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CONDITIONS FOR SUCCESSFUL AUTOMATION IN INDUSTRIAL APPLICATIONS. A POINT OF VIEW

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Abstract: Global competition forces developed countries to be much more efficient in manufacturing than ever to keep its industrial basis. Price is no more a result of the manufacturing process, and cost minimization is a matter of survival. This paper takes a screwer machine to exemplify in the practical field the key concepts needed to achieve this goal when manufacturing in consumer electronics. Automation is not useful by itself: there are a lot of additional requirements to accomplish its function as needed.
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1. INTRODUCTION

This paper focuses on industrial production in high-volume and in a highly competitive economic environment. Consumer electronics is one of the basic references.

In developed countries, a condition for survival is efficient and effective use of automation to compete with low labour cost countries, assuring the best Total Quality.

In fact, at the industrial level, the type and amount of automation depends on the cost of the labour factor. When in competition not only within the boundaries of the hard consuming market, but also with countries that are manufacturing with much more lower salaries (more than 10 times lower, even 20), developed countries need to put more knowledge, more intelligence and more effort to make proper use of technology and process organization in order to be much more efficacious. This means not only putting automation into the factories; this means putting automation just where it is needed, and just where it is economically justified. And this strongly means putting automation *properly*.

1.1 Market democracy?

We are the democrats or the dictators, but in fact we don’t know it. We take buying decisions not having in mind what the best buy for social purposes is, but just considering what the right choice is for each of us (or, eventually, our family).

In making buying decisions, we are voting for one or another product. We vote the type of product, its quality-price relationship, even the country or the region where it was produced. Sometimes in some kind of products people votes fancy as well.

Price is the major element of choice for the consumer. Faced with similar products from a family that perform similarly – or the *perceived* performance is subjectively similar – usually price will be the final criteria for choice.

This makes us think about what our real natural behaviour is, and on what kind of social organisational balancing strategies should be established to equilibrate this natural tendency - and specially how to implement them. But this is not the subject of this paper.

This introduction to the problem is needed to understand one of its main consequences: *in market driven companies*, as most of the consumer electronics companies are, once a product is defined, prices are fixed by the market. In the strongly global competitiveness, price is no more a variable established by the manufacturer or a result of a manufacturing process. Being able to compete effectively forces manufacturing costs to a minimum. So the task for a constant and maximum reduction costs is the main challenge in solving and managing the manufacturing problem, and all the efforts have to be made in that direction. In fact, this challenge is never completely achieved, and it is a problem never solved. Once cost reductions are made, there are, *always*, ways to reduce costs again by design, materials or productivity. Once a production output is reached at a fixed quality there are, always ways to improve production again. It is a never-ending improvement process.

Those are the tasks and the main goals for the plant and process engineers and for the purchasing manager as well.

1.2 Some figures

Imagine a plant producing 3.000 units of DVD readers, 500 TFT screens and 200 projection TV receivers per day, in many different models. But not only this: 600 mobile telephones per hour with different models as well. Working 24 hours a day: 14.400 telephones. If you plan to act in this area, you will need to comply with the concepts and practices we will talk about; if you are already there, maybe we can help you in some amount talking about our experience.

Let's define *cycle time* (or *tact time*) as the total time needed to do one operation. Let's define *throughout* as the number of finished units produced per hour.

Producing 600 mobile telephones per hour means a cycle time of 6 seconds. A 5-minute stop each day on the production line (by means of a fault, or other reasons) means 42 telephones not produced nor sold. Suppose 200 € per telephone: that means 8.400 € per hour, some 19.514.400 € per year. This figure could seem relatively not relevant when comparing with the total sales of big international companies, but this is not a correct way to think: the figure, by itself, corresponds to a lot of money, and in fact it increases the final cost of each unit produced, and this cost can induce a price not acceptable for the market – and/ or company losses.

1.3 Time to market

Another crucial concept to have in mind is *time to market*. In this highly competitive environment, you have to suppose that competition had the same idea for a product that your company had. Maybe competition had the idea before.

Once top management approves a product completely designed and marketing evaluated (virtual and/or physical rapid prototyping techniques should have been used) and completely specified, apply the Korean *pali pali*. Quickly, quickly, rapid, rapid. Fast, fast.

Immediate further work: raw materials supply, manufacturing (and the automatic systems involved) and delivery must be *extremely efficient* (figure 1). Minimizing time to market at a minimum cost is the equation to be solved by the people responsible for manufacturing.

Another point of view of manufacturing is to consider the whole process as an automatic system (figure 2), with some loops fed back by distinct technical teams.

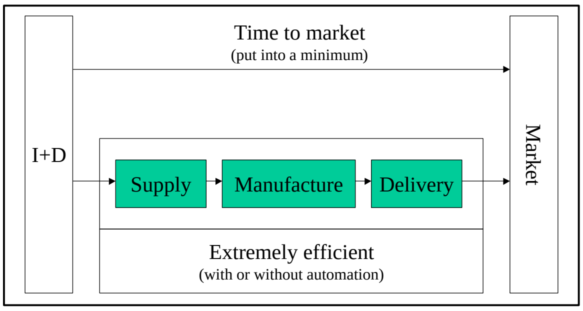

Fig. 1. Time to market minimization at minimum cost signals where to apply the conditions for successful automation mentioned in this paper

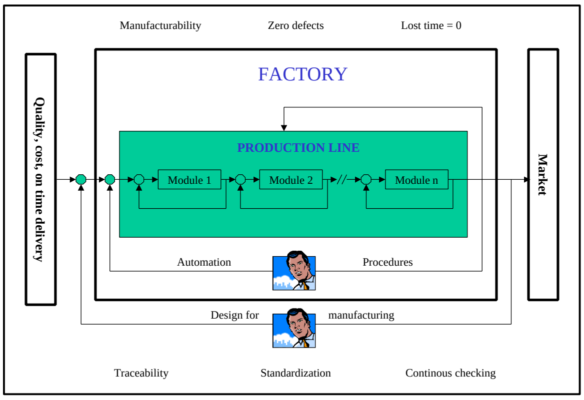

Fig. 2. A loop vision of the complete manufacturing process. Key concept fly over the whole system

2. MANUFACTURING IMPLICATIONS

2.1 Quality

Usually, the user is not concerned by technology (he wishes results). Example: most car owners do not care if 30% of their car cost is electronics. They certainly value security and comfort, and results, and even fancy, but they do not know, and are in fact not interested, in how it has been made (technology). Even they don't feel it present. But on the other side, they hate any defect or failure that move them to the garage. If it fails, they become angry.

In private life, people have in mind "*statistical error must be zero for me*". We are serving the market, we want *customer satisfaction*. So we need to translate this private mind into the industrial level.

