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A COMPREHENSIVE REVIEW OF MANUFACTURING WASTES: TOYOTA PRODUCTION SYSTEM LEAN PRINCIPLES

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ABSTRACT

Waste removal increases the profitability of any business. Processes are classified into value added and non-value added. The seven deadly wastes that could exist in any manufacturing process originated in Japan and are defined in the Toyota production system (TPS). The main goal became removing them. For each waste, there is a strategy to remove or eliminate it. What is less likely is that managers will know how any of these issues are affecting them and increasing costs. To remove each waste, you have to understand where it comes from, why it exists, and how it affects your business. In the economic recession, many companies are taking abstinence procedures to reduce costs. This might include layoff labors and reducing some wages. Actually, those actions might work for only a short period. Afterwards, the situation may return and in worse shape unless the company changes its way of doing things, including enacting a culture of continuous improvement. This puts us back to why the Toyota production system has been created.

Keywords: Lean manufacturing; Production engineering; Industrial engineering; Productivity improvement.

الخلاصة:

ازاله الفاقد تزيد من ربحيه أي عمل. العمليات يمكن تقسيمها الى عمليات تضيف قيمه وأخرى لا تضيف قيمه. الفواقد السبعة الموجودة في عمليات التصنيع تم تعريفها فى نظام الانتاج الخاص بتويوتا في اليابان. أصبح الهدف الرئيسي هو ازاله هذه الفواقد. لكل فاقد استراتيجية لإزالته والحد منه. الكثير من المديرين لا يعرفون كيف تؤثر هذه الفواقد على العمليات وتزيد من التكلفة. لإزالة أي فاقد يجب فهم مصدره وسبب وجوده وكيف يؤثر على العمل. في اوقات الركود الاقتصادي نجد الكثير من الشركات تأخذ اجراءات تقشفيه للحد من التكاليف. هذه الاجراءات قد تشمل تسريح العمالة وتقليل الاجور. هذه الاجراءات ربما تكون فاعليتها مؤقته. فيما بعد ربما تعود الحالة الى ما كانت عليها وبشكل أسوء من ذي قبل ما لم تقم الشركة باتخاذ اجراءات لتحسين طريقه العمل، وهذه يشمل زرع ثقافه التحسين المستمر. هذا يجعلنا نعود الى اسباب خلق نظام انتاج تويوتا.

1. INTRODUCTION

Lean thinking was originated in Toyota. Lean has some principles that should be the goal of any successful organization. All goals are intentionally looking from the perspective of the customer. The five principles of lean are defined by Borris [1] below:

Value: Specify what adds value to the customer and what doesn't. The customer needs a good quality, good prices, and good delivery speed. Quality should exceed the customer's expectations, no exception. Quality is what keeps any organization in business. A reliable, safe, and defect-free product as well as excellent service will help retain customers and maintain their loyalty. Non-value added processes are those works that customers are not willing to pay for. They add cost to the product and delay the process.

Value stream: This involves every step of the process, starting with the supplier and ending with the customer. Every step must bring the product closer to completion and add value to it.

Make the product flow: All obstacles that constrain the flow of the parts through the manufacturing process must be removed. Lean strives for one-piece flow, which is about providing smooth flow for each piece of product with no wastes in time, performance, and quality in order to deliver the right product on time to the customer.

Pull not push: Produce what customers need and avoid over productivity, which creates the most waste in any production process. By producing more than the customer demands, you are investing all your resources, including money, space, manpower, equipment, tools, material, etc., in building an inventory that may not be sold for a period of time. The production at the customer process should be regulated by the customer's process withdrawals from the supplying process's store, rather than by a schedule. A pull system begins with the customer, then backs up through production where the user goes to get-or pull-parts from supplier operations in just the amount needed, only when needed. This continue all the way back to raw material suppliers so that every segment of the business, from grower or miner to consumer, is tied together like links of a chain [2].

Strive for perfection: There must be a vision for perfection. Companies should strive to continuously improve the process rather than be good at what they are doing. Processes tend to slip back and lose their sustainability if the cycle of continuous improvement, or plan-do-check-act cycle, has not been repeated continuously.

