APPLICATION OF SELECTED BALANCING METHODS FOR ANALYSIS AND EVALUATION OF THE WORKING EFFICIENCY OF THE ASSEMBLY LINE ON THE EXAMPLE OF A SELECTED PRODUCT

Zastosowanie wybranych metod balansowania do analizy i oceny wydajności pracy linii montażowej na przykładzie wybranego produktu

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A b s t r a c t: Economic development requires from production companies to use more and more effective production methods. The growing demand for goods requires from them to reduce the lead time and to produce products of the best quality and competitive price. One of the problems of production lines is their proper balance. Balancing the production line consists in finding the optimal order of performed operations and assigning operations to individual operations in such a way, that work on positions is comparable. In this way, it is strive to minimize machine downtime and to distribute the work evenly between them. In the work, the performance analysis of the assembly line was made on the example of a selected product using three methods of balancing: the experimental method, the RPW (Ranked Positional Weight) heuristic method and SPT (Shortest Processing Time) method. The obtained results were analyzed and solutions were proposed to improve the work of the line.
K e y w o r d s: assembly line performance, RPW (Ranked Positional Weight) method, SPT (Shortest Processing Time) method, balancing the production line

S t r e s z c z e n i e: Rozwój gospodarczy wymaga od przedsiębiorstw produkcyjnych stosowania coraz to bardziej efektywnych metod produkcyjnych. Rosnący popyt na towary wymaga od nich zmniejszenia czasu potrzebnego na produkcję wyrobów o jak najlepszej, jakości i konkurencyjnej cenie. Jednym z problemów linii produkcyjnych jest ich prawidłowe zbalansowanie. Balansowanie linii produkcyjnej polega na znalezieniu optymalnej kolejności wykonywanych operacji oraz przypisaniu czynności poszczególnym operacjom w taki sposób, aby praca na stanowiskach była porównywalna. Dąży się w ten sposób do zminimalizowania czasów przestoju maszyn oraz do jak najbardziej równomiernego rozłożenia pracy pomiędzy nimi. W pracy wykonano analizę wydajności pracy linii montażowej na przykładzie wybranego wyrobu z wykorzystanie trzech metod balansowania: metody doświadczalnej, metody heurystycznej RPW (ang. Ranked Positional Weight) oraz metody SPT (ang. Shortest Processing Time). Dokonano analizy uzyskanych wyników i zaproponowano rozwiązania pozwalające na usprawnienie pracy linii.
S ł o w a k l u c z o w e: wydajność linii montażu, metoda RPW (ang. Ranked Positional Weight), metoda SPT (ang. Shortest Processing Time), balansowanie linii produkcyjnej

Introduction

Constant economic development requires manufacturers to use more and more effective production methods. The growing demand for goods requires producers to drastically reduce the time needed to produce the best quality and competitive price. This allowed a significant reduction in production cycle time and an almost two-fold reduction in production costs. Ford's success, as the first in history to adapt the production line to the production of cars, initiated the dynamic development of line production in almost all branches of industry, from agriculture to the defense industry. This allowed a significant reduction in production cycle time and an almost two-fold reduction in production costs. The biggest problem of production lines is their proper balancing. It strives to minimize machine downtime and to distribute work as evenly as possible between them. In the rest of the work, it will focus on presenting the methods of balancing production lines and carry out performance analysis for the assembly line of the chosen product.

Characteristics and analysis of selected methods of balancing assembly lines

Balancing of the production line consists in minimizing machine downtime and the most even distribution of work between them. In order for the balancing process to be completed, each operation should be assigned once and only to one workstation (Fig. 1) [1-8]. The basis of the balancing problem is to assign a set of tasks to an ordered set of workstations so that the order relations are met and the quality indicators optimized. The assembly line is properly balanced if all operations have been carried out, without prejudice to production assumptions on the line [5, 13, 15]. Due to the optimality criterion, two basic types of assembly line balancing problems are distinguished:

- type 1, minimizing the number of assembly stations at a constant cycle value, the goal is to minimize station downtime, which is equivalent to minimizing the number of work stations [9-12, 13]. The estimated number of workstations is calculated according to formula (1).

$$K_s = \left\lceil \frac{\sum_{i=1}^{N} t_i}{c} \right\rceil \tag{1}$$

where: K_s - estimated number of workstations, c - cycle value, N - number of tasks, t_i - task completion time i.