Manufacturability is a basic concept for many of the concepts involved in the manufacturing problem, and we will find it many times in this paper. When considering manufacturing quality, manufacturability applies to the production line but, in fact, manufacturability comes from the design by providing the *right quality*, *right cost* and *easy manufacturing*. This will need a closer and jointly work between the design team and the manufacturing team.

To achieve proper quality at minimum cost, the design teams must include self-diagnostic programs for every component and its interactions, with the simplest and shorter possible sequences that not only detect a failure but also indicate where it is located. This will help not also the manufacturing team but the possible correction in the design as well, if indicated. Hopefully, designers would not forget the product until it is out of production.

Automation helps here in providing homogeneous operation. In many operations, people can sometimes make the work better than automation systems. In some operations, people perform better than any automatic machine, for the time being, but it is impossible for them to assure constant quality. Where reasonable cost is critical, inspecting the image quality of a screen, for example, is a task reserved, for the moment, to persons.

Many tools, both technical and procedural, help to achieve proper quality. From QMS, a complete information system (see 5.9), to methods supported on 6s policies.

<u>Focus on</u>: Zero defects.

2.2 Cost

Final manufacturing cost will be influenced by product design, maximum line efficiency, and the so-called *loss time* led into a minimum.

Product design. The manufacturability concept appears again for the designing team to combine the features and quality specified with the simplest possible parts, the minimum number of them and the minimum number and complexity of the assembly operations. The packaging area is concerned from the design as well.

Automation helps here by simulating the weak points and the assembly operations, avoiding machine incompatibility and simplifying the assembly operations. Software also exists to simulate the manufacturing process, step by step and as a whole.

Maximum line efficacy. It is related with line speed, which it seems has to be always improved to be *maximum* (it is in fact as rapid as the slowest system in the line).

Automation *helps here* by providing speeds higher than the operator one. But with three crucial ideas to consider:

1. Automatic systems have to be planned with a speed higher in 20-25% that the regular line speed. This is because, in case of a line incident, you can, on a short time basis, to ask people for an extra effort in order to recover lost production, and any phase of the line could, under this circumstances, act as a bottleneck if not foreseen.

2 Often, maximizing line speed is not the optimal criteria for maximum line efficacy. One can, for example, find line vibrations in conveyors, source of quality losses and repairing times. Get the maximum efficacy by good analysis of this kind of factors.

3 Finally: very careful with high speed systems. A *too much* high-speed system is nothing when it stops. It is usually better to be more conservative but assuring constant proper running. Always verify reliability, robustness, quality and efficacy.

A task of the process manager is to fix a tact (cycle) time goal, and to plan general work for that target. Once reached, a new and more demanding target has to be defined. Improvement never ends.

Another important concept when applying automation is to provide further evolution, meaning the systems have to be able to be upgraded at a reasonable cost. Step by step, but continually improving. And have in mind that a proper tact time in a particular moment fails to be acceptable from then on.

<u>Focus on</u>: Optimal line speed.

Loss time. This term is defined by the time corresponding to the difference between the number of final units that the line could produce during one hour at its optimal performance, and the real number of units actually produced.

Methods as SMED (Single Minute Exchange of Die) were put in place by Toyota in the 80’s (Shingo, 1985). Single elements as bolds, levers, limit switches, labelling, cranes, and a large etc, combined in a suitable manner and with strictly defined procedures, allow to reach the big challenge: loss time → 0.

Four are the technical factors influencing loss time: quality, maintenance, feeding times and productivity.

- *Quality:* Measured in percentage, it is the number of rejected units produced.
- *Maintenance:* Usually measured in minutes per week, it is the time the line has to stop for maintenance purposes.
- *Feeding times:* Usually measured in seconds per day, it is the time needed to fulfil the machines with the consumables (screws, labels…)

When adding these three factors, subtracting the result from the maximum possible performance, and comparing to the measured reality, one observes that it is still under this value. Where is the difference? The difference is related to productivity. One even observes that this difference is the biggest value when compared with any of the previous ones (figure 3).

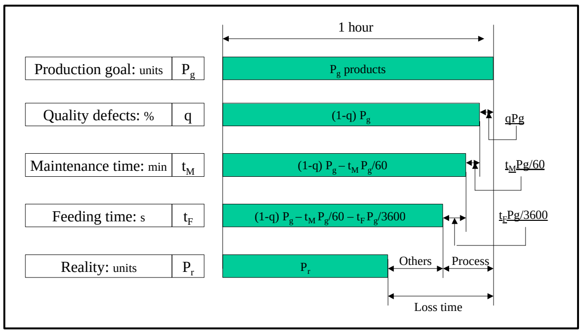

Fig. 3. The key role of the productivity in the efficacy of manufacturing. Loss time includes losses by quality defects, maintenance time and stop time for consumable feeding. The sum of this three losses results in a value lower that the measured reality. The difference is productivity.

This clearly shows the key importance of persons in manufacturing and in manufacturing automation. That's why we mentioned people as the first requirement. Positive people and motivation are musts for succeeding in minimizing loss time (see 5.1).

When implementing a new improvement, preview reversible steps and have control on each one.

What if line stops? It must be prepared for stopping in a tidy, well-organized and controlled way, along with and a friendly restart. The faulty screw must be ejected outside the DVD frame when the screwing machine is in trouble or, alternatively, when the line restarts.

<u>Focus on</u>: Taking people into account as the first requirement

Loss time → *0.* Correct policy for the top management is to ask for loss time → 0. This results from:

1. Minimizing the three technical factors mentioned before (use SMED techniques, see 5.6) and maximizing the forth one.
2. Minimizing the time between the decision to implement an improvement and its real implementation.
3. Doing things well done at the first time. In terms of automation design it means avoiding corrections once installed and, in process terms, be organized to achieve that all the finished products were between tolerances in order to avoid final inspection. And this without any increase in cost, either direct or indirect, both internal or external.

Automation helps here in many ways: improving quality, reducing maintenance time and providing optimal feeding. But also by simulating procedures by means of modelling programs.

<u>Focus on</u>: Zero loss time

2.3 On time delivery

Customers expect to receive the product on time. This means delivering at the expected date, reducing lead-time. In such a way that the customer receives the material at the expected time: delay from order to delivery has to be lower than, say, five days on average to serve the European market. It is also important to be able to answer a customer, who is calling for his order, where it is and when and what time it will arrive. This is a way for customer satisfaction, one of the components of a driven market company.

