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FACTOR HIERARCHY ANALYSIS OF ASSEMBLY LINE EFFICIENCY IN ELECTRONIC INDUSTRY

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Abstract. *Industrial production line efficiency is crucial to production cost, product quality and enterprise competitiveness. Based on the empirical study of electronic enterprises, factors contributing to production line efficiency of electronic industry are indicated and Interpretative Structural Modeling (ISM) is applied to analyze the hierarchical relationship among these factors. These multiple, correlated and latent relationships construct a valuable information source for the production and management of assembly lines to identify faults and take steps. Results appear from the bottom to the top of the hierarchy model, the bottom level factor, machine/model, counts for efficiency differences, and the second level factors referring to production line control, such as layout of production facilities and support of engineering departments, correlate suggesting machine efficiency and contribute most to assembly line efficiency. The third level factor, staff, is the most problematic, and deserves the most attention; factors at the top concerning production preparation, are the premise of assembly line production. Combining with the factor hierarchy model, the measures to improve production line efficiency of electronic industry are proposed.*

Keywords: Production line efficiency, Factor hierarchical relationship, Interpretative structural modeling, Electronic industry

1. **Introduction.** Reducing costs while maintaining the structural capability is one of the challenges and yet important goals which enterprise managers aim at, especially in the lukewarm consumer demand and rising commodity prices context. Only at a cost lower than the social average labor consumption, can enterprises make profit in this market. However, during an assembly line production process something often tweaks. Take Company C as an example. C, a Taiwan-funded enterprise producing monitors, LCD TVs and other electronic products, is one of the leaders in the monitor and LCD TV manufacturing industry worldwide. The company began to produce the monitors in 1992 and the LCD TVs in 2004. After years of development, with 12 assembly lines of LCD TVs, its output reaches over ten million pounds recently. However, for the assembly line production of Company C, it always happens that the daily production cannot reach the goal and overtime work has to be carried out to achieve the task; items being processed are of high defective rate (about 5%) and needs to be fixed before going back to the production lines; finished products are brought back from the warehouse to the production line to be reworked due to quality problems, etc. Poor efficiency of assembly lines increases the production cost and hinders the improvement of product quality. Apparently, efficiency is naturally multi-hierarchical in latent factors, and the multiple, correlated and latent relationships among these factors can construct valuable information sources for the improvement of assembly line performance. In order to reduce the risk of low efficiency, it

is imperative to identify the affecting factors and demonstrate their different significance in the hierarchy relationship so as to take steps to control and improve assembly line production.

2. Literature Review. Recent relevant literatures about production lines focus on work or worker study at work stations, the assembly line design and balancing, or efficiency calculation (availability, performance and quality related to operation time), while scarce research is available on the factor hierarchy analysis of assembly line efficiency.

Subramaniam et al. (2009) [1] divided factors contributing to production line efficiency into manpower utilization and machine efficiency, and discussed that overall equipment effectiveness is essential or decision making and production data helps to monitor the workers. The category of factors brings to light the hierarchy model of assembly line efficiency, where the factors are not well interpreted.

Unreliable lines, of which a station breaks down and production stops temporarily, have been the subject of production research and experimentation. Shaaban (2012) [2] explored the manual buffer design in unreliable production lines in order to ensure flexibility and for complex or detailed finishing or customization. It is concluded that buffer space is allocated depending on the strategic and practical aims of production, and a somewhat allocation of buffer capacity can either slightly reduce idle time or increase throughput. However, it is also indicated that a line imbalanced in the wrong way might lead to the opposite effect. The unreliability of production lines suggests all the factors need to be taken into account.

Venkatesh and Dabade (2008) [3] and Alpay (2009) [4] concentrated on hybrid lines, and studied the operational performance evaluation and production line scheduling of mixture lines. Alpay processed the relink and cohesion of mixed assembly line by the application of greedy randomized adaptive search procedure (GRASP). These literatures emphasize mathematical algorithms to balance the assembly line; meanwhile they have also proved the effectiveness of the algorithm on the improvement of assembly line efficiency.