2. WHAT ARE THE SEVEN WASTES?

The seven wastes are those non-value added steps that create obstacles to the flow of the stream, add cost to the product, reduce quality, and delay the delivery to customers. For example, suppose there is a manufacturing process consisting of several processes, such as cutting, casting, assembly, handling, maintenance, inspection, and changeovers. The added value works, which involve making what customers need, are just a few processes: cutting, casting, and assembly. The others are those non-value added works that need to be removed or minimized to improve the process. The seven wastes define those non-value added works in terms of transportation, inventory, motion, waiting, over processing, over productivity, and defect. The eighth waste is the underutilization of human capabilities, or untapped human potential. Toyota production system also recognize those essential non-value added activities such as preventive maintenance and safety inspections which should be minimized not eliminated and considered for improvement.

2.1 Relationship Between Wastes and Profitability

Frequently, the inexperienced estimators will perform a cost estimate assuming everything is perfect and the plant is working at full capacity. This approach is totally erroneous as it does not consider all operation wastes, such as downtimes, waiting between processes, inventory carrying for long periods, re-working for quality, and delay of orders delivery.

Borris [1] stated the relation between profitability and operation wastes through this simple formula:

$$\text{Profit} = \text{Revenue} - \{(\text{Fixed Cost} + \text{Variable Cost}) + \text{Wastes}\} \quad (1)$$

The fixed and the variable costs are the manufacturing operation costs required to make the product. Organizations that are working at or near the break-even point can find ways to be more profitable through the losses. Furthermore, if a company is running at 80% of its actual capability and can sell 100% of its capacity, there is an opportunity to produce the extra 20% through the losses. Those twenty percentages of losses are the sales losses that can be recovered through the removal of the operation wastes. The losses are the price of the unsold parts which recover the profit, labor salaries, maintenance costs, overheads, and indirect expenses.

3. TRANSPORTATION

Transportation is about material handling. It involves all material movements from the supplier to the customer. What creates wastes in the manufacturing process is the movement of parts between the process lines. It adds more cost on the product and could affect external customers directly, causing a delay in orders delivery.

3.1 Sources of Transportation Waste

Most of transportation problems in plant facilities are subjected to the layout of the plant and production style. This involves the distance between the process steps, the distance between the machines inside each workstation, how close the workstations and machines are to the tools, how far the inventory warehouses are from the production facilities, and how far the other service departments, such as the maintenance workshops, are from the production lines.

3.2 Strategies to Remove the Transportation Waste

Mistakenly, many manufacturers tend to arrange machines by similarity rather than by the sequence of the process steps by the mean of mass production. For example, if there are two processes, cutting and skimming, and a process of heat treatment that is required between both, then the oven should be placed between the cutting machine and the skimming machine. Also, long distances between the process steps increases the time it takes to produce one piece of product, and more resources will be needed to move one product from one process to another.

Machines' arrangement should take into consideration the following things: minimizing the work-in-process (WIP) inventory; minimizing the time it takes to produce one piece of product; minimizing the travelling distance of one product; and being faster than the takt time, which is the customer demand rate for a product or group of products. Also, ensure that all workstations, machines, and operation tools are as close as possible to avoid waiting for tools or parts issue and to avoid creating ergonomics in the workplace.

A cell-based process by grouping machines, processes, people, and methods together is a key for improving the productivity and shortening the lead times to achieve the lean goal [3].

An example of high transportation cost comes from a big glass manufacturing company in Egypt. The layout of the plant looked terrible. The cost of transporting the work-in-process, or WIP, inventory between the process steps was estimated to be thousands of dollars per month! That was due to the high number of elevators being used to transport materials through different floor levels. The production processes were quite far from one another. Materials were being carried using forklifts, and heavy parts being carried through those elevators that sometimes exceeded the maximum allowable weight of the elevator. This was affecting the elevators' mechanical parts significantly. The huge effort spent in maintaining those elevators and the high frequency of replacing damaged parts were very costly, as elevators are human-risk machines and should be highly maintained and inspected frequently.

According to Rother [4] a cellular layout is ideal for one-piece flow of product. A production facility where product goes through different floor levels is not good for lean environments and doesn't serve the goal of creating a smooth and continuous flow.

3.3 Cost Effects of Transportation

This usually involves the cost of the transportation equipment like forklifts, cost of operators driving those equipment, safety risks due to using forklifts in the working areas, labor wages, cost of resources, the risk of product deterioration during the handling process, and the effect of delays on the customer.