Automation helps here by using many concepts that are being in use (from advanced planning systems to global positioning systems) and others under development, i.e., when recognizing intangible properties, now made by humans: looking at a monitor screen, hearing quality of sound…

GPS is a system full of automation techniques focused to know the current place where the finished product is during its transportation. This feature requires, indeed, a lot of office automation.

2. DESIGNING AUTOMATION FOR HIGH VOLUME COMPETITIVE PRODUCTION OF GOODS

So the role of the process manager in charge of automation is to help the production line to manufacture goods at always improving requirements. Sometimes it can be difficult to reach, but it is *always possible*: automation makes it possible. But remember: automation is not always the right solution, and automation, by itself, is absolutely not enough to achieve these goals.

3.1. Is automation needed?

How to repeat a paragraph:

When writing in a PC it is often necessary to repeat a word or a paragraph. What is the first method that comes in mind? The use of the automatic and familiar *copy and paste* function - and the junior automation engineer of course makes *automatic* use of it. But the experienced user of a word processor knows already that, often, if he wants to consider efficacy in terms of typing (and clicking) time, the best way is to simply re-write those characters.

What the decision criteria to better proceed are? Many, and they should be processed very quickly while editing: length of the word or paragraph in terms of number of characters; character complexity; distance, meaning finding time between current document, page and line from one of the previous writings to copy...

Considering the duality time-cost, this example takes us to a first conclusion: in the real world, automation is sometimes not the right solution for a given process.

In practical manufacturing automation, engineers have to decide fast about the implementation of a new method: whether manual, semi-automatic or automatic and, for the last choice, to what extend the complexity and cost of the machines, subsystems and /or instrumentation should be.

3.2 The needs of automation

We have seen that automation strongly helps in most of those areas, and high technology is nowadays available to push these needs at very high levels. Electronic component inserting machines, for example, are able to treat 10 components per second, with a positioning precision of 0,001 mm. This machine, working 24/365, must not alter the operational stability of the production line.

But more than automation by itself the challenge is to make it properly running. High technology - if needed - is not enough to guarantee that those manufacturing implications are achieved.

It is easy for a new engineer to design a sequential control. With some work, he can design a complete production line to produce a good. A good team can even achieve a cycle that is considered correct. An experienced team could successfully put in final places many boxes with hundreds or thousands of units each at the targeted *time to dispatch* and *time to delivery* (TTD[2]). But, what do you need to keep the same performance 24/365?

The automatic systems implemented must consider all the environmental conditions, must be simple, its application must be rapid, it must be flexible and, indeed, the simplest possible. As simple as it can be temporally replaced by persons. It is not acceptable to find that it needs to be removed or corrected some time later.

The big mistake where the vast majority of we, engineers, fail, is to believe that automation solves the problems *automatically*. But a vast amount of external factors influence the projects success.

For a manufacturing engineer dealing with plant automation, it is critical to have in mind that proper automation is much more than a matter of mechatronics, mathematics, algorithms or arms: the real problem is to define the environment conditions in a complete and consistent manner. And to have in mind that, where there is a need for a system to control the quality at the end of the line, there is an engineering team that does not have enough knowledge on what's is really happening on it.

It means not only reliability, but also a high degree of robustness, and this is often more way-of-work dependent than technology dependent. For example, processing power is today much more higher in a standard car than what it was in the Geminis shuttle. Servo-steering, airbag, ABS, air-conditioning, EDS…

3.3 How complex?

Technology allows nowadays the implementation of a big data processing system to control all the operations of a set of complex automatic machines to operate them. We have the software, we have the mechanical concepts, the mechanical and electronic hardware, the software… but we still don't have the way of implementing it with enough efficacy considering the needs mentioned.

In fact, the use of such a system is a weak organizational point. Two are the main reasons that experience shows can support this statement in order the line not to stop: single component failure and model change.

Single component problem. When a single component fails, the whole system could stop, and we already know that this is not acceptable.

Model change. Model change might happen more than 15 times a day for a lot of economical reasons (see 5.7). When the line needs to produce a different model, the number of parameters to be changed could be as high that, providing you cannot test off-line, the line becomes the test system. But the line has to be able to assure perfect quality at any time. Lack of flexibility is not acceptable.

Not only the highly sophisticated machines or systems are very expensive, but also the costs involved are excessive and, usually, not explicit. So the payback is very long. Usually, you cannot know its value, but be sure it is not acceptable.

The practical answer to this situation is to implement distributed automation, as simple as possible, which can be supervised by non technical people, that could eventually be replaced by a person (or a number of persons) and to link - operationally, avoiding data processing connection as far as possible - any number of them as much you need.

The lesson here is that it is better, at least in high volume consumer electronics production, to ensure a number of single task automatisms successively arranged than complex systems that make the whole work. If, for any reason, some of them are interconnected, include autonomous running modules that start when in trouble: it will be better to have a line underperformant than a line stopped. So integrated systems for this kind of needs are not recommended.

The curve “automation system complexity versus global factory efficacy” has a Rayleigh shape, which maximum value signals the optimal amount of complexity to implement at the factory (figure 4). This maximum degree of complexity could be defined by the ability to substitute the damaged machine by people, during *reasonable* periods of time.

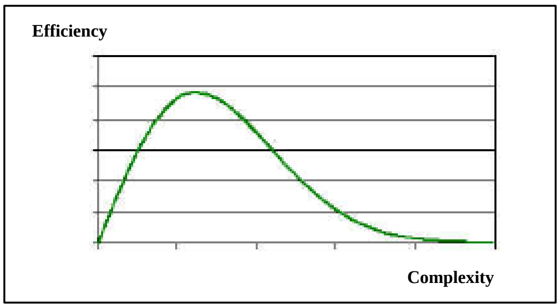

Fig. 4. The Rayleigh shape of the efficiency vs. complexity curve. The maximum signals the optimal complexity to apply

With all kind of components, both software and hardware, both for plant and office, both for data processing or the mechanical, pneumatic, hydraulic and other supplies, improvements are not attained by looking at the top. It is better to agree with a standardized provider who supplies standardized items and provides a path for evolution.

3.4 Do work systematically

The long time respected business guru Peter Drucker strongly maintains, and repeated in an interview published in Industry Week in 1998, that “if you define manufacturing as the production of things - and even if you extend the traditional definition to embrace the entire system of bringing a product to a market, I disagree with the assumption that manufacturing is the most important part of any world-class economy. But I emphatically agree if you extend the definition to read ‘*the systematic process of production*’ whether the end product is a ‘thing’ turned out in a factory, an ‘intangible’ such as software or a ‘service’, such as a mutual-fund share”. Some companies have gone far from the principles he presented in his best seller (Drucker, 1989). Peter Druker announced new elaborations on the four principles and practices included in his work (Panchak-Drucker, 1998).