Lin and Guo (2012) [5] used Operation Loading Chart and Information Flow Diagram, based on the JIT scheme to improve the production line balance rate. The results above provided the empirical basis for collecting the affecting factors and proposed possibilities to overcome some problems to improve assembly line efficiency. This paper intends to analyze the affecting factors of assembly line efficiency in electronic industry, establish the hierarchical relationships of their different significance to the assembly line efficiency, thus problematic factors can be identified and steps be taken for productivity improvements and higher operating efficiency.

3. Factor Analysis of Assembly Line Efficiency. A production line is a set of sequential processes with the transformation of raw materials or components into finished products in a set route or speed in an industrial workshop or panel, and it often involves six stages and four elements, with six stages: procurement, fabrication, assembly, testing, packaging and distribution, and four elements: human, object, technology and information. Here the LCD TV production of Company C is used to analyze factors affecting the line efficiency. LCD TV consists of three different production lines, which are Line F (processing the front and back shell, the iron and the support), Line M (processing the main board, keyboard and power board) and Line T (assembling and sealing the complete machine) respectively. From its empirical production process, the production elements of assembly lines can be listed as follows.

Factor (1) Raw material

Raw materials are basic constituents of a complete machine. If materials used are not qualified, quality of the whole product will be affected directly. Also the poor condition of materials affects the output of assembly lines, even in some cases leading to production stoppage. Therefore, before starting to produce, it should be ensured that the qualities of all materials and accessories are right. The wrong storage must be not allowed into the process of production. Additionally, the storing environment should be kept eyes on to avoid any chemical change of the substances which may affect their qualities.

Factor (2) Staff

Staff mainly refers to workers or operators working on the lines, whose attitudes and skills affect the capability and efficiency of assembly lines. On one hand, repeated actions, tedious circumstance may make them feel alienated and exhausted, or cause their pessimistic attitudes. In this context, they tend to just finish their assignments passively, rather than tackling their procedures seriously. On the other hand, the staff's intellective levels refer to how they master the operation skills within their own stations, including essential techniques such as supervising and calculating. If workers fail to follow the production pace (unable to pass an item on to the succeeding station, "blocking"), work-in-process (WIP) items will be temporarily held. Or if they are not familiar with the operation requirements and take an irregular operation, damage will be brought out. For the screw lock of the shell, if a shell is not paid a vertical lock according to the rule, it tends to be damaged and gets the wrong appearance.

Factor (3) Production line equipment

Equipment of production lines consists of the assembly line body, testing and regulating instruments, and Shop Floor Integrated System (SFIS). SFIS, which is composed of PC, reading code gun and a swiping card reader, is set to collect the information about the status of all production activities and provide it to managers. The bug of production lines will lead to the delay of delivery schedule, so testing and regulating are common procedures during the production process to find and clear problems (if needed) in order to guarantee the continuous production of the lines. For example, a faulty board placed in a TV can be pinpointed the moment once it is processed on line, rather than finding the defect after assembling the entire product together. In order to keep watching the assembly line and the items, equipment should be ensured to work normally. Obviously, progressive check points increase production time and reduce final product defects.

Factor (4) Production environment

Environmental factors link with the assembly line workers' psychological feelings and attitudes, work efficiency and job satisfaction, and even the physical and mental health. Humidity, dust, noise, vibration, radiation and temperature make sense to the product qualities. For instance, sound detection is important for LCD TV test, so noise should be avoided during the sound test.

Factor (5) Synchronization of processes

A production line retains its productive pace to maintain product output. Synchronization of processes, also assembly line balancing, means given a line rhythm, an assembly line can be operated in an optimum of working time and worker utilization. If a line speed is higher than the set rhythm, some workstations may be overloaded and workers may be out of time to operate, blocking occurs; or workers have to be in such a rush to catch up with the speed that the operation requirements may be ignored. On the contrary, if a line pace is slower, some workstations are deprived of having a work piece to process (known as "starving"), which leads to time and manpower wasting. Synchronization of processes should be set properly in practice for assembly line balancing.

