered to the workcell without entering the work space. Gravity feed conveyors serve this purpose well. In the event that scrap or containers must be removed from the cell, an additional gravity feed conveyor may be mounted in the reverse direction.

In instances where parts are very heavy, lift assist devices are recommended. Heavy parts or boxes of parts can be loaded onto a case lifter and raised to the proper work height with electric, pneumatic, or hydraulic power.

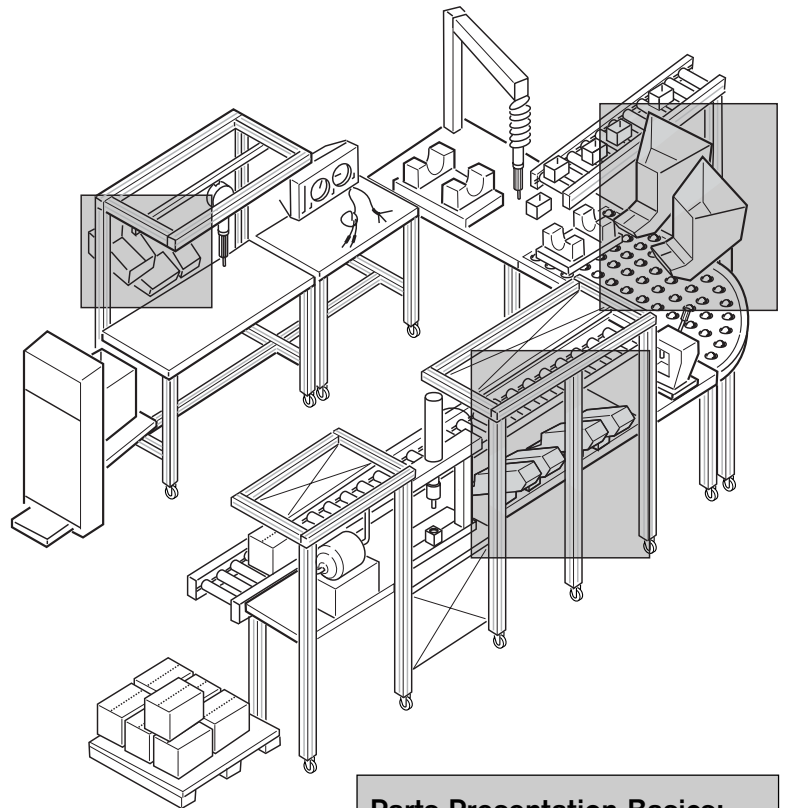


Fig. 4a: Gravity feed conveyor

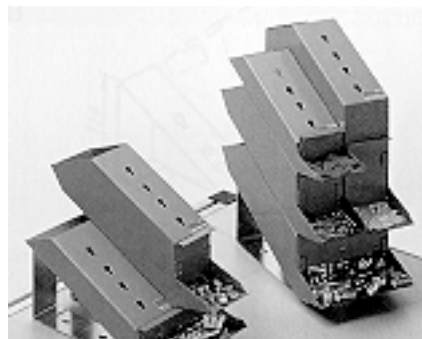


Fig. 4b: Gravity feed parts bins

### Parts Presentation Basics:

- Supply parts as needed
- Parts loaded from outside the cell
- Use gravity feed as the preferred method
- FIFO parts presentation

### Benefits:

Easy reconfiguration, reduce wasted motion, uninterrupted production, quick changeover

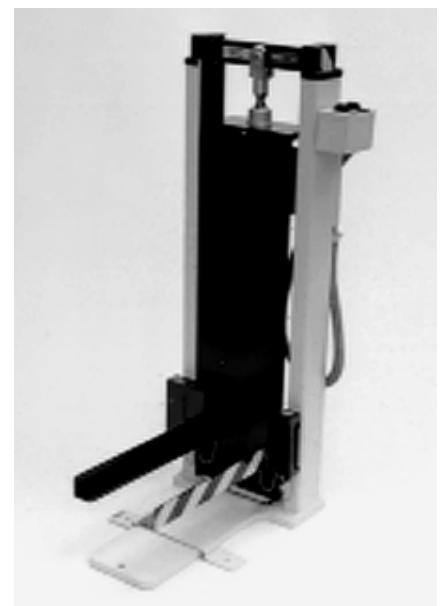


Fig. 4c: Case Lifter

## 5. Reconfigurability

A properly designed lean workcell must be easy to reconfigure. In fact, the ability to change the process and go from good part to good part as quickly as possible is a must. The faster the changeover, the less production time is lost.