A common thinking is that the transportation problems have no solution if the root cause comes to a point where the company must rearrange machines and processes to be closer. This action is considered very costly, so many companies won't even think about it. This is not exactly correct, as long as the main goal is to have an efficient process with minimum wastes and the shortest lead time for long-term benefit. Such wastes could affect any organization financially on both the long and short terms. Also, this may affect the external customers, and customer satisfaction is worth more than money. If a cost benefit analysis is performed to determine whether to rearrange the process steps by sequence or keep them as they are, the accumulative cost of keeping the current conditions over weeks, months, and years could be much higher than the cost of doing the job once and forever. This is the key point. The cost benefit should be estimated and considered over months and years. Also, when the company decides to make the changeover, it can perform the changeover gradually, depending on the financial situation.

3.4 Transportation Methods

Harris et al. [5] stated that when designing the delivery routes and arranging production cells there are many methods to convey parts from the purchased market to the point of use. Either use tugger, walking, or forklifts. Tugger is the best method when the purchased parts market is quite far from the production cells. Walking is the best method when the purchased market is close to the production facility. Forklifts should be avoided whenever possible as they are expensive, not easy to maintain, its operation cost is relativity high and can cause safety problems. Forklifts also require skilled drivers so the transported product doesn't get damaged.

3.5 Cost Benefit Analysis Involved in Decision Making

Frequently, accountants and inexperienced estimators perform a cost benefit analysis to determine the benefits of the next step required in the lean improvement initiative.

The above example of rearranging the machines and processes by order shows that the cost of the job is expensive on the short-term financial benefit. On the long term, it may have a remarkable effect on the performance of the production. Thus, CBA is not a short-term focus process and should be considered over months and years. The cost of doing the job right now can be less than the cost of keeping the situation as it is with all the current existence wastes. Also, customer satisfaction and delivery speeds should not be neglected as customers are what keep any organization in business.

Indeed, management decisions should be based on long-term improvement that matches the company's vision and goals [6-8]. And as long as this improvement is in the company's vision, cost benefit analysis can be carried only to determine the best method to make the improvement, not to decide whether to make it or not.

4. INVENTORY

This is one of the greatest wastes. Inventory issues are greatly affected by the production style. But the improper sales forecasting and the bad procurement planning are also reasons for inventory problems.

Reducing the inventory storing value has become the main goal of any industrial company. The just-in-time (JIT) theory and approaches like kanban have been utilized to serve the manufacturers' demands in reducing the inventories, produce only what is needed and when needed while keeping a little buffer for emergencies.

Inventory types are the raw material inventory, the work-in-process (WIP) inventory, and the finished product inventory. Inventory always costs the space, return on investment, risk, and the handling efforts. You want to spend money on materials and quickly get the return by selling the finished goods. The total selling revenue recovers profits and other costs, such as indirect salaries, direct salaries, plant expenses, manufacturing overheads, depreciation, taxes, and insurance.

4.1 Cost Effects of Inventory

The direct cost of the inventory carrying can be estimated through the following parameters:

4.1.1 Return on Investment (ROI): Any investment should have a return. The quicker you get this return, the better it will be. If money has been spent to buy some materials needed for the production process, a quick return is good; a delay in selling the finished product to the customer is bad. This investment amount could have been spent on something else or put in the bank. Delay in getting the return involves the interest losses during this period and the opportunity cost. This money could have been invested in another profitable opportunity or project rather than being wasted on some sluggish materials.

4.1.2 Risk: The risk of parts deterioration and damage varies. It depends on the product type. If the product has an expiration date, like food or glue, then it will be very risky to store it. Therefore, most fast-moving-consumer-goods (FMCG) companies try to accelerate the inventory movement and keep as minimum value as possible in their warehouses.

Furthermore, stocking too much inventories puts the whole business at risk should there be a market change, such as a change in the raw material prices or a change in the market demand. At this point, the finished goods inventory might become obsolete. Also, there is a risk of change in the currency value and accidents, such as fires.

At the same time, having no inventory puts the business at another risk if the supplier goes out of business unexpectedly due to an economic problem or a natural disaster, such as the earthquakes and tsunamis in Japan [8].