Factor (6) Relevant production lines

As for Line T, the relevant production lines are Line F and Line M. Front frame, back shell and the support are processed in Line F, while the main board, keyboard and power board are manufactured in Line M. The items finished in Line F and Line M are ported to Line T to be assembled before entering the warehouse. The quality of Line F and Line M connects with the quality and capacity of Line T.

Factor (7) Support of engineering department

The engineering department, which involves industrial engineers (IE) and product/process engineers (PE), is mainly responsible for the production guidance, software formation and equipment maintenance. IE determines the timing and cost, the standard of consumable materials, line design, environmental 8S, fixture design, the maintenance of process flow and the arrangement of ERP routine, while PE is in charge of the instruction releases about detecting technique, procedure management and other software guidance. Engineering support is highly demanded to solve problems occurring during the line production. It is believed that how the engineering department solves problems has vital influence on assembly line smoothing.

Factor (8) Machine/Model

As a company of make-to-order (MTO), the machine changes with different orders. Different types of raw materials, facility location and testing procedures are adopted in different machines. When the demand switches, raw materials, test equipment, procedures and staff involved need to be rearranged. It is necessary to make time to prepare the production for the new kinds of machines in order not to affect the capacity of lines.

Factor (9) Production information

Production information involves production schedules, raw material supplying and using, line machine kinds and exception-handling information. If the production information cannot flow smoothly, the production line efficiency will be brought down. Particularly, SFIS can get information about the LCD TV production, for example, which positions the work-in-process goes through, and whether the accessories (remote control, power cord and user guide) are all put into the box.

Factor (10) Layout of production facilities

The reasonable arrangement of production units within a workshop can shorten the time in which relevant items and workers reach their workstations and cut down the logistics cost. For instance, Line T is generally allocated not far away from Line F and Line M.

4. Factor Hierarchy Model of Assembly Line Efficiency.

Grouping into hierarchies is common in research and practice. Interpretative Structural Modeling (ISM), invented by J. Warfield in 1973, is one kind of structured modeling techniques based on the directed graph and matrix theory by decomposing matrix into multilevel structure model for complex systems. As a tool of complex system analysis, it is widely applied in financial management to explore the characteristics of stability, periodicity and hierarchy respectively, and also used in the fields of core competence, value chain, and company strategy to analyze the affecting factors and discuss the affecting degrees, etc. However, as a tool of analyzing the complex level relationships among different factors, ISM is rarely applied to the efficiency study, even rare in the fields of operation and production management.

4.1. Building the adjacent matrix.

Suppose R_i denotes a certain element within the factor set $R = \{R_1, R_2, \ldots, R_{10}\}$, the relationship between two elements is listed as follows:

Scenario 1. *$R_i \times R_j$, R_i and R_j can form a circuit, which means if $R_i \times R_j$, then $R_{ij} = R_{ji} = 1$;*

Scenario 2. *$R_i \circ R_j$, R_i and R_j have no connection; which is if $R_i \circ R_j$, then $R_{ij} = R_{ji} = 0$;*

Scenario 3. *$R_i \wedge R_j$, R_i has influence on R_j, but R_j has nothing to do with R_i, which can be described as if $R_i \wedge R_j$, then $R_{ij} = 1$, $R_{ji} = 0$;*
Scenario 4. *$R_i \vee R_j$, contrary to scenario 3, R_i contributes nothing to R_j, but R_j can impose influence on R_i; it is if $R_i \vee R_j$, then $R_{ij} = 0$, $R_{ji} = 1$.*

The adjacent matrix describes the specific relationship between any two of the elements in the factor set. Here Matrix A can be constructed based on the value R_{ij} which reflects the specific relationship between the factor R_i and R_j. Combining with the factor analysis above, the relationships among these factors can be inferred.