- type 2, minimizing the production cycle with a constant number of workstations, the goal is to minimize the cycle line balanced, which is equivalent to maximizing production [9, 14]. The estimated number of workstations is calculated according to the formula (2).

$$c_s = \left\lceil \frac{\sum_{i=1}^{N} t_i}{K} \right\rceil \tag{2}$$

where: c_s - estimated cycle value, K - number of workstations, N - number of tasks, t_i - time of task implementation i.

Balancing the production line consists in reducing machine downtime and for even distribution of work between workstations. There are many values that allow you to compare assembly line balancing methods.

The most commonly used quantities allowing for comparison of balancing results are [13]: assembly line efficiency, smoothness factor and line time.

The efficiency of the assembly line is calculated according to the formula (3):

$$LE = \frac{\sum_{i=1}^{K} ST_i}{c \cdot K} \cdot 100\% \tag{3}$$

where: c - cycle time, K - number of assembly stations, LE - line efectiveness, ST_i - time of use of every (i) station.

The line smoothness factor expresses a value representing the relative smoothness of a balanced assembly line. The better balanced the line, the closer to zero the smoothness factor will be. The smoothness coefficient is described by the formula (4):

$$SI = \sqrt{\sum_{i=1}^{K} (ST_{\max} - ST_i)^2} \tag{4}$$

where: SI - smoothness factor, ST_i - time of use of i - this station, ST_{max} - maximum time of use of the workstation.

The value that allows comparison of balancing results is the time of the line. This ratio is strictly dependent on the number of workstations. The shorter the line time, the better balanced the line will be. The line time is calculated according to the formula (5):

$$LT = (K-1) \cdot c + ST_K \tag{5}$$

where: c - cycle time, K - number of workstations, LT - line time, ST_k - time of the last workstation.

Various types of algorithms are used to solve the problem of assembly line balancing. Generally, these algorithms were divided into two groups [9, 13]: exact algorithms and heuristic algorithms. Accurate algorithms are those that are able to provide a clear solution to the problem or no solution to it. Accurate algorithms are mainly based on methods [10, 13]: linear discrete programming, network programming, dynamic programming as well as division and constraints. Heuristic algorithms allow finding an approximate solution to the problem. They make it possible to indicate an acceptable or even optimal solution in a relatively short time. Heuristic algorithms are characterized by great diversity. In general, it was divided into algorithms [9]: scheduling and allocation. Examples of heuristic methods include the RPW- Ranked Positional Weight, RRPW - Reversed Ranked Positional Weight, K&W (Kilbridge & Wester), Hoffman order matrix, and IUFF-Immediate Update First - Fit method.

Analysis and assessment of the working efficiency of the assembly line for the production of the automotive industry

- **Collecting data on the process and preliminary analysis of the line's operation**

The assembly line, which will be rebalanced in this work, produces products for the automotive industry. This line is a serial construction, which means that all operations are carried out in a strictly defined order between workstations. The parts are transported through a conveyor belt. The assembly line consists of eight assembly stations and one finished product testing station. The number of operators envisaged for all machines is six people. Currently, production is envisaged in a three-shift system five days a week. The working time is seven and a half hours. The weekly demand for the product is

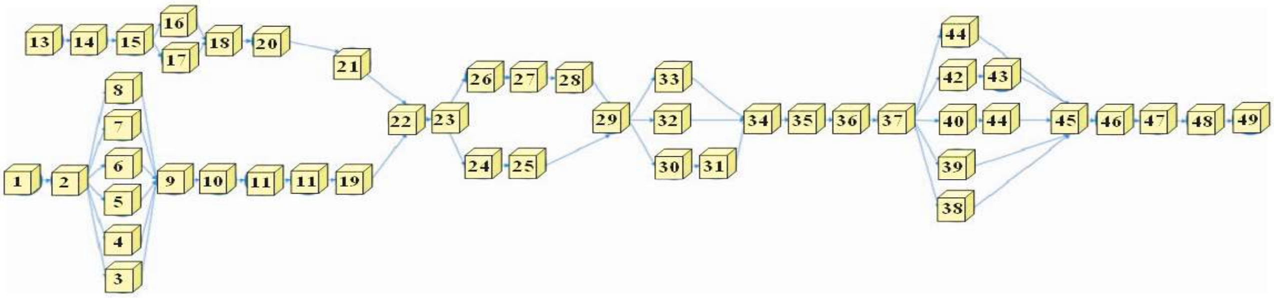

Fig.1. Graph of the relationship of the consequences of individual tasks of the product assembly process

2780 pieces.The total working time on the line is 24,07 hours a day. The minimum number of working days in a month is 24 days.

