Autonomation: The Future of Manufacturing

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Abstract

This paper discusses the autonomation process in terms of conversion from manual processes to the use of complex systems that not only automate the manufacturing process but also automatically monitor and control it. In light of the high initial investment for autonomation, this paper presents the long-term benefits of the ability of automated lines to do a type of self-diagnosis when a problem arises and either make a correction or prescribe a correction to human technicians. As a method of reducing defects and waste in many ways, autonomation is portrayed here as an important and effective tool of lean production that has seen great developments for better decision-making and more applications. This paper not only discusses the details of autonomation, also known as *jidoka* in Japanese, but also looks at common elements and ways for effective implementation in manufacturing systems today.

Introduction

Just as in the life cycle of humans, after the adolescent stage, there is the strong urge to be independent and move out of the family house, the same has been seen in the industrial world. The production and manufacturing industry has grown to the point where machines and processes are autonomous, requiring less human intervention. Machines want to be able to think for themselves and make their own corrections when possible.

The industrial world has seen a rapid change in manufacturing and production over the past years from the mould systems which produce single pieces at a time to modern manufacturing lines that produces mass volumes per day. The last time the world witnessed a revolution in manufacturing systems was in 1913 when the world came to Detroit to see Henry Ford's line [1]. Today, manufacturing has advanced, and industry has reached a point where products can be manufactured in production sequences that usually involve less or no human intervention from start to finish in a process called automation. Most often, automation is confused with autonomation, while automation is a function of autonomation. The latter cannot exist without the former. The term "autonomation" is a combination of autonomy and automation. It implies the independence of automation or allowing a process

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to be able to make its own decisions, thereby giving it a human touch. The autonomation process is a conversion from manual processes to the use of complex and often expensive manufacturing systems, presenting long-term benefits with the application of lean principles. This has been improved over the years to enable these automated lines to do a type of self-diagnosis when a problem arises. This self-diagnosis as a quality control measure among automated lines is what is commonly referred to as autonomation.

Table 1. Difference between automation and autonomation

Category	Automation	Autonomation
People	Manual processes become easier but still needs human supervision	Supervisors can multi-task and productivity improves
Machines	Machines complete cycle until stop button is activated	Machine detection of errors and correction is autonomous
Quality	Defects can be produced in mass quantities due to machine malfunction	Machine crashes are prevented by auto-stop, hence defects are avoided
Error and Diagnosis	Errors are discovered later and root cause analysis is long term	Errors are discovered and corrected quicker

Autonomation is a term commonly associated with Toyota, where early applications of this process were experimented and documented. The first example of this at Toyota was the auto-activated loom of Sakichi Toyoda that automatically and immediately stopped the loom if the vertical or lateral threads broke or ran out. Taiichi Ohno is considered the inventor of this idea, and he describes this tool as one pillar of the Toyota Production System. Shigeo Shingo calls it pre-automation.

The autonomation process today has been essentially incorporated into machine design, allowing the machine to malfunction or stop during an unusual process. Modern applications of autonomation does not limit it to just the stopping of machines when they malfunction. It is rather a complete and clever approach to automation. Real autonomation includes a complete automation strategy, with series of steps to automate fabrication and assembly operations, as well as an approach to managing the daily interactions between humans and machines on a manufacturing shop floor. This is in line with modern lean principles of manufacturing that aim towards reduction of waste or elimination of anything that is not considered as adding value to the production process for which a customer is willing to pay.

Autonomation prevents the production of defective products, eliminates overproduction, and focuses attention on understanding the problem to ensure that it never recurs, during process review and improvement of design.