$$A = \begin{array}{c} \\ R_1 \\ R_2 \\ R_3 \\ R_4 \\ R_5 \\ R_6 \\ R_7 \\ R_8 \\ R_9 \\ R_{10} \end{array} \begin{array}{c} \begin{array}{cccccccccc} R_1 & R_2 & R_3 & R_4 & R_5 & R_6 & R_7 & R_8 & R_9 & R_{10} \end{array} \\ \left\{ \begin{array}{cccccccccc} 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 \\ 1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{array} \right\} \end{array}$$

4.2. **Obtaining the reachable matrix.** The method of building the reachable matrix M by the adjacent matrix A can be:

$$\textit{If } (A+I)^{i-1} \neq (A+I)^i = (A+I)^{i+1}, \textit{ then } M = (A+I)^i$$

By calculation, $(A+I)^3 \neq (A+I)^4 = (A+I)^5$, the reachable matrix M is obtained:

$$M = (A+I)^4 = \begin{array}{c} \\ R_1 \\ R_2 \\ R_3 \\ R_4 \\ R_5 \\ R_6 \\ R_7 \\ R_8 \\ R_9 \\ R_{10} \end{array} \begin{array}{c} \begin{array}{cccccccccc} R_1 & R_2 & R_3 & R_4 & R_5 & R_6 & R_7 & R_8 & R_9 & R_{10} \end{array} \\ \left\{ \begin{array}{cccccccccc} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 \\ 1 & 1 & 1 & 0 & 1 & 1 & 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 & 0 & 1 & 0 & 0 & 1 & 0 \\ 1 & 1 & 1 & 0 & 1 & 1 & 1 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 & 1 & 1 & 1 & 0 & 1 & 1 \\ 1 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 1 & 1 & 1 & 0 & 1 & 1 & 1 & 0 & 1 & 1 \end{array} \right\} \end{array}$$

4.3. **Hierarchy distribution for each element.** The reachable set $P(R_i)$ means all the elements within this set can be reached from the element R_i, which corresponds to the value 1 in the i-th row of reachable matrix M, then the relevant columns can be labeled, $P(R_i) = \{R_j \mid m_{ij} = 1\}$. Similarly, for the advance set $Q(R_i)$, which contains all the value 1 in the i-th column of reachable matrix M, the corresponding rows can be marked, $Q(R_i) = \{R_j \mid m_{ji} = 1\}$. Then the set L_i can be determined by $P(R_i) \cap Q(R_i) = P(R_i)$. The characteristics of elements in L set can be described as these elements within set L can be reached from other elements, but they are not accessible for other elements.

For the reachable matrix M, once L_i is obtained, the elements within the set L_i can be allocated to the i-th level. Then delete the elements of set L_i from the original reachable matrix M, and repeat the calculation for the new reachable matrix M' to determine the set L_2, L_3, L_4, etc., as Table 1.

TABLE 1. Reachable sets and advance sets about affecting factors

R_i	$P(R_i)$	$Q(R_i)$	$P(R_i) \cap Q(R_i)$
R_1	1	1,2,3,4,5,7,8,10	1
R_2	1,2,6,9	2,3,4,5,7,8,10	2
R_3	1,2,3,5,6,7,9,10	3,5,7,8,10	3,5,7,10
R_4	1,2,4,6,9	4	4
R_5	1,2,3,5,6,7,9,10	3,5,7,8,10	3,5,7,10
R_6	6	2,3,4,5,6,7,8,10	6
R_7	1,2,3,5,6,7,9,10	3,5,7,8,10	3,5,7,10
R_8	1,2,3,5,6,7,8,9,10	8	8
R_9	9	2,3,4,5,7,8,9,10	9
R_{10}	1,2,3,5,6,7,9,10	3,5,7,8,10	3,5,7,10
			$L_1 = \{1, 6, 9\}$
R_i	$P(R_i)$	$Q(R_i)$	$P(R_i) \cap Q(R_i)$
R_2	2	2	2
R_3	2,3,5,7,10	3,5,7,8,10	3,5,7,10
R_4	2,4	4	4
R_5	2,3,5,7,10	3,5,7,8,10	3,5,7,10
R_7	2,3,5,7,10	3,5,7,8,10	3,5,7,10
R_8	2,3,5,7,8,10	8	8
R_{10}	2,3,5,7,10	3,5,7,8,10	3,5,7,10
			$L_2 = \{2\}$
R_i	$P(R_i)$	$Q(R_i)$	$P(R_i) \cap Q(R_i)$
R_3	3,5,7,10	3,5,7,8,10	3,5,7,10
R_4	4	4	4
R_5	3,5,7,10	3,5,7,8,10	3,5,7,10
R_7	3,5,7,10	3,5,7,8,10	3,5,7,10
R_8	3,5,7,8,10	8	8
R_{10}	3,5,7,10	3,5,7,8,10	3,5,7,10
			$L_3 = \{3, 4, 5, 7, 10\}$
R_i	$P(R_i)$	$Q(R_i)$	$P(R_i) \cap Q(R_i)$
R_8	8	8	8
			$L_4 = \{8\}$