More from Drucker: manufacturing is still totally based on Taylor. We know that we now need to act quite different. But we need to know what Taylor said about manual work and the manual worker to know what the difference with the knowledge work and the knowledge worker is. The key question is that “all work on the productivity of manual work asks how should the work be done. It never asks what should the task be. And that question must be the starting point of any work on the productivity of the knowledge worker”. But “the change is not primarily a change in technology. It is primarily a change in social organisation”. Even: “in every organisation we will have to be able to be organized for three different tasks: 1) We need hierarchy”, specially when we entering a period of rapid change. “In a crisis there has to be somebody to make the final decision. Everyone needs to know who the person is, who has the right to be obeyed (...) But 2) the same person also will have to act as a team leader... and 3) in other situations he will have to act as a team member and partner”. Three different roles for everybody to play: how many people are trained for effective communication in each of them? (Panchak-Drucker, 1998).

The rules of the game in new product development are changing. Many companies have discovered that it takes more than the accepted basics of high quality, low cost and differentiation to excel in today’s competitive market. It also takes speed and flexibility (Hirotaka, 1986).

4. LESSONS FROM THE SCREWS

The operation of screwing is performed by a person. All day labour journey long screwing. It is a tedious and non-creative job, and those would be the sole reasons for automating this post. It is a disease-involving task, and its dignity for a human being makes it hardly acceptable. In economic terms, human errors could occur, and even this sole worker could stop the line.

Solution? Put automation in this post. A screwing machine.

But it is not so easy. Screws that before were making its role properly now don’t. They are not homogeneous in shape, and the angle of the gap does not match the existing tools for the existing machines with the characteristics (precision, repeatability, speed, reliability) needed for the operation. The reason is that the operator was acting as a filter, absorbing little defects, but machine does not.

With the machine on the shop floor, you have to recall the worker to screw at hand. The employee will not screw with the same motivation, so his o her number of errors increases.

The number of times for the screwing machine to stop can be calculated from the number of faulty screws. Supposing 1/1000. Every DVD reader has 4 screws, and the production output is 3000 DVD per 8 hours day. 12.000 screws that will stop the line 12 times a day. How long each one?

Experience shows that each incident in the production line induces an average of 3-4 more units failing production (and inversely, an improvement on producing that avoids a failure means 3-4 more units produced). The reason is that repairing time is unpredictable (but must be minimized, see 5.8). So 4x12 = 48 DVD not produced. Assume selling price is 200 €. Roughly 9.600 € lost per 8-hour working day. A loss in sales 5,808.00 € / year. But the factory is running for 20 hour a day. The total loss is 2.904.000 € / year. Same figures than those calculated for mobile telephones. Absolutely not acceptable. Machine depreciation, another cost factor, seems very few compared with that cost implication.

You ask your screw manufacturer to make the type of screws you need. He takes some weeks to comply with your requirements and finally began to supply the expected material. In little amounts? No, he wants to be a good partner and doesn't want you to be worried about the screws for long time.

You use the new screws. The screwing machines runs very well. But suddenly it stops. The line stops. What happened with the screwing machine? No, the problem is still the screws. Its quality is not homogeneous due to the type of steel used.

You have to discuss with the screw provider whether you will pay or not the high amount of screws supplied. Energy (cost) wasted. Decision about to change the screw supplier. Need to look for a new supplier. The current supplier accepts a good deal for you concerning the last supply and you accept to make a last test with him. There is a new operator, still a practitioner, and first day he does not perform very fast and is, to some extend, irregular. Add costs: line variability, (cheap) screws unused, and storage, need to get them back or to throw them away. Time lost.

The screws material will be changed. But, one month later, the supplier recognises that he is unable to produce the quality and quantity of screws you need. Fortunately, the screwing worker learned already his work and performs reasonably well. But the machine is still not operational. If the engineer responsible for the project is new (or even if not) some people begins to smile maliciously... this, will be, sometime later, a cost as well.

In the meanwhile, the marketing department convinced the top management to change the shape of the product. The plastic parts would not assembled with screws; welding process is being considered. What about the new screws? What about the machine? What about the time consumed?

If a manager, when budgeting, would have taken into account all the costs potentially involved in putting automation in this operation, it is possible that he, compelled to consider a "reasonable worst case scenario", decided not to automate this post for the moment. Before that, he must be sure that all sides of the problem are understood and correctly planned. It is better to preview some time for an engineer to precisely analyse the problem, consider dangers, quantify them and, next year, (eventually, not sure) proceed to automate the screwing task.

5. KEY POINTS TO HAVE IN MIND

5.1 People

We have seen, when considering loss time, the strong influence of people in plant efficacy. This is the first and critical point to have in mind when managing a factory. This is the most important point if you wish to succeed when implementing a new automatic system or machine.

A new automatism planned for the improvement of any of the issues concerning production must fall in a favourable human environment. The key concept for everybody is that *"this is here to help me"*.

We are trying to avoid persons to screw. Palletization for delivery purposes is another non-human task: robotize this post. It should be easier than automatic screwing.

But consider other sides as well. Automation should be friendly to the people that are going to use it continuously or eventually. "Sell" a new system to the production manager and the maintenance manager. Count with the operator to substitute or to be in charge of it.

Consider always that the operators know very well this particular phase of the process: they work in it hundreds or thousands of times per day. Count on them when defining the new system. And, when implemented, ask users, after a certain running time, what they like and what they would improve. Operators will tinge frequently in the good direction. Do it from shop floor managers to line workers.

More: the impulsion allowed by a new system or method must be kept in terms of strictly accomplishing the regulations involved. People tend to flag some time later the initial stages, mostly when enthusiasm wakes, motivation is not very high or too much problems (subjectively) happened.

This causes the efficacy of the improvement fall down. If you don't pay attention to correct this situation, the effect is cumulative and, after the successive improvements an important loss in it its efficacy is induced (figure 5) (Standard, 1999).

Effectiveness of movements is another side to have in mind. This means minimizing pick and place times, with an amount of effort no more than strictly needed. This is to avoid physical troubles and keeping health, safety and, again, good working climate. This also means short displacements within the factory for everybody. Layout simulation programs can help.

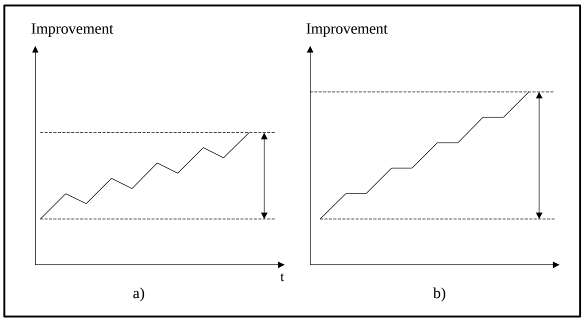

Fig. 5. The importance of motivation and procedure documentation. a) Failure on keeping improvement impulsion of a new system or method; b) Improvement impulsion kept

Be very careful with the net substitution of automatisms by people. If, as a result of a new improvement, you hire people and that is considered a consequence of the new system, climate could turn down and further improvements could be more difficult to apply (Standard, 1999).