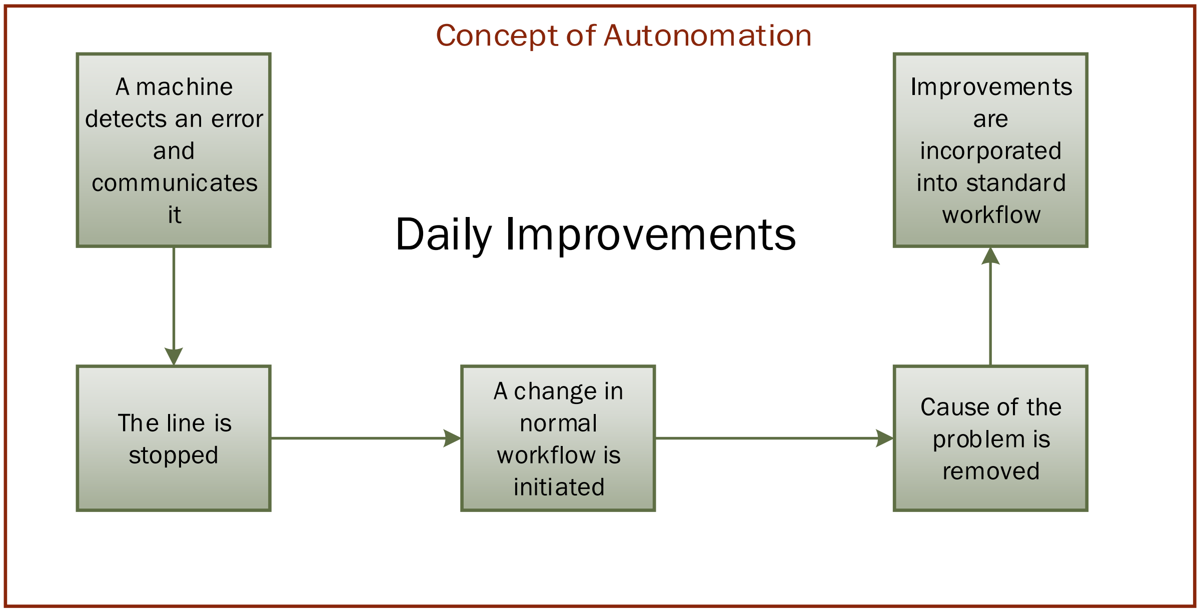

Figure 1. Concept of autonomation

Common causes of defects are detected, investigated, and eliminated:

- Wrong operating procedures
- Excessive variation in operations
- Defective raw material
- Machine or human error

From a production perspective, supervision has been integrated in the machine; human intervention only comes in when the problem cannot be self-rectified. This is integrated quality control, a necessary step in the design of the factory with a future as discussed in J. T. Black's book [1].

The Toyota Story

The autonomation concept was born out of the invention of the automatic loom by Sakichi Toyoda, founder of the Toyota Group. The automatic loom is a machine that spins thread for cloth and weaves textiles automatically.

Before automated devices were commonplace, back-strap looms, ground looms, and high-warp looms were used to manually weave cloth. In 1896, Sakichi Toyoda invented Japan's first self-powered loom, the "Toyoda Power Loom." Subsequently, he incorporated numerous revolutionary inventions into his looms, including the weft-breakage automatic stopping device (which automatically stopped the loom when a thread breakage was detected), the warp supply device, and the automatic shuttle changer. Then in 1924, Sakichi invented the world's first automatic loom, called the "Type-G Toyoda Automatic Loom (with non-stop shuttle-change motion)," which could change shuttles without stopping operation [3].

This basic idea revolutionized the industry where previously, instead of an operator having to sit beside each machine, waiting and searching for a problem, one operator could now multi-task by watching several machines and just taking action when a problem occurred, thus increasing quality and productivity.

Autonomation is the strategy that Toyota uses for its machines and an important factor for its success story today, instead of investing in huge monolith machines that can do everything but take a long time to set up and require to run huge batches, they invest in small machines that do specific tasks that humans find difficult or repetitive and use autonomation principles to ensure that the operator only has to interrupt the cycle if something goes wrong.

At Toyota, every worker has the authority and the responsibility to stop an entire line when a problem arises. The purpose is to bring attention to the problem, regardless of how small, and focus effort on it. This results in a permanent solution. It has been common law at automotive plants that an assembly line must never stop. When Taiichi Ohno first told supervisors to stop the production lines when an issue came up, they were skeptical.

Ohno tells the story of two supervisors: one who followed orders and stopped the line immediately when trouble developed and another who was reluctant to stop the line. Initially, the line that stopped frequently had lower production output. Several months later, the situation reversed. The line that rarely stopped still had the same problems. These problems stalled productivity improvements and created rework that lowered total efficiency. The line that initially saw frequent stoppages overall efficiency had improved considerably and eventually had less production stops [2].