The technological process of product assembly consists of 9 operations divided into 49 assembly tasks. Each assembly task is assigned to individual assembly stations, taking into account their duration. Based on the collected information, a graph of the consequences of individual tasks was created (Fig. 1). This graph is designed to clearly show all the relationships between production stages.

Then, for the analyzed assembly line, cycle time was measured for each task included in the process. Based on the results obtaineddetermined the production time, cycle time and theoretical minimum number of workstations were [12].

The production time allowed was determined from formula (6).

$$Tp = npr \cdot z \cdot nh \qquad (6)$$

where: Tp - production time allowed, npr - number of working days per week, z - weekly number of shifts, nh - number of working hours per shift.

The production line cycle was determined from formula (7).

$$T = Tp \,/\, P \qquad (7)$$

where: T - production line cycle, Tp - production time allowed, P - weekly production demand pcs / week.

The theoretical minimum number of workstations from formula (8).

$$LS_{min} = \frac{\sum_{i=1}^{I} T_i}{T} \qquad (8)$$

where: LS_min- theoretical minimum number of workstations T - production line cycle, $\sum_{i=1}^{I} T_i$- total execution time and - these tasks.

The following results were obtained: the allowable production time was Tp= 120s, the tact time T= 150s and the theoretical minimum number of work stations: LS= min 6.94≈7. Calculations indicate that seven positions are enough to ensure optimal performance on the assembly line. Currently, the analyzed assembly line has as many as nine stations, which indicates that it has not been thoroughly analyzed at the modeling stage.

In addition, the results of the measurement of cycle times of individual tasks allowed assigning tasks to workstations, thanks to which it will show to what extent they are used (Fig. 2).

The analysis of the results obtained indicates that the big problem of the analyzed assembly line is the lack of even loading of work stations. In addition, too many assembly stations are another problem. The assembly line rebalancing process was carried out to eliminate the identified problems. The experimental method, RPW *(Ranked Positional Weight)* method and SPT *(Shortest Processing Time)* method were used for the analysis.

Development and analysis of new models - experimental method

The first method used was the experimental method. Its first element was the reduction of the number of assembly stations from 9 to 7, and then the reassignment of tasks to individual positions based on the obtained cycle times. Figure 3 presents the load diagram of individual assembly stations after modification.

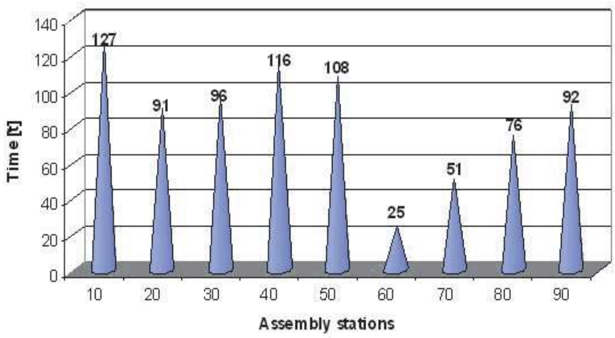

Fig. 2. Graph of current loads of individual assembly stations

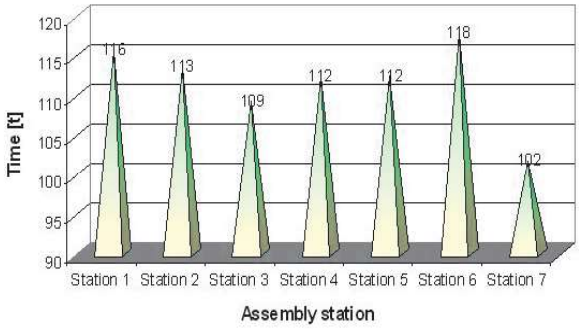

Fig. 3. Load diagram of individual assembly stations after modification

The results obtained after the modification indicate that earlier disparities between cycle times of individual stations have been reduced.