Focus on: Motivating people: big improvements will happen.

5.2 Environmental conditions

The screws and every other issue are already correct for the screwing machine to work in a non-stop basis. The screwing machine is already implemented on the production line, at the beginning of the fall. After many weeks and months, he keeps running without any incident. The whole factory is happy.

But 9 months later the machine stops again. When restarting, the machine runs for 10 minutes, and stops again. Restart, and it runs for 3 hours. Everything seems to be in order; anything seems to be different from what it was until now. Engineering meeting. Anybody knows. Let's substitute the machine for a person temporarily.

Further on the line an operator indicates that the screen of a PC turned blue. It is blocked. Fortunately, this computer is just an information system and not a critical element for production.

What about power supply? Plant manager contacts the electrical company: no problems registered on the quality of the supply at this particular time and area. But he receives a suggestion: the problem might occur in the connection between the transformer substation and the factory.

Yes. North Mediterranean climate characterizes for 2-3 very warm and dry months long (June to August), followed by a storm time 4-6 weeks long. Dust accumulated on isolators, and suddenly wet, failed its function and slightly and randomly conducts. This malfunction alters the quality of the power supply and induces power supply failures longer than 1 µs. Only in August-September.

So the power supply of the screwing machine must be stabilised already in January (there is a possibility that this kind of weather cycles occur at any moment). Not only you should stabilize the computers with proper UPS systems: you need that every time computers are reset, its free RAM memory is filled with stack instructions ordering the system to restart immediately without any human intervention (minimizing loss time). Provide fast operating system and program loading. Consider having the operating system on ROM.

One of the systems with more compelling environmental conditions are car radios, cassettes or CD. The car manufacturer needs to take into account that this car can run along the Sahara desert and visit the North pole some time, so the temperature margin comes from +40 ºC and –25 ºC. No: when the car is under the sun and completely closed, the interior reaches some 60-70ºC. Plan the system for this conditions and you will still fail: in the North pole, you are very comfortable inside the car at, say, 22 ºC, and when you open the door the temperature falls 40 ºC. So the degree of the gradients has also to be considered for success.

Plastics injection moulders know that machines mostly fail when restarting work after some stopping time: early in the morning, after holidays… To avoid this situation one can operate on a 24-hour basis or it could be useful to maintain the machines at suitable temperatures.

Count also on this factor when implementing automatisms in the line. Think that the screwing machine may not be ready for operation on Monday morning when, just at the start of work, temperatures can reach 5-7 ºC.

Other sources of problems can be originated by *electromagnetic interferences* (EMI). High voltage spark generation is a good way for testing the EM robustness of an automatism to properly operate in production line.
Mechanical shocks have to be avoided as well. The screwing machine must absolutely not contact its front panel.

Consider also that automatisms that could well operate in California are not sure to operate properly in the forests of Brazil (wet) or in Moscow or in Barcelona. And inversely. More: are *tectonic* movements equal in Barcelona than in California? Does California need to stabilize the factory floor for a highly integrated circuit manufacturing plant?

Finally, we can consider consumables and an environmental factor for a machine, so proper feeding is needed (see 5.6)

Focus on: Temperature, humidity, power supply, EMI, dust, shocks, feeding conditions…

5.3 Cost effectiveness

We have seen that the screwing machine, on the paper, was of course cost efficient. But reality showed it was not. Be very careful about that when budgeting or implementing.

Machine payback in short time (6 months as a maximum) is recommended. Analysis should be made and only if quality assurance is considered, and value not measured, it can be considered. But when dealing with payback, one must consider much more than what it was explicit in the economical analysis. In fact, the goal is to gain competitiveness through the bottom line. Some factors influence it in a positive manner; others operate against it.

The factors that operate against the payback (considering bottom line) are as many and often unpredictable (they must be predicted!) than those set as examples when inserting the screwing machine on the line (remember it is still not running). Good documentation and avoiding line incidences help to reduce this side of the payback.

But there are two main factors that operate for the bottom line to be improved: they are quality and safety.

Safety is important by itself (see 5.10), but also to get healthy human climate, key condition for successful automation in manufacturing. Please allow us to insist in that point.

Quality and security are directly related to productivity, but it is impossible to quantify it.

Focus on: Considering all factors influencing the bottom line when dealing with payback

5.4 Materials handling

In materials handling, consider all extreme conditions this material may arrive by itself or by the forwarding system, and minimise the recovery system in case of failure (SMED).

Manufacturability. The term appears again indicating that design had to have in mind avoiding complex assembly, joining or welding processes. Packaging tasks are affected by manufacturability as well: boxes must be standard for maximum efficiency in truck disposal, pallets must be uniform. Beauty packages for impulsion selling purposes are not useful if they arrive damaged to the distributor.

Manufacturability is a concept applying not only to the product quality but also for the process quality.

Zero stock in raw materials. Valid as a goal, but unreal. Procurement time is higher than delivery time, so a kind of accordion is unavoidable. Good planning by automatic data acquisition in customer forecasting and other variables are ways to adjust our own forecasting and implement optimally predicting policies.

Of course it is not useful to receive the screws one by one from the supplier; some kind of storage is needed for consumables

Process layout. Optimal disposal of the production units has to be simulated for minimum transportation time inside the factory. Avoid, as far as possible, the use of transportation systems such as long conveyors, automating guided vehicles (AGV)… which are often a signal of inappropriate layout.

Palletization. Algorithms for palletization, operation that can also be simulated, are needed in order to optimise the volume of the transportation needs considering the type and amount of orders received. Out of the factory, transportation to customers with control by global positioning systems (GPS) is concerned.
Zero output stock. Market driven means we are producing what it was already sold. So there is no need for stocking, and once packaged the box has to go directly to the transportation system (usually a truck). Time to shipment (TTS), that follows time to dispatch (TTD), has to be targeted to zero.

We saw what the problem is when an epidemic error appears in the line. Imagine a product losses fancy or competitors put a similar product on the market with a very cheaper price: we may down costs even more, but there is a practical limit: not to produce it anymore is an option. So what if you have an output stock?

When working with margins from 0,5% to 1% every saving is important: financial savings of course. Having an output stock means financing, and this could mean credit needs. It is enough to finance customers, even if they pay a week later than delivery.