Toyota is the best and the leader of inventory management. The company stocks parts from more than one supplier—indeed, two suppliers for each part type. When the Japanese tsunami and earthquake occurred, some suppliers went down, but Toyota took numerous actions to rectify the issues quickly.

4.1.3 Material Handling: This is the cost of transporting goods. Some accountants believe that stocking the inventory one time per year is economically good from the perspective of cost reduction in transportation, but actually this approach is a waste of money.

4.1.4 Space: Inventory takes up much space and can requires additional space renting or buying. The space is valuable whether it is rented or owned by the manufacturer. The company may find itself having to rebuy more space for more production lines to expand its business, while there is a lot of inventory already taking up valuable space in the factory. It is better to minimize the inventory rather than buy more space to store it. That additional space will require more resources, such as a ventilation system, manpower, equipment, energy, and a data recording system.

4.1.5 Insurance and Taxes: Space needs insurance, as does all transportation equipment and manpower. Also, taxes are applied in some areas on the inventory.

4.2 Strategies to Remove the Inventory Waste

Production style affects the inventory, building too much work-in-process (WIP) inventory between the process steps or using a production system based on large batches, which constrains the parts flow through the manufacturing processes. A process might have to wait for parts that need to be made until they are all finished with the other process that supplies it. The main lean goal is to make one-piece flow through the production processes, which minimizes the WIP inventories. Producing with small batches is a good idea because it will help facilitate the transportation without requiring heavy equipment like forklifts. Trolleys and other light equipment are preferable for both cost and safety issues.

Eliminating the inventory is good; however, having zero WIP inventory will also put the process at risk of stoppage if another process supplying it with parts goes down unexpectedly. Using an inventory buffering system is a good idea to avoid such emergencies. Materials or parts can still be pulled to the production lines but with a little bit of safety stock, using a technique like kanban (pull cards) to provide the needed materials on time and with the right quantity [6].

The ideal goal is usually one-piece flow not zero inventory but as explained by Liker [6] Toyota production system is based on zero inventory, and since there are natural breaks in flow from transforming raw materials into finished products delivered to customers, you have to build in some necessary inventory. When pure flow is not possible because processes are too far a part or cycle times to perform the operations vary a great deal, the next best choice is often Toyota kanban system.

Toyota kanban is an organized system of inventory buffer. And according to Ohno in [6], inventory is a waste. So kanban is something to strive to get rid of, not to be proud of. Toyota itself is shame of those kanban. Unfortunately, many companies forget that the goal is improving the buffer and they strive to make an efficient system to control those buffer. Definitely working with your suppliers is the key to reduce buffer and reduce the inventory holding value.

5. MOTION

This is the ergonomics. The operator needs to have his tools available and within easy reach and the necessary parts or materials handed to him in exactly the right orientation to eliminate wasted walking and handling losses. Operator should never leave his work to search for parts or tools.

5S is a good technique to eliminate the operator searching for tools issue. Ensure that there are enough tools available in place and give them a location to be returned to after use. By arranging the tools and putting them in a clear place, access to the tools becomes much easier. Shadow boards are helpful in revealing whether a tool is missing. Basically, the tools are outlined on the shadow board, and a missing tool shows a shadow when it is not there [9]. The board should be monitored regularly to ensure that tools are returned after use.

6. WAITING

This is the time waste factor, and it involves the following activities: Waiting for materials, waiting for spare parts, waiting for the quality inspection process, waiting for maintenance service, waiting due to low machine performance or speed, waiting due to machine downtime, repairs, and preventive maintenance, waiting for operators to get tools or spare parts, waiting for changeovers from one product to another, waiting for CNC machine loading program, and waiting for instructions or design drawing [9].

When calculating the takt time, and customer demand rate, those are the variables and the unplanned activities that need to be eliminated to improve the effective operating time and increase the available time for actual production [4].

A root cause analysis for each problem above must be carried out. There could be many issues behind each problem. For example, a long time spent changing from one product type to another could be due to operator skills, insufficient training, or missing tools [9].

$$Takt\ time = \frac{(Effective\ Operating\ Time\ per\ Shift)}{Quantity\ Customer\ Requires\ per\ Shift} \qquad (2)$$

7. OVERPRODUCTION

Over productivity and inventory issues are related. Over productivity creates most production wastes. Making more product than is actually needed or over the capacity of the selling department is a waste of money in enormous rates. The losses are the costs that have been spent to make this product plus all the inventory losses. Even if this product is going to be sold later, there is still a problem with the return on investment of the used raw materials and the other resources that have been expended to make this product.