4.4. **Generating a hierarchical structure.** Each factor can be allocated to the relevant level from top to bottom of the hierarchy structure model, as Figure 1.

As seen from Figure 1, factors affecting assembly line efficiency can be grouped into four hierarchies. From the bottom up, machine/model is the most basic factor, which affects assembly line efficiency ultimately. All factors have connection with it; meanwhile, it influences synchronization of process and support of engineering departments at the second level directly.

Besides production environment, the second level factors layout of production facilities and production line equipment connect each other and make great sense to the upper level factors.

The staff is the intermediate element at the third level, which links the production elements at the bottom levels and the material elements at the upper level; while quality and capacity of relevant production lines, raw materials and production information position

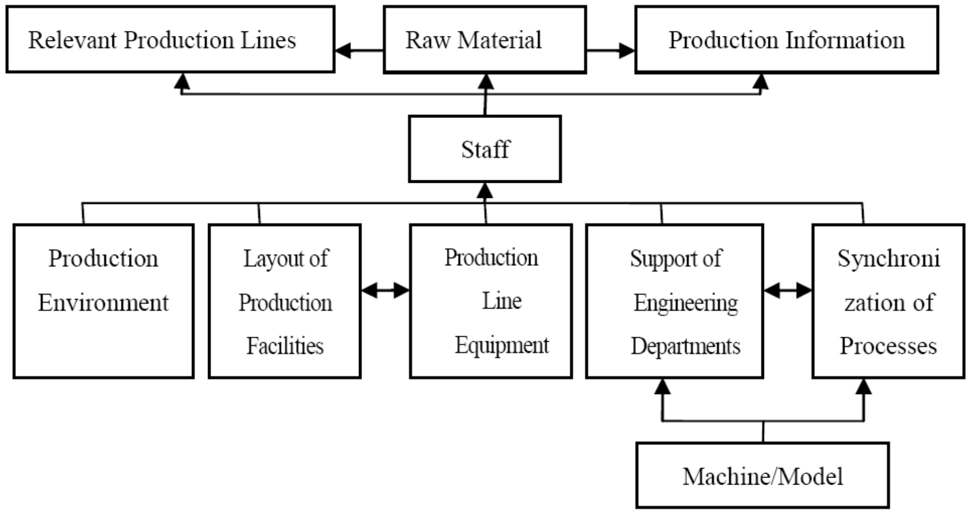

Figure 1. Factor hierarchy model of assembly line efficiency

at the top level, which can be relatively easy-controlled and improved due to no direct connection with other factors.

5. **Application of Factor Hierarchy Structure.** According to the different level distribution of factor hierarchy structure, faulty factors can be identified and paid attention to in order to improve efficiency of assembly lines.

5.1. **Bottom factors (production line control).** Factors locating at the bottom levels, such as machine kinds, production environment, layout of production facilities, production line equipment, support of engineering departments and synchronization of processes, which can be generalized to production line control, are the fundamental elements and affect assembly line efficiency radically. Therefore, production line control is the underpinning of higher efficiency.