Principles and Characteristics

The purpose of autonomation is the quick response, identification and correction of mistakes that occur in a process. Instead of waiting until the end of a production line to inspect a finished product, autonomation may be employed at early stages of the process to reduce the amount of work that is performed on a defective product.

Autonomation by principle is a quality control process that applies these four basic principles:

- *Detect the abnormality:* This involves placing detective mechanisms along the production line at critical points to identify mistakes in production or defects. Mechanical devices such as lasers, photoelectric tube, magnetic coils, etc. are used to identify discrepancies in physical properties such as weight, texture, shape, torque etc.

- *Stop the production sequence*: stop signals are activated after detection of any abnormality and this halts conveyor belts, transfer chains, connecting links etc. The entire production process does not really stop, depending on the process and stage at which the error was detected. Usually it is a specific sequence within the production stage that halts. The entire production line stops, however, if the error is likely to cause a chain reaction involving the other processes.

- *Fix or correct the immediate condition:* Alarm systems with blinking lights are activated when errors are detected in places where human intervention is required. Automated systems with self-correction devices send relay signals to a processor system for problem identification and sends feedback signals for rectification action to the machine.

- *Investigate the root cause and install a countermeasure*: A review system is a critical function of autonomation and this involves, investigating past error incidences to identify what caused it and how to avoid such problems from recurring. It is a periodic and continuous process.

The autonomation concept was developed due to many reasons, most commonly

- Overproduction of goods
- Waste of time during manufacturing at the machine
- Waste of time in transporting defective material
- Waste of time during defective piece re-processing
- Inventory waste

Autonomation Application Examples

Some devices are also known as *poka yoke* devices or mistake proofing; these are simple ideas that prevent the creation of defects and are very much part of autonomation. Examples are mechanisms such as sensors that register when all holding clamps on a fixture are fully closed as a sign that all components are loaded correctly. Shaped fixtures that will only accept the correct orientation of components, pins in fixtures that mate with holes in components preventing a worker from fitting the wrong components are simple examples of *poka yoke*.

Figure 2 shows a simple coil feeder [5] that provides a continuous supply of steel sheet to an automated press stamping out components, without any form of autonomation sensor, an operator would have to observe this to ensure that the tension was correct and that the steel has not run out. Simple sensors will alert the operator if any problems occur and stop the press to prevent defects being produced or even damage to the press. This allows the operator to multi-task and improves productivity and quality.

The stamping press feeds components through a small slide to load the next machine in the process, if that next machine stops for any reason, a sensor on the slide will indicate the build-up of extra components on the slide and stop the stamping press immediately to prevent overproduction of parts that would overflow the slide and potentially cause jams and extensive damage.

Other examples cover simple devices that measure the number of fasteners that are tightened and the torques that are tightened; if the correct torque is not reached or not enough fasteners are tightened, the worker cannot proceed onto the next process, therefore highlighting the defect.

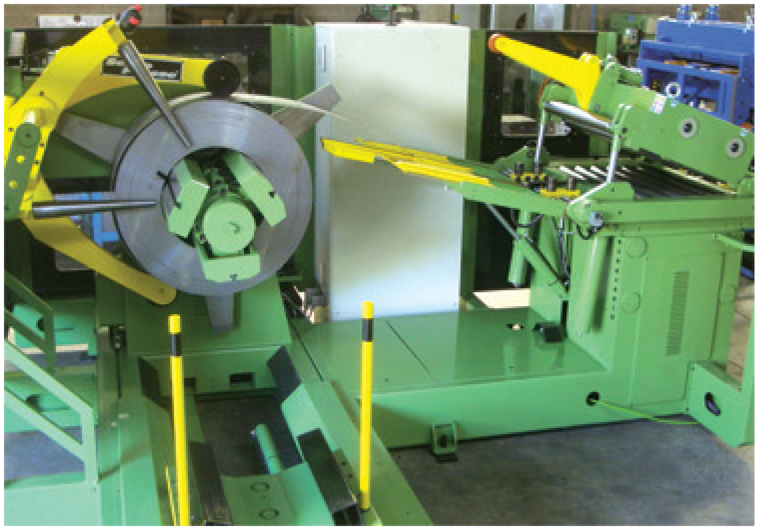

Figure 2. Coil feeder

In the 1950s, 60s, and 70s, automation relied on relay logic and often required a human operator to detect errors. This limited the benefits of automation immensely. Even in the 1950s interlocks, such as the simple limit switch illustrated in Figure 3, were available. What differed at Toyota was the extent of their use. Like many of Taiichi Ohno's methods, this is a simple idea that he pursued consistently for decades until it became a strategic competitive advantage and is being used widely in today's global market.