Quick-change fixtures are one way this can be accomplished. With a good quick-change fixture, changeover can be accomplished in a matter of seconds. A number of different fixtures may be stored at the workstation and swapped as the situation requires.

In Fig. 5a, for example, an assembly fixture is locked to the T-slot at the front of a workbench with a star knob and quarter turn connector. Once the assembly of a specific product is complete, a new fixture can be easily positioned.

At times, due to process changes or other factors, a lean cell must be quickly reconfigured or even moved to accommodate assembly of a new product. In the event that a machine or workstation must be changed, the ability to move each component of the workcell quickly becomes extremely important. Lockable casters on machines or workstations provide the mobility necessary for rapid and efficient changeover.

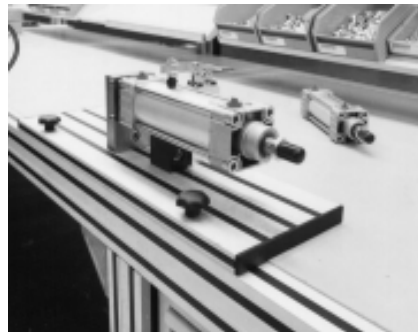
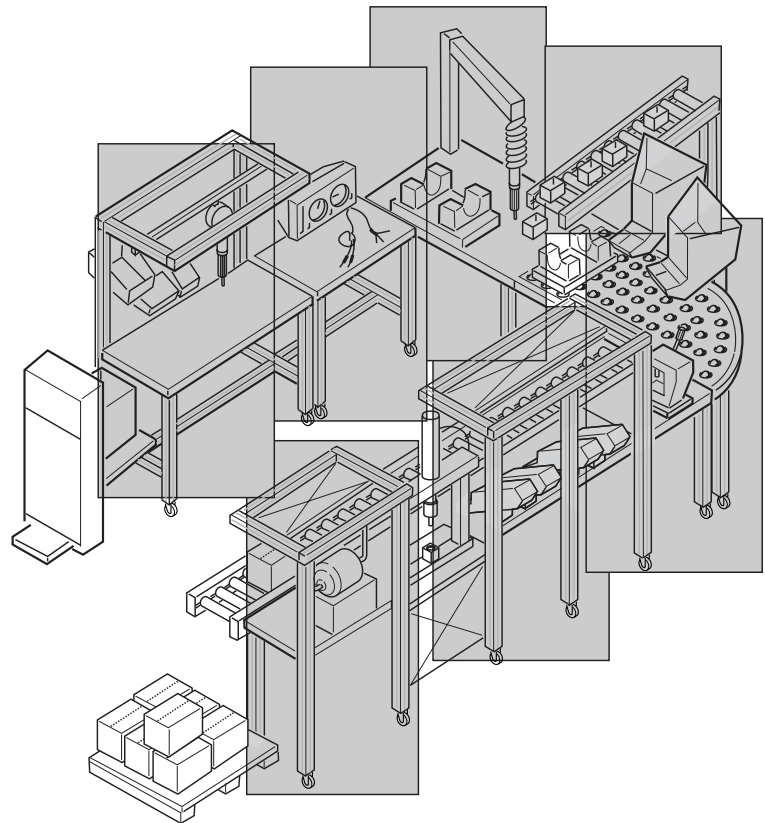