Pulling products to customers is one of the main lean goals. Building products must be only done according to the takt time, which is the rate of the customer demand, calculated per second. If the product is a computer or a modern electronic device, the company will be in trouble if it has built more than the demand. Technology changes fast, so these products cannot be stored for a period of time.

In addition, producing mass quantities of a product that has an expiration limitation date with no realization of where or when this product is going to be sold puts it in danger of damage and deterioration. The goal is to make only what is needed and when needed. A method like kanban can be used with the finished goods to produce according to the customer demand.

Some companies choose to process a large batch size from one product type rather than leveling the product mix and adjusting the batch size to run before changing over to another product type. They want to overcome the high frequency need of changeover and transportation processes. Single minute exchange of die SMED technique should be a part of any production leveling effort.

When hejunka (the Japanese technique for leveling) was firstly introduced as one of the main pillar in the Toyota production system, it was not possible to level both the product mix and volume without developing a method that improves the machines changeover process [6]. SMED became a part of the solution to accelerate changeovers and make this process easier.

Establishing a supermarket between the pacemaker process and the customer can allow you to level production requirements. A tool like kanban can be useful for such a purpose. Kanban is a production regulation function designed to supply the finished product to the customer only when needed and with the right demand quantity. It can also be used to supply the raw material to the production lines from the place where it is stored and signal the needed material between the production lines from one process to another [4].

7.1 Cost Effects of Overproduction

Over productivity creates the most manufacturing wastes. Mass productivity technique hides many downtime problems and quality issues behind it. Producing in one-piece flow or smaller batches will help pinpoint the production obstacles quickly and discover the root causes before problems are developed. Changing to one-piece flow should be carried slowly and improved step by step. It doesn't make sense to change the batch size dramatically from 1000 pieces to 5 pieces, this can create a lot of problems and will halt the production process in environments that has operated for years under a system that produces according to a schedule with little or no attention to real customer demand (a push system), and because the processes were building large batches of work-in-process (WIP) inventories using the mass production technique, the company might experience problems that have remained hidden for years when switching to one-piece flow and a complete pull system. It is time to think about solutions to these problems and engage your employees at all levels.

7.2 Strategies to Remove the Overproduction Waste

One of the most debated issues is the use of mass production technique. The approach involves making as many parts as possible using the maximum available resources and all available machines. It doesn't take into consideration the customer demand rate or the sales forecasting because the main goal is reducing the cost per piece without considering the other wastes [6]. Furthermore, if you were making five hundred parts, and there was a problem with the production process, a quality failure could occur with all of those parts. Problems are hidden with the mass productivity approach; it can also be difficult to discover where the errors are coming from. Thus, the root causes might remain hidden.

If a supplier process is producing with mass productivity and building too much WIP inventory, the downstream process will find all of what it needs even if the supplier process has gone down suddenly. The downtime is hidden and is not important; no one will consider preventing it in the future unless it has an obvious effect on the production process. Also, if the operator at the supplier process is spending time getting tools or parts, the downstream process is still receiving the parts it needs to make through the available WIP inventory. So problems are not surfacing.

With pull concept, and producing only what is needed for each process step and between the production lines, there will be a minimum of WIP inventory. If a process goes down, the downstream process won't be able to receive parts, and the upstream process won't be able to produce and build WIP inventory. Problems will surface, and everyone will strive to fix the downtime and prevent the recurrence of this downtime.

Mass productivity creates the inventory problems, hides many wastes behind it, and affects the delivery time to customers. A lot of "waiting" wastes result from not properly having a smooth product flow. A small example of mass production versus one-piece flow of product is a product being assembled through three different processes; if it takes one minute at each process, then waiting for ten pieces to be assembled will take thirty minutes. The cycle time of one piece becomes twenty-one minutes although the add value time is only three minutes. Assembling all ten pieces will take thirty minutes using batch processing, while assembling ten pieces can take only twelve minutes using one-piece flow.