Development and analysis of new models - the RPW method

The second method used to rebalance the line was the heuristic method RPW (Ranked Positional Weight). The steps to follow when using this method are as follows:

- Specify the weight position for each task. (The longest path time from the beginning of the operation to the rest of the network).
- Then organize the network tasks based on weight positions. The task with the highest weight position takes first place.
- Match tasks to work stations. Priority is given to elements of the highest weight.
- If there is time remaining on any workstation after assigning the task, assign the tasks until the order of sequence order is exceeded or the cycle is exceeded.
- Repeat steps 3 and 4 until all items are assigned to workstations.

The use of this method requires determination of the weight position for each task. Starting from task number 1 up to task 49. The weight relationship graph was used to determine the results of individual tasks (Fig. 1.)

The weight position for task number1 is 564. It is calculated by adding together the next longest lasting tasks up to task number 49 according to Table 1. Table 1 presents the values and components of weight items for tasks from 1 to 13.

Table 1. Values and components of weight items for tasks from 1 to 13

no.	1	2	3	4	5	6	7	8	9	10	11	12	13
Time Ti [s]	11	5	6	3	3	5	3	5	66	6	12	91	11
	11	5	6	3	3	5	3	5	66	6	11	91	11
	5	6	66	66	66	66	66	66	6	12	91	6	16
	6	66	6	6	6	6	6	6	12	91	6	6	4
	66	6	12	12	12	12	12	12	91	6	6	52	17
	6	12	91	91	91	91	91	91	6	6	52	7	18
	12	91	6	6	6	6	6	6	6	52	7	15	9
	91	6	6	6	6	6	6	6	52	7	15	32	7
	6	6	52	52	52	52	52	52	7	15	32	13	6
	6	52	7	7	7	7	7	7	15	32	14	39	52
	52	7	15	15	15	15	15	15	32	14	39	25	7
	7	15	32	32	32	32	32	32	14	39	25	51	15
	15	32	13	13	13	13	13	13	39	25	51	5	32
	32	14	39	39	39	39	39	39	25	51	5	16	13
	13	39	25	25	25	25	25	25	51	5	16	5	39
	39	25	51	51	51	51	51	51	5	16	5	5	25
	25	51	5	5	5	5	5	5	16	5	5	17	51
	51	5	16	16	16	16	16	16	5	5	17	43	5
	5	16	5	5	5	5	5	5	5	17	42	25	16
	15	5	5	5	5	5	5	5	16	41	24		5
	5	5	17	17	17	17	17	17	43 43	25			5
	5	17	43	43	43	43	43	43	26 26				17
	17	43	26	26	26	26	26	26					43
	43	26											26
	26												
Weigh	**564**	**553**	**548**	**545**	**545**	**547**	**545**	**547**	**541**	**475**	**469**	**457**	**442**

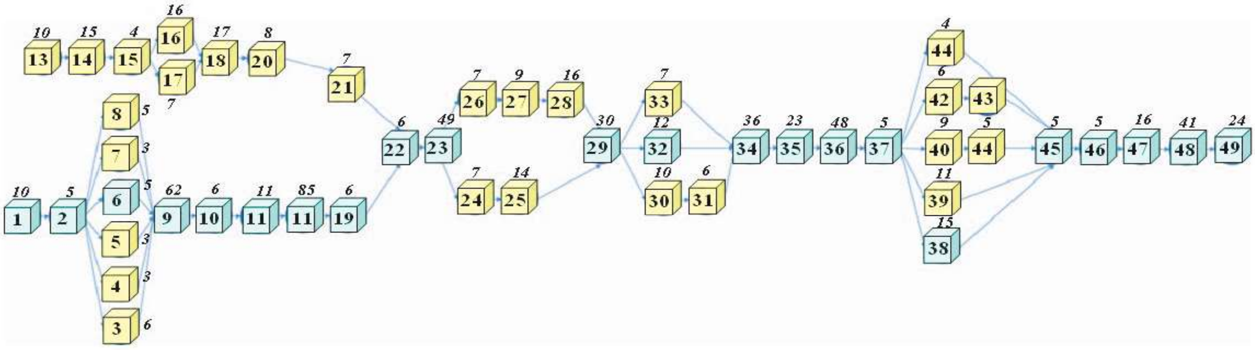

Fig. 4. Graph of the relationship of the consequences of individual tasks of the product assembly process with the longest path marked in green for task number 1

Figure 4 shows the longest possible path for task number 1 in green.