Fig. 5a: Quick change fixture

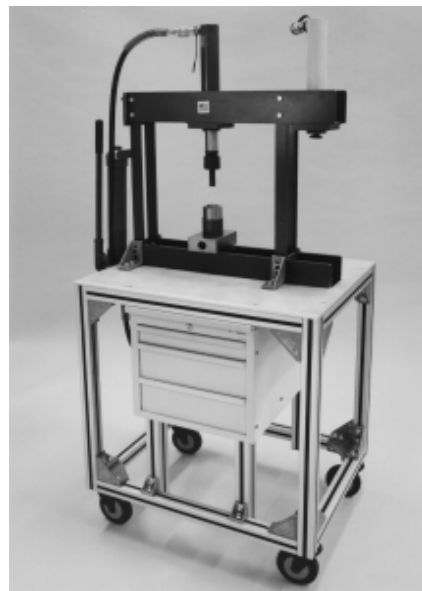


Fig. 5b: Casters on a machine stand

### Reconfigurability Basics:

- Fixtures must be easy to change
- Mobility is critical
- Good part to good part as quickly as possible

### Benefits:

Minimize downtime, quick changeover, uninterrupted workpiece flow

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## 6. Quality

One of the results of one-at-a-time manufacturing is a decrease in quality problems. As each part is produced, visual inspection by the worker can verify that it is correctly assembled. If verification is required through gages, they should be mounted to the machine or workstation and be easily replaced. Quick release of fixtures using star knobs or locking levers is a necessity.

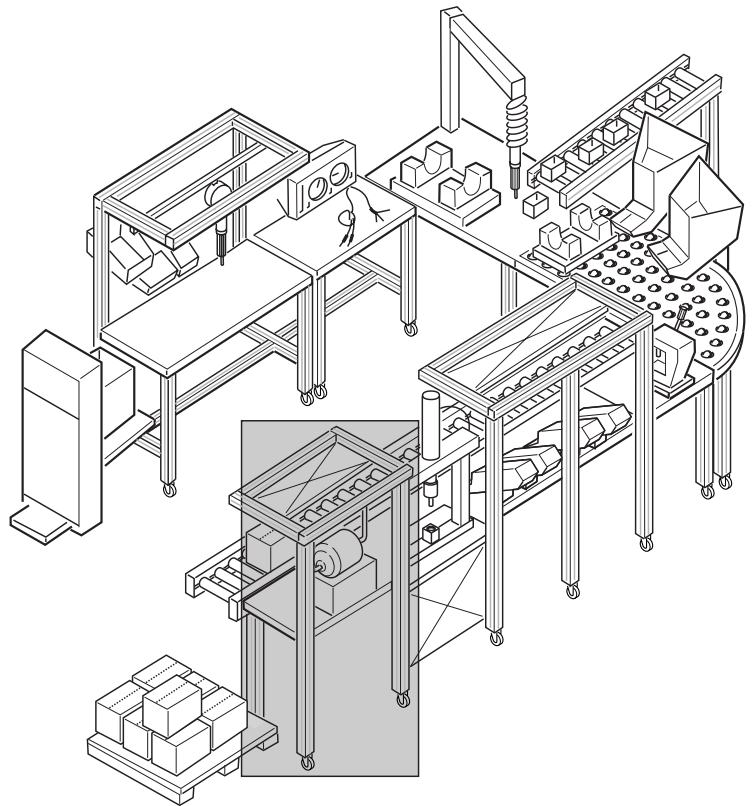
There may be time when a quality problem cannot be easily fixed. A flawed process or malfunctioning machine may be the source of the quality problems.

In the case of a flawed process, the structural framing system allows changes, no matter how great, in a minimum amount of time. Once again, bolt-together construction solves a major problem in minimum time.

A malfunctioning machine may also be easily replaced, particularly if quick disconnects for all pneumatic or electric lines are provided for when the lean cell is designed. In addition, no pneumatic or electrical connections should be present between machines in the lean cell. These would slow the changing of the machines within the cell.

Once the machine has been disconnected from all power sources, it can be easily transported if mounted on lockable casters.

Ease of reconfiguration and changeover eliminate any reluctance on the part of the worker or management to try to "make do" with machines or processes that are "almost" right. This change in attitude can contribute greatly to true quality production.



### Quality Basics:

- Visual inspection is the primary means of quality assurance
- Test fixtures & gages must be easy to replace or change out
- Easy reconfiguration encourages changes for quality's sake

### Benefits:

Immediate feedback on quality as workers inspect parts; platform for continuous improvement; eliminate rework areas; encourage changeover to solve "minor" quality problems; greater quality assurance by giving the responsibility to the assembler; rapid change of quality gages as assembled product or process changes.