We talked about the delivery goal. So the flow between end of line, palletisation and transportation must be continuous. Here stock zero is not only a goal, but also a need and a reality.

Focus on: Zero stock and SMED

5.5 Checking

We know that, unfortunately, the screwer machine was not tested enough and loss time produced result in losses for the company bottom line.

Test new automation systems. When buying automation systems, it is not enough to certificate providers. Extensive tests must be conducted for each system not in-house, but in the provider's house. These tests must have to be in charge of the responsible of the acceptation of new entries. He is also responsible for the compliance with safety internal regulations and environmental impact.

When a system is developed in house, the same tests have to be conducted exhaustively off line.

It is important to be cautious with the results of the preliminary tests because, being off line and the environment conditions being different than in laboratory, results could be different when in line. So having in mind all the functional environment conditions is again very important. Be careful also with the test manuals: they exist from failure history and one must anticipate new problems.

So when new systems, once checked, are to be implemented on the line, one must run failure sequences to test the system on line and even testing the fault detecting systems.

Avoid final inspection. Checking must be implemented all along the line, at the output of every production phase or automation module, with the goal of avoiding final full inspection. It means that, if there is a manufacturing fault on the production line - that has to be quickly solved at this particular phase - further time-consuming tests must not check the parameters already taken into account in previous operations.

The use of statistical methods such as SPC is unsuitable. It reveals a lack of knowledge on what is exactly happening on the line. It allows bad products to be put on the market, source of lack of company image and confidence on its products. Customer satisfaction suffers.

We can even consider that the need of any checking reveals lack of enough knowledge on each particular operation. In fact it is. So make sure to check at every stage.

When checking a process, assure physical variables, but also the recovery system automatically (SMED)

Test the testing machines. The designers must have into account the manufacturability concept by, among others, provide sequences of self-diagnosis and various ways of help for the diverse tooling systems. Even they have to include some trapdoors devoted to test the testing machines by misleading them.

Focus on: Zero defects, minimum test time

5.6 Feeding

Our screwer machine needs to be fed with the panels or the result of previous phase and with screws as well.

Define how to feed the machine (screwer machine, stapler machine, label disposal machine…) in such a way no loss time is produced by a person *with no technical skills*.

Changing operators for a label disposal machine or improving a label printer. Not so easy. Don't only think on the printer. Think also on ribbons of labels. More: on the carbon paper.

Labels are fed in the form of continuous paper support, but the paper is not really continuous, as the ribbons must be replaced regularly. But carbon paper is also sometimes needed and, if the engineer fails in realizing that the length of the copy paper ribbon is different, you will have two stops. Imagine if you have two or more printers. Time losses grow geometrically. This little project fails and costs in non-producing grow.

Focus on: SMED

5.7 Flexibility

Producing in small lots is a result of planning, but it has other advantages: if an epidemic error appears on the line, small lots mean limited effect on costs; serving in small lots limits the stock size of the distributor customer; to serve high amount of units to a single customer could result in not properly serve another customer. Remember the value of customer satisfaction.

In consumer electronics the selling price decreases continuously once launched. Cost can be revised by redesign that may happen several times a year. In same line different models (electrical, physical...) require no loss time even if model change is necessary many times a day.

Rapid model change – not only restyling - is one of the strongest issue to worry about. Cutting tools, moulds or dies, for example, still need hours to be changed in many factories: they must be changed *in less than a minute...*

The screwer machine should be not only programmable but also with auxiliary components organized in such a way changes are easy and fast.

Apply SMED for model change and any other physical operation. And consider manufacturability again, in the sense that a model needs to be sensible to previous models, and indicate, in jointly work design / manufacturing, how to obtain no loss time when changing some line functionalities.

Fortunately new automation is full of reprogrammable software, which has to be ready of course for the models being produced, but in making suppositions about new models to come as well. They are able to arrive suddenly without previous advise.

Other mechanical components are involved, which have to be chosen properly and whose layout interconnection has to result in a flexible system.

Focus on: 0 seconds or SMED

5.8 Productive maintenance

Reliability is a term describing the assurance concept applied to measuring and positioning, to repeatability, In brief, to the complete operation.

But at the industrial and manufacturing level reliability must include other factors as *robustness*, error control (*fail not found*) and assurance of the proper running with *zero stops* and *zero in line quality defects*.

Reliability of a machine is a combination of the reliability of each single component; reliability of the whole line is also a combination of each single component. *So the natural trend for the line is to be in trouble*, and its stabilisation is the work of the plant engineers. MTBF of the line system must be maximized acting in several different ways.

When dealing with software, use the network as far as you can. Some providers offer remote maintenance (upgrading software, remote diagnosis or remote repair). System control has to be in house, but better if you have external qualified support. Make all the necessary tests and obligate them contractually. Put them under test on a regular basis.

Predictive maintenance. When buying a machine or system, suppliers must include a complete guide for maintenance. We need to know the recommended life of each component, and the manufacturer has to advise, in a commitment way, when to replace each one.

A frequent error when designing a new automation system in house is not to have in mind reliability when specifying a new automation system. It is understood by default that the system will be reliable enough.

So when designing automation in house, exhaustive off-line checking must be made and a complete and clear maintenance manual should be written as if it was externally acquired. Expert maintenance systems help in establishing the replacement periods.

Preventive maintenance. One particularly effective way to go on that direction is *standardization*. Standardization avoids experiments on the line, reduces supply times and provides work with what it is already understood and tested. Standard materials and components may limit a design, but might assure the machine maintenance at a reasonable cost-time relationship and reducing spare parts maintenance as well.

The standardisation of the measurements, for example, avoids human errors and allows more homogeneity in the product quality.

The use of PC's, widely accepted, must be very careful in terms of robust hardware already available on the market (dust, electromagnetic compatibility facing both power supply and ether), but particularly about software. Don't use the latest version until it is wholly tested under the hardware identical to the hardware already on the line. Standardize hardware providers, operating system, programming language and database format. Summarizing: obtain a *deterministic system*. And be sure people involved knows this software enough.

The same applies for numerical controls if present and programmable logic controllers (PLC).

Standardisation should come from the design, where new models should consider the use of components of the old models that have already showed its proper behaviour (providing environment conditions are equivalent). Standardisation is a component of the manufacturability concept.

Reactive maintenance. All about, problems occur. So ensure effective repairing by being *emergency ready* anytime, anywhere: have the "emergency kit" and spare parts close to the system involved, be sure these parts are correct by testing them on a regular basis, keep this particular maintenance manual behind the machine… In short, ensure that the maintenance cycles are properly done and test the response time for an incident; take policies to minimize them as well.