Having calculated weight position values for all events of the production process, events were assigned to workstations, taking into account operations of the highest importance first. If there is free time left in the open position after assigning the task, assign the next until the measure is not exceeded or the order of the order is disturbed. Figure 5 presents a graph of loads of individual assembly stations after applying the RPW method.

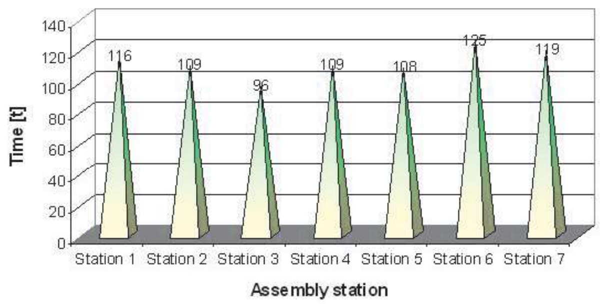

Fig. 5. Load diagram of individual assembly stations after using the RPW method

Development and analysis of new models - the SPT method

The SPT (Shortest Processing Time) method consists in determining the shortest path needed for a given event to achieve the last task. The methodology for using this method is very similar to the RPW method, but with the difference that using the graph of the consequences of individual tasks is determined not the longest, but the shortest path to overcome for each task. Fig. 6 in orange shows the shortest path for task number 13.

Then, similarly to the RPW method, weights were calculated for each task of the production process. This time the basic difference will be the way events are selected. The RPW method should aim to find the event with the longest possible duration, remembering not to violate the order of order tasks. In the SPT method, however, you need to find the shortest possible way to overcome subsequent events. Having calculated weight position values for all events of the production process, events were assigned to workstations, taking into account operations with the lowest weight first. Figure 7 presents a graph of loads of individual assembly stations after the SPT method.

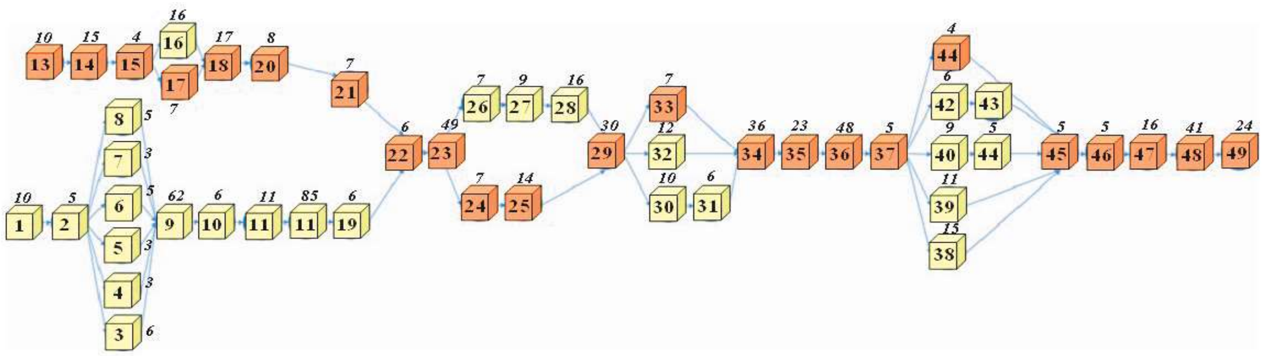

Fig. 6. Graph of relations between the consequences of individual tasks of the product assembly process and the shortest path for task number 13

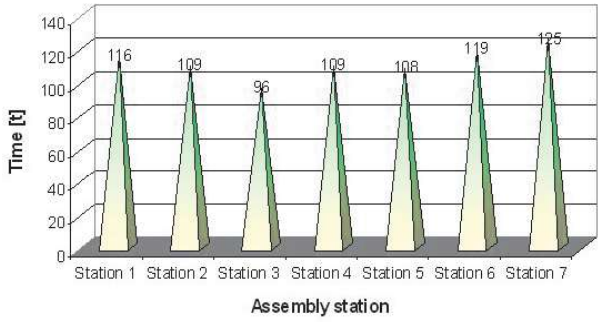

Fig. 7. Load diagram of individual assembly stations after applying the SPT method