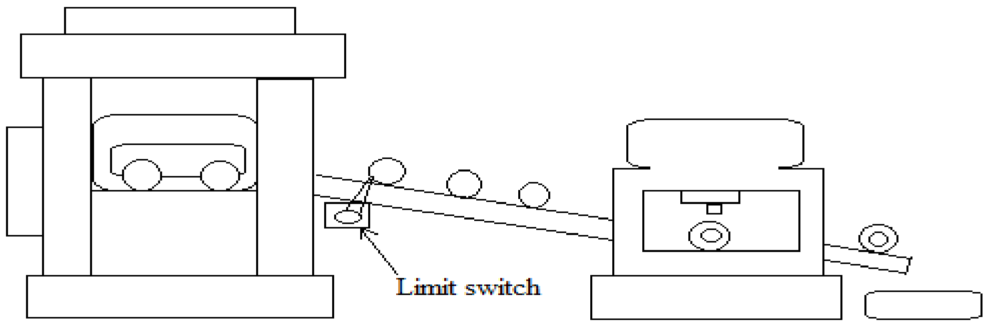

Figure 3. Autonomation interlocks: a limit switch stops the process flow when the transfer conveyor has a specified number of pieces

Different Categories of Enterprise and Their Practical Use of Autonomation

The introduction and implementation of lean production principles, including autonomation, over the last 20 years has had a notable impact on many manufacturing enterprises. The practice shows that lean production methods and instruments are not equally applicable to large and small companies. After the implementation in large enterprises belonging to the automotive sector, the concept of lean thinking was introduced successfully in medium-sized enterprises.

Most of the instruments of lean production have their origin in large companies and are very suitable for this type of organization [4]. Certain methods of *jidoka* are only recommendable for large organizations, because the complexity and the effort for implementation are only realizable for firms with enough resources in sense of qualified personnel, time, and capital.

A manufacturer must therefore identify which category of enterprise best describes his company and analyze how suitable it is to implement autonomation. Small enterprises can start by automating their manual processes and then utilize basic forms of *poka yoke* as described earlier on and large firms can move on to more complicated applications of *jidoka*. Most of the micro enterprises use *poka yoke* without knowing it, and this can be combined with automation of their manual processes to give autonomation. They, however, face challenges in the conversion, and this is explained below.

Table 2 contains feasibility studies conducted on lean methods, including autonomation, and their practical application in the various enterprise sizes.

Table 2. Cluster of lean production methods and their suitability for different enterprise size classes

Type	Lean Production Methods	Micro	Small	Medium	Large
MACHINERY AND EQUIPMENT	Basic automation	1	3	4	2
	Total Equipment Effectiveness	0	1	3	4
	Preventive Maintenance	1	2	4	4
	Setup Time Reduction	1	3	4	4
	Total Productive Maintenance	0	1	3	4
MATERIAL FLOW AND LAYOUT	Cellular Manufacturing	0	3	4	3
	First in first out (FIFO)	4	4	4	4
	One-piece-flow	0	1	3	4
	Simulation software	0	0	2	4
	Supply chain optimization	0	3	4	4
	Value Stream Mapping	0	3	4	4
	Work Station design	1	3	4	4
ORGANIZATION AND STAFF	5S	1	4	4	4
	Autonomous work groups	0	3	4	4
	Benchmarking	4	4	4	4
	Ideas Management	4	4	3	3
	Job Rotation	1	3	3	4
	Lean Administration	0	1	2	4
	Kaizen	2	4	4	4
	Standardization	2	3	4	4
PRODUCTION PLANNING AND CONTROL	Just in Sequence	0	1	2	4
	Just in Time	2	4	4	4
	Kanban	0	3	3	4
	Line balancing and Muda reduction	0	1	2	4
	Milkrun	0	1	2	4
	PPS Simulation software	0	0	2	4
	Economic lot size	0	2	4	4
	Visual Management	2	4	4	4
QUALITY	FMEA	0	0	2	4
	Poka Yoke	1	3	4	4
	Quality Circles	0	2	4	4
	Quality Function Deployment	0	0	2	4
	Six- Sigma	0	0	2	4
	Statistical Process Control (SPC)	0	1	4	4
	Supplier Development	0	1	3	4
	Total Quality Management	0	1	3	4
	Autonomation	0	4	2	4