Test new automation systems. When buying automation systems, it is not enough to certificate providers. Extensive tests must be conducted for each system not in-house, but in the provider's house. These tests must have to be in charge of the responsible of the acceptation of new entries. He is also responsible for the compliance with safety internal regulations and environmental impact.

When new systems, once checked, are to be implemented on the line, one must run failure sequences to test the system on line and even testing the fault detecting systems.

Tooling, spindles and each mechanical component for machining, handling, assembly or packaging have to be chosen having in mind *easy adjustments.*

Maintaining the test systems. This drives us to a new idea: the electrical isolation of each DVD unit must be tested under 2.000 V because of law (and even without law it would be necessary for safety and quality reasons). To ensure that the system is properly running, you must establish a maintenance procedure that makes the system activate the alarm detecting a non-isolated frame.

So the usually silent test units must be regularly verified by activating the alarm output: we can name it a counter-test for an automatic testing device.

Maintaining the maintenance systems. Don't forget to maintain the maintenance systems, and remember also to eventually update the computer aided maintenance software.

All about, the line stops. All the precautions taken, the line will stop somehow. A simple switch or lever near a person who is working in a different job is needed. It should be managed by people with no technical skills and in short time. For loss time → 0 purposes, restart time should be not higher than 1 second (remember SMED).

<u>Focus on</u>: Minimizing the impact of maintenance on the line.

5.9 Information

We had to discover that the problem with the screwer machine was the screws. This is not the best way: information must be exhaustive, information acquired must be relevant: at least we know how many screws were used, the cycle time of the machine, its electrical consumption.

Information is key for the efficiency of the whole factory. It is involved in many processes: checking tasks, process information, operation procedures, maintenance procedures and delivery (note that there is no stock).

There are three different access levels to information: *job manual*, for basic operating and maintenance instructions; *technical manual*, a step higher in complexity; and *expert manual*, for deep knowledge.

Particular product information. A *genetic* bar code with this information has to be granted to each individual product, all along its useful life. This is not only for further maintenance purposes, but to be able, by means of traceability, to follow back and to eventually rectify a the production process accordingly, or even the design.

Specification of automation systems. One must establish what could be called a "Technical specification procedures and general regulations for the machinery and installations" handbook, both for the external systems bought and those designed in house.

It must be detailed, containing:

- Technical data sheet, schematics, mechanical and electromechanical design
- Running regulations and safety for the electric, pneumatic, hydraulic and mechanical components
- Every software version with its releases and justification for change
- Data sheet of the components used
- Material references (providers and serial number)
- Software in back up on tape or CD
- Documents containing acceptance by the production, quality, engineering and maintenance department
- Document from the project evaluator
- Document from the technical manager or the person responsible for the project

Establish a control for the acceptance, the guarantee, delivery delay and payment. In Europe it must be, at least, CE compliant.

Each system needs a running hypothesis. For this purpose it is key to train the final user clear initial conditions to be respected for proper operation. This task is made when implementing the system on line and training for the first time.

Process information. Every task performed for every product to manufacture has to be recorded in real time both for further statistical analysis and for *traceability* purposes (figure 6). Traceability means that all product data and every process operation for every produced unit has to be recorded and kept with reliable back up systems. And both physical and electrical values should be taken into account. Completeness is here the main concept.

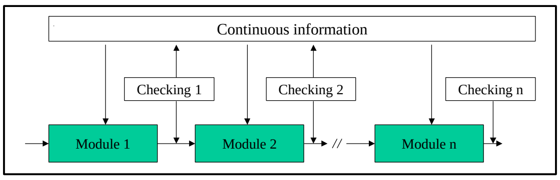

Fig. 6.- Integrated process information and checking system. Successive tests don't look at parameters already checked in previous steps

This information system has to inform about:

- Daily production plan
- Spot theoretical line speed
- Spot real line speed (finished goods)
- Balancing the sets that should have been finished and those that are not
- Line speed (goods per hour)
- Defects (sets and %)
- Already repaired and repair pending (daily and cumulated)
- Production command
- Current model on line

When lacks of quality, one can get down to know, for example:

- What defects has a particular unit with a particular serial number

- How many units have the same defect
- What are the three main defects
- Etc

This system allows to feedback:

- To supervisors, leaders and operators of each level about how they are producing in terms of quality and productivity
- The engineering team about the epidemic defects of the product
- The quality department about the supply level of each provider
- The sales department about the accomplishment of the orders
- To planning department about how to plan the MRP, production orders and quantities to match the sales plans
- To technical services or customers to know when a particular product has been produced and where and when the fault has appeared (factory repaired, transportation…)

Operation procedures. Operation manuals for each machine or system in a "*how to" structure* should be available at any time and have to be located behind the machines. New or substituting operators when ill would need it frequently even if they have been properly trained.

Maintenance procedures. Clear troubleshooting manuals have to be put in each station they could be needed, written in a *"problem – answer – action"* structure. Those manuals should be alive, not only in the sense that each new event has to be included but also in upgrading its clear and operational writing.

Delivery information. How many boxes per truck with what kind and number of products each, output time, GPS control for localisation purposes and confirmation of correct delivery to the client

Follow-up and analysis. Carefully define key parameters measured and others calculated that you think are relevant to you, and provide a system that allows to show those figures every time you want, in real time. Don't forget to reconsider constantly if those are the most relevant, and if you can obtain new indicators. On the other hand, select a number of parameters you – and anybody in the managing team – can easily understand. *Format of presentation* is more important than usually thought.

For every parameter, establish the period (daily, weekly, monthly…) you want to be informed about.

Generally speaking, all procedures have to be clearly described not only in an *Intranet or Extranet system query-oriented* but also in print form. Manuals have to be located near where they are needed (a long course to the office looking for manuals makes loss time grow).

<u>Focus on</u>: Constant improvement on exhaustive and clear information.

5.10 Safety

The screwer machine is healthy than human operation, but…

Machine should not make any damage to persons or goods in the line by all means. All worst cases should be considered. Meet all the safety standards (ex: EC) not only because law.

Because in industrial plant operation, we have very good news: safety is not only a human must, but also a profitable economic investment. Costs involved in accidents are working climate, absenteeism, company public image, damage on properties…

Automation systems must avoid, as far as possible, cylinders where operator can see his hands got caught: a physical protection is needed, or alternatively a security barrier which will tidy shut down systems if surpassed.

Take into account that in manual operations motivated people trend to organize themselves for maximum productivity; they trapdoor safety regulations and often his willingness goes too far: that is the moment of the accident, or the lack of health inducing losses in the whole line productivity

Regulations in this field should be especially rigorous and strictly followed.