Fig. 6: Visual Inspection verifies parts are correctly assembled and function properly.

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## 7. Maintainability

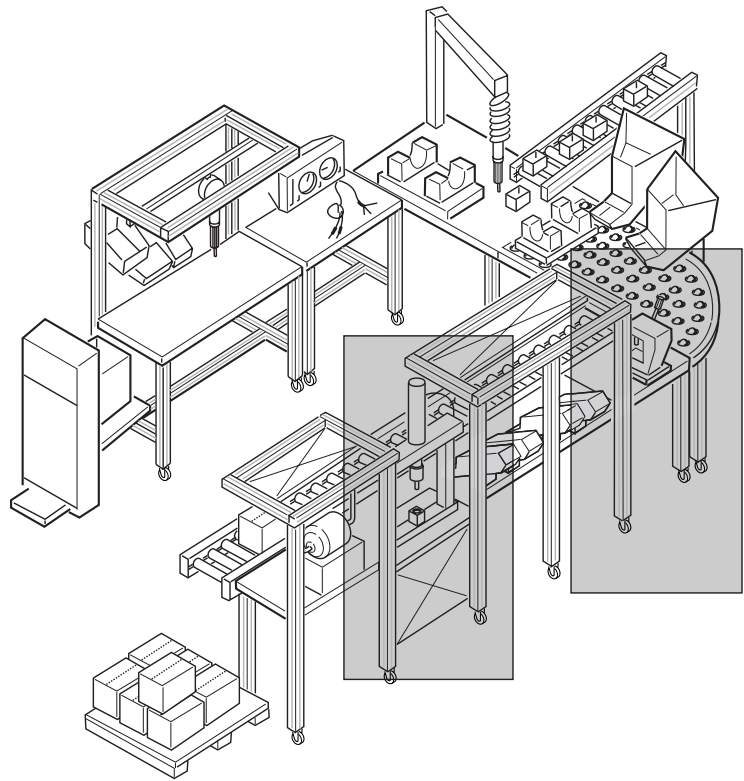
Ease of service is another requirement of a lean cell. Long down times cannot be tolerated in a pull-through system. When customer demand exists, the product must be produced. A modular structural framing system provides the ultimate in maintainability.

Components can be replaced or reconfigured in a matter of minutes. Bolt-together construction ensures machine stands, guards, workstations, or parts presentation equipment can be serviced in a matter of minutes. Even entire machine bases can be rebuilt in a minimum amount of time.

The structural framing system also provides a source for common components for all machine bases, guards, and workstations. With standardized components, a minimum number of tools is required to maintain a structure. With a structural framing system, three or four simple hand tools are sufficient to build or repair any structure.

Another benefit is that common components eliminate the need for a large inventory of spare parts. It is possible to standardize on one size of aluminum profile, one or two connectors, and a few accessories to create virtually any structure.

Finally, no finish work is required with an aluminum structure. No welding or painting is required. Repairs can be accomplished in the minimum amount of time.



*Fig. 7: A lean cell constructed from modular aluminum framing provides for easy maintenance and repair*

### Maintainability Basics:

- Ease of service
- Manual back-up
- Put the operator manual on machine
- Standardize as many components as possible
- Use common tools and fixtures
- No finish work required on system components.
- Minimum spare parts necessary