Analysis of the obtained results

The analysis of the obtained results was carried out by comparing the balancing results for each developed model: assembly line efficiency (LE), smoothness factor (SI) and line time (LT). Fig. 8 presents the values of coefficients characterizing the line's work efficiency. The ideal solution is one in which the value of the assembly efficiency factor will be as high as possible. It should be noted that for the current state it is only 68.3%, which makes it the lowest. The results obtained for the SPT and RPW methods are 89.2% each. The experimental method gave the best result, for which the efficiency ratio is equal to 95%.

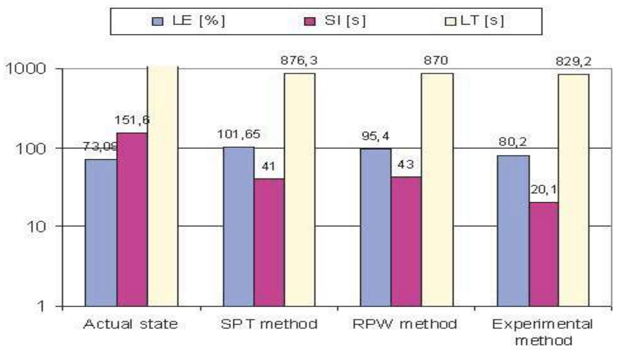

Fig. 7. Load diagram of individual assembly stations after applying the SPT method

The higher the SI value, the worse the line will be balanced. The obtained results clearly show that the best result was obtained by the experimental method 20.1 s. The SPT and RPW methods achieved 41 and 43 equally. The initial parameter was as much as 151,6 s. The results show that the assembly line time significantly decreased, which before modification it was as much as 1110 s. The SPT method reduced this time to 876.3 s. The RPW method proved to be slightly better giving 870 s. Again, as in previous cases, the best result was obtained thanks to the experimental method. It amounts to 829.2 s.

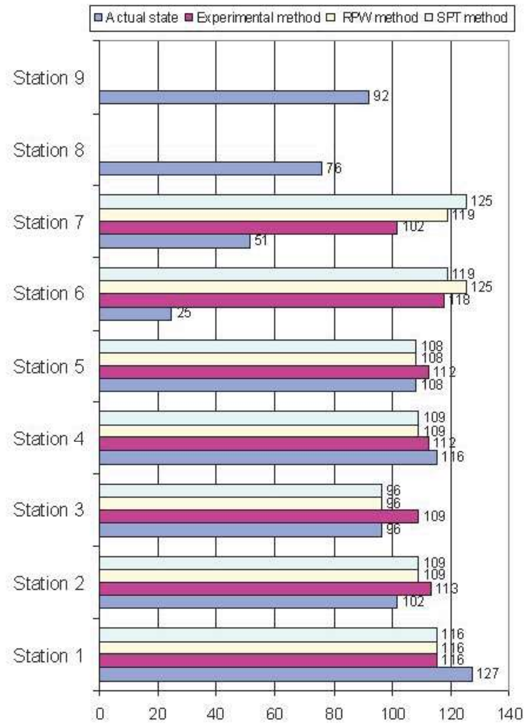

Fig. 8. List of coefficients describing the efficiency of the module assembly line before and after modifications

Figure 9 presents a load diagram of individual assembly stations before and after the proposed modifications.

On fig. 9 the load on assembly stations is before applying modifications is presented. The biggest difference was noticed between stations number 1 and number 6, whose working time was only 25 seconds. Initially, the number of stands was nine, where in reality only seven are needed to meet production requirements. After reducing the number of stations, operations were assigned to other stations. This allowed for balancing the loads on individual assembly stations.

Conclusion

The purpose of this work was to analyze the performance of the product assembly line for the automotive industry. In order to identify the problems of assembly line operation, a performance analysis was carried out for the current condition of the line. Then methods were used to balance it. Conducting a detailed analysis of the results obtained showed that the methods proposed have obtained a measurable effect. The best results were obtained after applying the experimental method. A very comparable effect was obtained using RPW and SPT methods. To sum up, by using the right ones, significant improvement was achieved in the basic factors determining work efficiency on the line.

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