Forced accomplishment regulations for a new automation system to be implemented:

- Electrical safety regulation
- Biocompatibility regulation
- Electromagnetic compatibility regulation
- Functionality and risk analysis regulation
- In Europe, every material has to exhibit the CE mark

<u>Focus on</u>: People

5.10+1 Continuous evolving capabilities

Able to continuous improvement, capable to work at higher speed than the line tact time.

Just once this feature is achieved, and never before, next step is to push the line efficacy. It is of course not useful to grow in line speed when we are certain by experience and statistics that there will be losses of time or line stops.

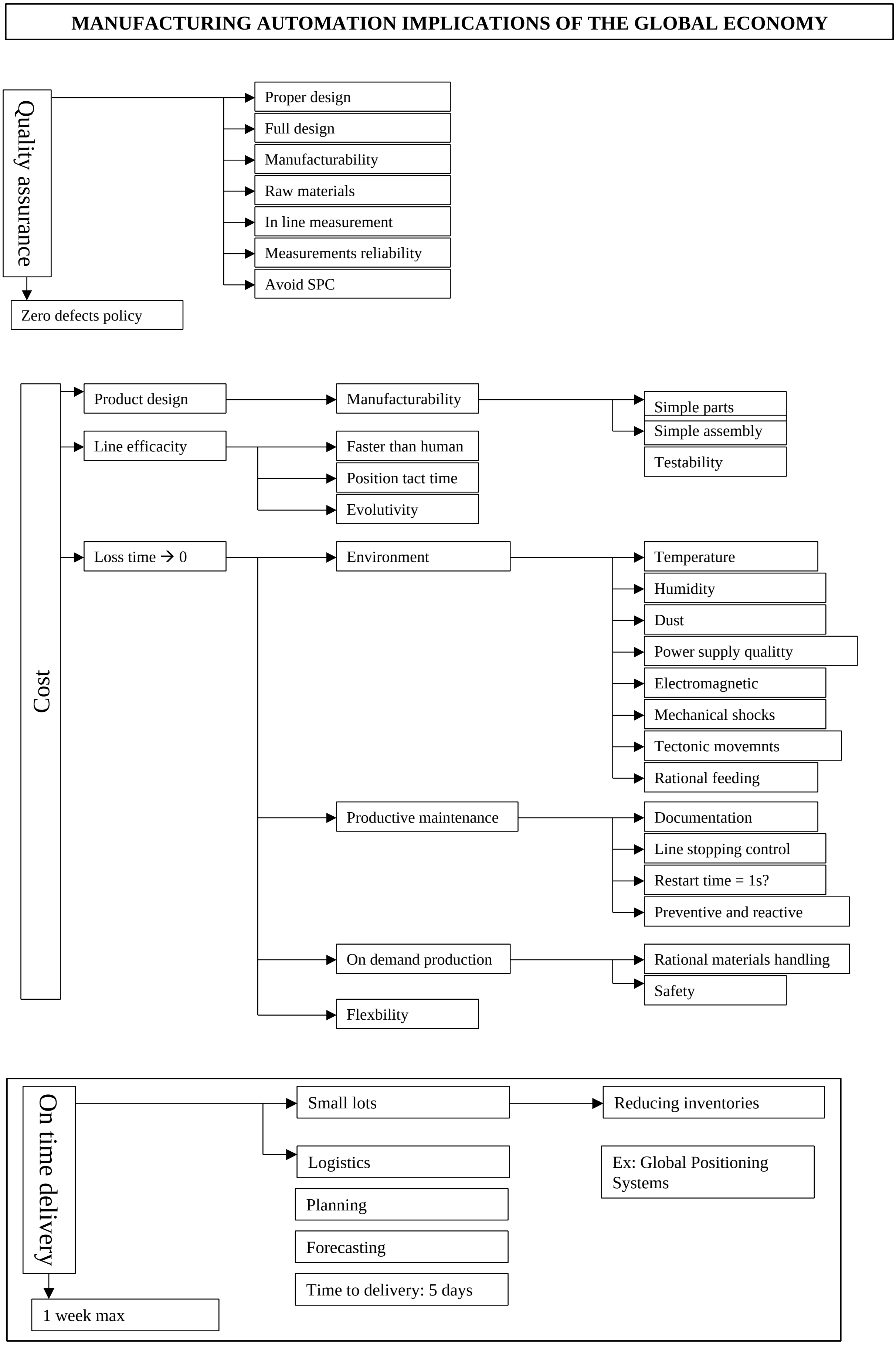

Fig. 8. Summary of the various concepts developed in the paper

The automatic systems present in the production line must evolve enough in a sense that its manufacturer or ourselves need to know how to upgrade them when necessary. Imagine that you work hard to increase the line speed. The palletising system must also accept upgrading if it does not want to be seen, suddenly, as a bottleneck.

Focus on: Improving is a never-ending task.

6. SUMMARY IN DECALOG MODE +1

When consider the implementation of automatic systems on the production line, 10+1 are the concepts to deal with (Table I).

See also figure 7, when main concepts explained are summarized.

DECALOGUE+1 PROPOSED FOR EFFICIENT AUTOMATION IN MANUFACTURING

1. People
2. Environmental conditions
3. Cost effectiveness
4. Optimal materials handling
5. Checking
6. Feeding
7. Flexibility
8. Productive maintenance
9. Information
10. Safety

10+1 Continuous evolving capabilities

GENERAL MUSTS

Manufacturability
Loss time → 0
Defects = 0
Standardization
Traceability
Forecasting

Table I. The proposed Decalogue + 1

7. CONCLUSION

When considering a batch high-volume industrial production process for the manufacturing of goods that will be offered to the market in heavy competition with others in terms of quality, durability and cost, so maximum competitiveness defined by the board of directors, this kind of considerations are crucial for success (and even survival).

Many are the reasons for implementing an automatic system in a production line. Main justifications are economic; buy today safety and working healthy have to be in mind. Systems must be user-friendly.

The point of view of the authors is that proper use of these recommendations strongly helps in the success of automation practical implementation. 17 Two are the main factors to keep in mind: the exhaustive analysis of the environment and the conception of the system.

Manufacturability, standardization, traceability, continuous checking, exhaustive information are also key concepts than plane over those to main factors with the continuous work focused on zero defects and zero loss time.

The concepts described could apply both for non-continuous processes, batch processes and continuous processes. But, when applying them properly, non-continuous and batch processes come closer to a continuous process.

Last but not least, training, training and training. Of course on techniques and on procedures. And make people understand why this level of high efficiency in needed. Why the need for permanent improvement is. Show them the figures here described, and others more particular. Justify the need. Repeat it frequently

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