### Benefits:

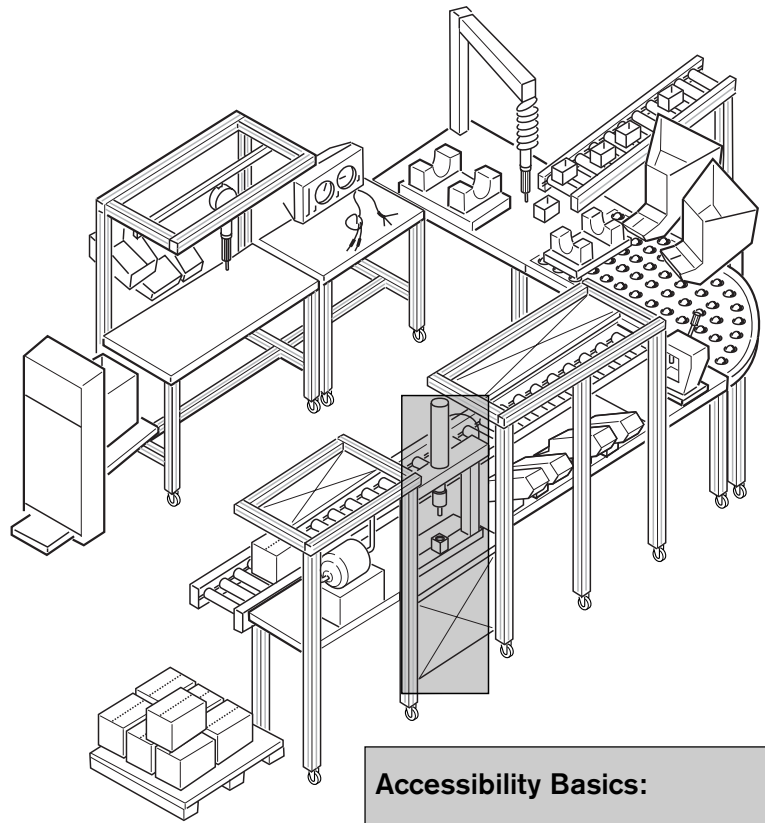
Minimum down time, easy-to-source replacement parts, quick service

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## 8. Ease of Access

Using an aluminum framing system as the foundation of a lean cell, all necessary work components can be mounted in easily accessible locations because each surface is a potential mounting surface. Parts bins, tools, shelves, and fixtures can all be positioned in the optimum location for efficient work. The T-slot on the framing system's surface also allows quick repositioning of pneumatic or hydraulic components if clearance space is critical (Fig. 8a).

Components may be added quickly to any workstation and easily repositioned to insure accessibility for each worker. In addition, entire guards or individual panels (Fig. 8c) can be removed quickly with simple hand tools, enabling service technicians to perform maintenance in a matter of minutes.



### Accessibility Basics:

- All controls or fixtures positioned with ergonomics in mind
- All serviceable components at rear of machine/workstation to eliminate interference of maintenance personnel with production
- Clearance for all tools for ease of use
- All guards easy to remove with simple hand tools

### Benefits:

Minimum down time, easy serviceability, optimum ergonomic design.



Fig. 8a: Valves mounted to T-slot



Fig. 8b: Accessibility in workstation design

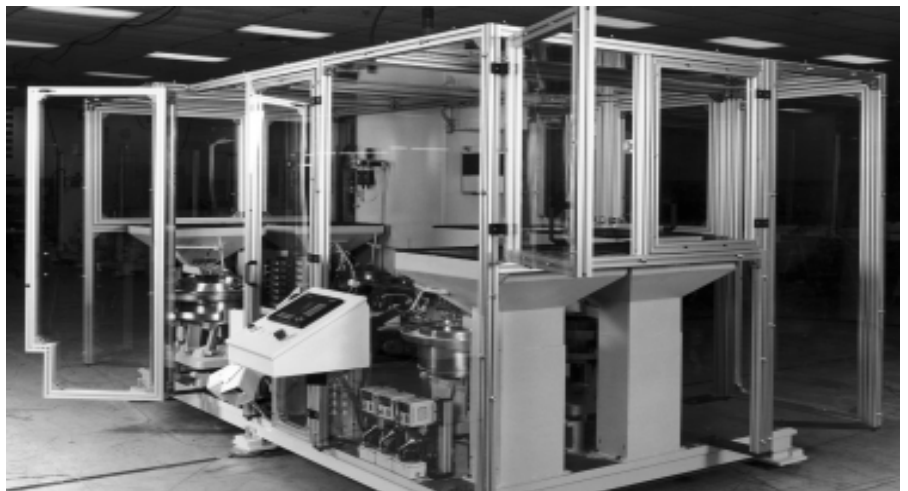


Fig. 8c: Machine guard with sliding access doors and easy to remove panels

# 9. Ergonomics

## Height

Finally, the worker must be protected from ergonomic problems. Any properly designed lean workcell must, by definition, be *ergonomically* designed. Maintaining the work at the ergonomically correct height throughout the workcell is always important. Although it is frequently not taken into consideration, designing for the average worker height is also a necessity. Since average heights vary from country to country, the height of a machine or workstation must be easily changed if there is any chance that a workstation may be shipped from country to country.