Tips for production line control involve machine arrangement and workers' coordination. As for machine arrangement, calculating the assembly line balance precisely, designing the production space properly, carrying out site management, and the reasonable synchronization of processes before production, are sure to benefit assembly line production. Simultaneously, production environment and production line equipment need to be detected daily so as to be in good condition. Products at each assembly point should have a short testing procedure as they move along the lines to prevent costly defects and ensure no defective pieces remaining. These steps help the line stay productive and profitable.

Integrating with the staff factor of the upper level, each member of staff needs be positioned in a suitable workstation in order to adapt a different machine pace. For example, placing slower moving operators near the ends of production line and faster workers close to the middle of line can save manufacturing time; determining the assembly line bottlenecks and adding more workers at particular points to expedite the process. Additionally, to ensure they understand production tasks clearly, standard operating procedure (SOP) for the next items had better be hung in advance and the staff are obliged to follow its requirement strictly. Due to the bottom factors' great contribution to efficiency, even the slightest enhancement can result in considerable gains.

5.2. **Intermediate factor (staff motivation).** Staff at the second level is the most insignificant factor to assembly line efficiency, especially in an industry where labor costs are high and rapid changes require workers to be flexible and to learn new skills fast. It has a high possibility of going wrong. Hence, staff management is the hinge to improve assembly line efficiency. Combining with factors at the lower levels, the improvement of production line implies the optimization of assembly line balancing, with the best utilization of human resources.

Apart from getting them to obtain regular training, the irregular replacement of their positions and effective incentive mechanism do really make sense not only to increase skills, but also to avoid passive attitudes due to repeating the same operation for long time. Besides, creating a kind of pleasant production environment and communication atmosphere also counts for stress prevention or stress elimination for assembly-line workers.

On the other hand sometimes "unpaced" lines turn out better, which means workers are free to set their own pace and pass their work pieces to the next station, rather than picking up the line pace when a mechanically-based assembly line keeps products moving at a particular pace. For instance, a worker can put the accessories together at one work station and pass it to the next station at his/her own pace. As a result, he/she is more relaxed to produce more output.

5.3. **Top factors (production preparation).** Factors at the top level such as raw materials, quality and capacity of relevant production lines, and production information are the premise of assembly line production. The quality of raw materials can be controlled by the suppliers sending a commissioner to the enterprise so as to detect problems and fix them timely. Additionally, due to the influence of the storage environment on product quality, all the items and parts need to reach the quality standard before being delivered to the next station, and it should be ensured that unqualified items are not on line. As for the relevant lines, it is imperative to exchange information with each other to enhance the product quality and the production capability. Information system can be applied to ensure the production information is reflected to the relevant departments in time to keep the product moving efficiently through the assembly process.

6. **Conclusions.** Higher assembly line efficiency helps to explore enterprises' potential, shorten the production cycle and improve enterprises' benefit. The affecting factors and their hierarchical relationship are illustrated to help enterprises control the assembly line production, and the factor hierarchy model obtained constructs the valuable information source for the improvement of assembly line performance. From the bottom up of the hierarchy model, factors locating at the bottom levels, such as machine kinds, production environment, layout of production facilities, production line equipment, support of engineering departments and synchronization of processes, which can be generalized to machine selection and production line control, are the underpinning of higher efficiency and contribute most to assembly line efficiency. Staff at the third level is the most important and problematic factor, which great importance needs to be attached to. Factors at the top of the hierarchy referring to production preparation, such as raw materials, quality and capacity of relevant production lines, and production information are the premise of assembly line production, and making good arrangements before carrying out production underpins the assembly line production. Meanwhile, as a tool of complex system analysis, Interpretative Structural Modeling is applied to analyze the complex assembly line system and explore the multi-hierarchical relationship among latent factors affecting assembly line efficiency. And the 'unpaced' coordination of machine and human can be further explored.

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