Scale: unsuitable (0), less suitable (1), suitable (2), well suitable (3), very suitable (4)

Advantages of Autonomation

- *Increased quality:* More refined products are produced because quality inspection is removed from the final product stage to various points of production. The problem review and continuous improvement program ensures that less defectives are produced in the future.

- *Lower costs:* Problem correction at various stages of production reduces the amount of work that needs to be done on a defective product, thereby saving more money as compared to waiting until the final product is out before any correction is done at a complex stage. Autonomation eliminates the cost involved with full automation, which usually fails; the majority of the benefits can be obtained using simple, low-cost machines with the operator being responsible for several.

- *Improved customer service:* Both internal and external customers are satisfied since autonomation gives the internal customer more time to supervise rather than be correcting problems that are now done by the machine, or he is only alerted to an issue when needed rather than watching out for it. The external customer also purchases a product with superior quality and value for the money. It makes sense to customers even if they have to pay more for superior quality products.

- *Improved productivity:* The company using autonomation is able to increase production per shift since more work can be done in less time when the machines are correcting themselves. The workers are therefore used efficiently as they attend to the necessary issues when needed.

- *Reduced lead-time:* Autonomation eliminates wait time that was previously used to watch out for defectives and correct the final defective product, since this is done by the machines at various stages now. This allows more work to be done in less time. Products are therefore ready-made when the final product has no defectives to be worked on, and this is the ultimate aim of just-in-time production.

- *Reduction in equipment failure rate:* Since defectives are stopped instantly for correction, a machine only works within the scope it was designed to. Damages and losses from working on defective parts are eliminated and there is longer machine and tool life.

Challenges Regarding Implementation of Autonomation

- *High cost of implementation:* Autonomation is a cost intensive and continuous process that requires financial input to realise short and long-term benefits. A lot of companies agree and support autonomation but financing sometimes becomes a bottleneck

- *Misunderstanding of autonomation leads to misapplication:* A company must really understand that the principles of autonomation involves continuous improvement and means investing in automation to enhance human capability, rather than replacing it. Actual autonomation is centered on human-machine interactions.

- *Difficulty of small enterprises hiring qualified staff:* The lack in qualification and intellectual capital is a generally difficulty for small enterprises. Many firms suffer under the rising complexity that requires qualified persons in product development and manufacturing. For firms that are trying to introduce productivity improvement programs the presence of a specialist or an industrial engineer seems to be critical. Because of the limited budget and the only moderate attractiveness for highly experienced engineers, many small firms hire young industrial engineers coming from the university or collaborate with external consultants.

When autonomation is discussed, there is a lot of uncertainty as to its rightful application. These are some of the reasons:

- The Japanese language, from which the steps were taken, seems less precise than English, and the several meanings of *jidoka* do not translate well.
- For historical reasons, the autonomation concept of yesterday seems less relevant today and more like ordinary good sense and practice.
- The line-stoppage version of *jidoka* is a bold decision that few managers are taking and those that are not still believe to be practicing it somehow.
- The original meaning of *jidoka* in its native Kanji, when translated to English is "automation."

Conclusion

The autonomation process, presents long-term benefits that make it worth the investment. It reduces the physical and mental load on workers. Autonomation is an important component of lean manufacturing strategy for high-production, low- variety operations, particularly where product life cycles are measured in years or decades. In high-variety, low-volume situations, the time and effort required is not recommended as indicated in the enterprise table. This process of giving production system self-control is ongoing and should be adapted where possible to stay ahead in today's competitive global market.

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Biographies

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