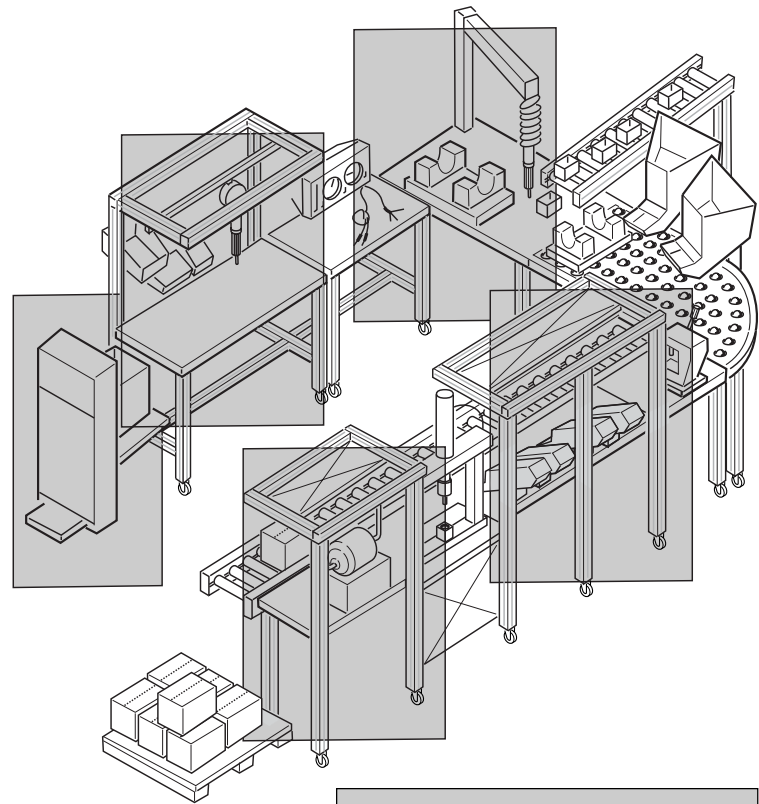


Fig. 9a: Proper height is critical in any lean workcell

workcell is constructed can be a powerful tool. Use of such a software package lets you settle ergonomic issues in the design stage rather than on the factory floor, providing significant potential savings in both time and money.

### Ergonomics Basics:

- Position workpiece at optimum height for worker
- Use NIOSH standards to determine maximum lifting loads
- Position all tools within the worker's field of reach
- Provide lighting sufficient to accomplish the task

### Benefits:

Fewer work-related injuries, lower employee turnover, better working environment, fewer cumulative trauma problems

## Lifting

Lift assist devices must be considered where the weight of parts or boxes of parts exceeds lifting standards. In this case, pneumatic, hydraulic, or electric devices may be used, but it is important to keep in mind that simpler is better in lean manufacturing cells.

In order to prevent delays in manufacturing caused by faulty design, a software package that allows you to test the ergonomics of a workcell before the