While presenting the fundamental concept of Toyota's production system that is based on fewer inventories, Ohno [10] described the inventory as a river carrying a boat that is travelling on it; with more water in the river, the rocks are hidden below the surface and become invisible to the boaters. As the water falls, however, the rocks will break the surface, and the boat must stop until the rocks are eliminated. The rocks signify problems like downtimes, quality, and so on.

8. OVERPROCESSING

Over processing means making more steps in the process than are actually needed or making steps that are not needed. To allocate the over processing wastes in any process, some questions should be considered while mapping the process: Why do we do this step? Is this step needed? Why do we do it now? Why do we do it this way? Is there an easier way to do it? Do we need this step? Can we eliminate this step? Or can we reduce its time? Can we do two steps together at the same time? Can the step be grouped with others and pre-assembled? [1]

Many processes can be improved and reduced in time through the removal of the unnecessary steps. The improvement is not limited to the manufacturing process alone, but also applies to the other processes in the value stream such as changeover, maintenance, and material movement.

The most common reason why over processing exists is the work standardization. No standardization will create many wastes. Standardization is a good way to avoid over processing, mistakes, defects, and other wastes. It is also the foundation of continuous improvement [9]. Without a standard how do we know there is a problem? Problem is defined as a gap between a current and an ideal state.

9. DEFECT

Quality is so important for customers; this is really what keeps any organization in business [2]. Defects are not only in the production process; they can also be seen in any other process, such as the maintenance process. For instance, if a maintenance repair has been carried out and the fault rapidly returns, this indicates a defect in the repair process.

Standardization of work procedures is a good way to minimize the probability of failure and enhance the quality. Processes can be mapped, and the potential quality problems can be presented on the charts [9]. If a quality problem happens, the standard process should be reviewed and updated accordingly to prevent this error in the future [9].

The cost of quality is more than double the cost of making the product right the first time [9]. All resources and costs that have been spent to make the defected product are lost and will be spent again to compensate for this defect. Plus, there are always some other expenses, such as those incurred while making modifications, finding the root causes, and making an improvement to the process. So the cost of quality is the cost of [defects + re work + other essential requirements or modifications. Jidoka is the principle of building quality into the process not fixing quality problems, and it is the second pillar of Toyota production system.

10. UNTAPPED HUMAN POTENTIAL

This is the 8th waste. The loss of human creativity waste exists in any company that doesn't value its people and put much effort or investment in the training and coaching process.

Toyota provides the best example of a company valuing its employees. When Toyota invests in its leaders, it expects them to develop the other leaders using the skills and the knowledge they have learned through the Toyota leadership self-development program [4, 8].

In many companies, leaders have not been challenged to teach and develop others. They can be very valuable if they learn to coach others rather than doing the thinking just for themselves and treating others as followers [7]. At Toyota, the main function of the leader is to produce more leaders, not more followers [7-8].

The use of the operator or the maintenance craft to bring the tools or parts is another example of untapped human potential waste. This high-skilled laborer can control or supervise several processes and provide ideas for improving the way of doing jobs. They should be involved in the problem-solving process to improve their own works.

Using a high-skilled laborer to do little jobs increases the costs of this job. Not utilizing the laborer's skills and ideas to improve the process and instead hiring an external service to do the improvement is a waste.

11. CONCLUSION

Lean strives for one-piece flow of product in a production-based cell. A cell is an arrangement of people, machines, materials, and methods with the processing steps placed right next to each other in sequential order, through which parts are processed in a continuous flow (or in some cases, in a consistent, small batch size that is maintained through the sequence of the processing steps) [3]. This type of flow will help eliminate the inventory on the shop floor, shorten the lead times, reduce the cost of resources, minimize the non-value added work, maximize the human utilization, and ensure that problems surface so they can be targeted for improvement.

It is clear that Toyota's production system is based on minimum wastes. And most wastes are created from over productivity and excess inventory issues. What is not clear is that the real factor behind the success is the great effort, investment, value, and commitment that a company puts into developing and training its leaders [6-7]. Seven out of ten lean projects fail as companies try to copy and paste the Toyota system without understanding the real means of getting the results [4; 6-8]. Few companies realize that lean is not a toolkit, and that the contribution from all employees and workers in all levels to the continuous improvement of the system is what brings the system to life.

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