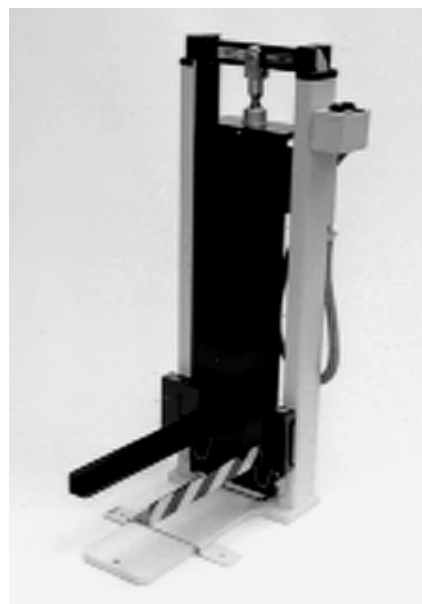


Fig. 9b: Case Lifter

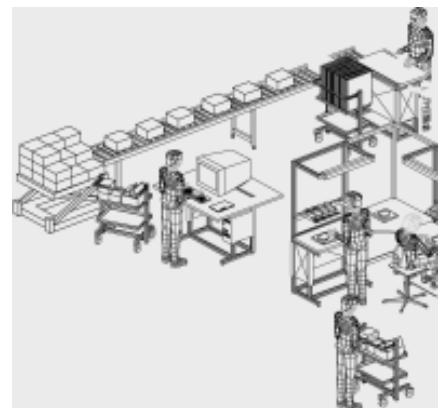


Fig. 9bc: Software for Ergonomic Workstation Layout

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## Final Considerations: Hybrid Systems

With all of its promise, the lean cell may not be the answer to all assembly needs. At times the U-shaped configuration simply does not fit the existing facility or process, and a change from automation or semi-automation to lean cell manufacturing could be counterproductive.

In keeping with the flexibility requirement for lean manufacturing, there may be times when a hybrid system rather than a pure lean system is best for the manufacturing process.

Hybrid manufacturing systems combine the economies of the lean system with the safety and efficiency of an automated

system. The result is a system in which some assembly is done manually while more dangerous or ergonomically difficult tasks are accomplished by machine.

In a hybrid system, workstations or cells may be combined with non-synchronous assembly conveyor systems to achieve desired production goals. The synergy between these two technologies can produce results far beyond the capabilities of either technology alone.

It is also possible to accomplish assembly in a lean cell and to have operations which are purely automated take place off line.

In this case, the automated portions of the process supply sub-assemblies or parts to the lean cell. Here, although the technologies are separated, both are still required to accomplish the task at hand.

The key to hybrid implementation is construction with components which are easily reconfigured. Bolt together technology fits the description perfectly. Flexible assembly systems using aluminum framing as the main structural element allow companies to mix and match manual and automatic operations at will, and to change them at any time in the future. The result is a worker-friendly, economically-sound system designed for optimum production.



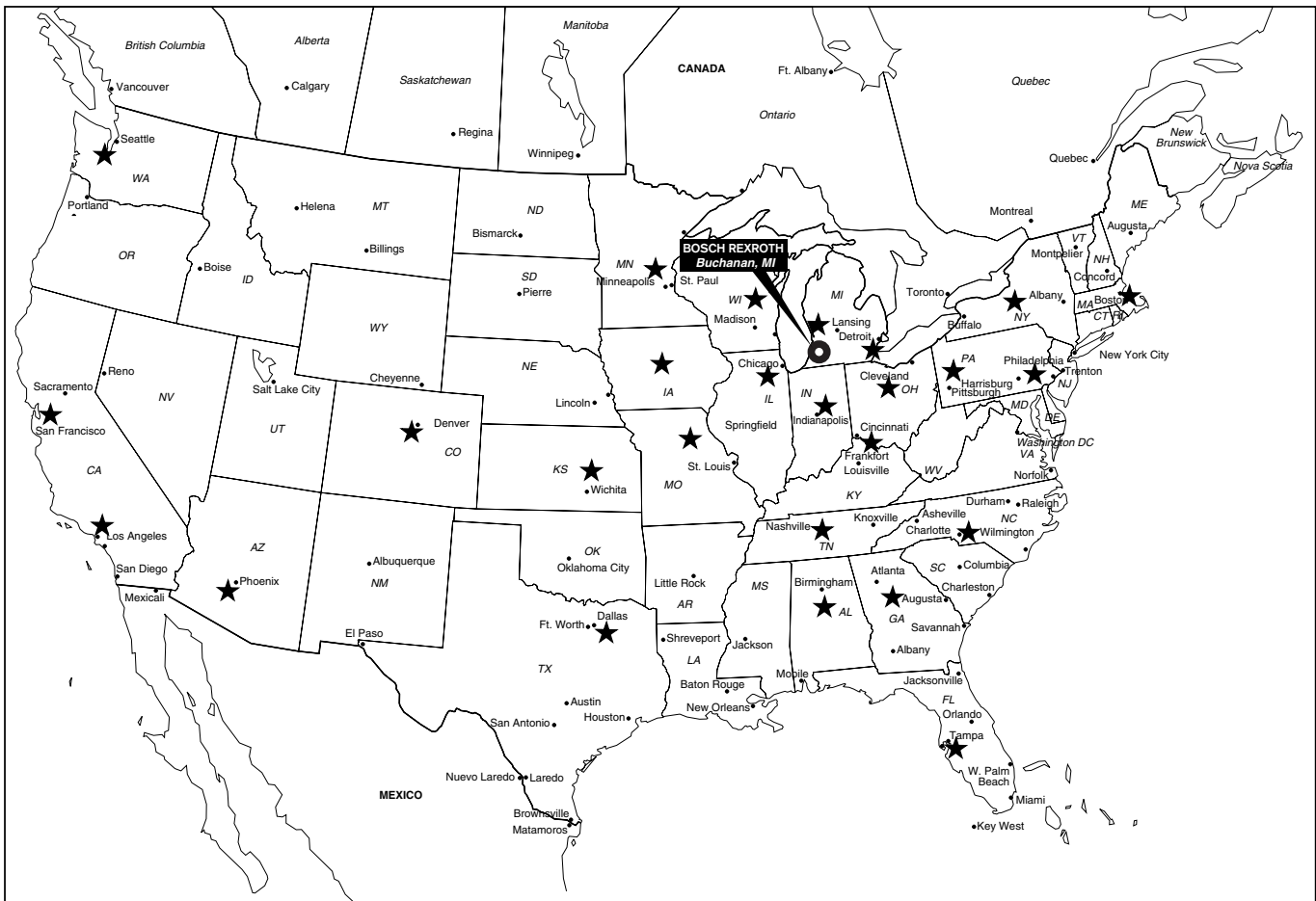
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# Bosch Rexroth - Your Partner in Lean Manufacturing

A switch to lean or hybrid manufacturing may entail radical changes in plant layout and equipment design. To ensure that you implement these changes smoothly and efficiently, you need a partner - Rexroth. Bosch Rexroth Corporation has a network of stocking distributors nationwide. In addition to local inventory, each distributor has Rexroth design experts on staff to assist you with your lean manufacturing projects.

Once your equipment is designed, your Rexroth distributor will provide machining, assembly, and other value-added services to move your project to a successful conclusion. Each Rexroth distributor is backed by more than 100 years of experience and quality. And worldwide availability of all Rexroth products ensures successful implementation even when lines are moved abroad. For lean manufacturing solutions, count on Bosch Rexroth Corporation as your expert partner.

## The Bosch Rexroth Structural Framing Network



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## Bosch Rexroth, the world brand leader in structural framing systems, ergonomic workstations and flexible assembly conveyors

Bosch Rexroth Corporation supplies the U.S. market with flexible manufacturing equipment for every manufacturing need. All Rexroth components are modular to provide maximum flexibility for easy reconfiguration and rapid manufacturing changeovers.

For years, Rexroth has supplied manufacturers worldwide with a broad range of ergonomic components ideally suited for lean manufacturing: easily customized workstations, tool holders, information boards, parts bins, and a broad range of workstation accessories. Combined with the Rexroth Aluminum Structural Framing System, these components let manufacturers build exactly the work environment required to match the parts, workers and workcells to their manufacturing processes.

If you've never used our aluminum structural framing before, you'll be surprised how easy it is. And our customer support system makes it even easier. For fastest service, order from your distributor on-line at [www.boschrexroth-us.com/framing\\_ec](http://www.boschrexroth-us.com/framing_ec). It's the world's first fully-functional on-line framing shop, now with an easy-to-use workstation configurator.

Bosch Rexroth Corporation is also the world's leading supplier of power and free non-synchronous assembly conveyors. These conveyors, in concert with the workplace equipment and structural framing system products, place Rexroth in a unique position as a supplier of overall factory automation. With this family of products, hybrid lean manufacturing systems are available from a single source, with completely interchangeable structural components.

When you're ready to order, you have several options. Call us toll-free at 1-800-REXROTH (739-7684) for the name of your local distributor, or follow the step-by-step ordering instructions at our website. A nearby Rexroth distributor will ship your order promptly. The Rexroth customer support system gives you tremendous flexibility to meet tight schedules and budgets.

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