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TECHNOLOGY ASSESSMENT PROCESS FOR NEW PRODUCTION LINE DEVELOPMENT – ANALYTIC NETWORK PROCESS APPROACH

Abstract

In a modern industry technology assessment have become an important factor of successful technological development. In this paper the problem of choosing right technology by manufacturing enterprise is studied. The use of Analytic Network Process is proposed as a supporting tool for the decision under several conflicting and interrelated criteria.

Keywords

Technology assessment, technology development, ANP.

Introduction

A modern enterprise working in industrial field faces a large number of technical and organizational challenges. The production of an even relatively simple article very often needs quite complicated technology. Rapidly changing and highly competitive environment demands fast and optimal response. While making decisions it is necessary to consider several criterions including technology, finance, personnel, environment and many others.

Technology Assessment (TA) is being increasingly viewed as an important tool in the shift towards technology development. However, this is a wide concept, evolving on different levels: national, industrial and corporate. This article aims to provide some practical guidance for choosing technology when the new production line is developed.

We consider the decision situation when the managers have to make several decisions in order to choose a technology being the part of new production line. Those decisions can be considered – to some extent – as independent, as very often there are various alternatives which are, in principle, replaceable. They all satisfy the basic demands but differ in many details and features. It is important to find the exhaustive set of criteria characterizing a technological solution which help to make the best decision. To get better insight into the problem criteria are usually further divided into a number of sub-criteria which describe the alternatives more accurately.

The number of criteria, sub-criteria and their interrelations are mapped into the framework based on Analytic Network Process (ANP) [6]. As a result we can practically support the decision concerning a choice of suitable technology for the new production line. All calculations were performed with the aid of "Super Decisions" software (ver. 1.6.0) [9].

1. Technology assesment process

1.1. Literature review

There are many empirical studies on TA [7, 10, 11]. Linstone's perspective [3] considers the dimensions of science and technology to be the kind of threat we may confront – countries, groups, or individuals with aggressive goals, intense commitment, rational or irrational selection of tools and strategies, preference for high risks, and unconventional tactics. Reference [4] presents a conceptualizing sustainability assessment and uses the concept of "integrated assessment" to achieve the impact of strategic assessment. Smits and Leijten [8] focus on TA as a process consisting of analyses of technological development and its consequences and of debate in with respect to these consequences. It provides information that could help the company involved in developing their strategies. Coates thinks that TA is a class of policy studies which systematically examines the effects on society that may occur when a technology is introduced, extended or modified. It emphasizes those consequences that are unintended, indirect or delayed. Cetron and Connor [1] attempt to establish an early warning system to detect, control, and direct technological changes and developments so as to maximize the public good while minimizing the public risks. Daddario [2] proposes a form of policy research which provides a balanced appraisal to the policy maker. Ideally, it is a system to ask the right questions and obtain correct and timely answers. It identifies policy issues, assesses the impact of alternative courses of action and presents findings. It is a method of analysis that systematically appraises the nature, significance, status, and merit of a technological program. Reference

[5] defines a framework by the hierarchical structure of the enterprise to assess the impact of manufacturing technology on the productivity and competitiveness of the enterprise.

1.2. Design of production line and choice of technology

When the new production line is under consideration, the management faces several partial decisions which involve a complex analysis of technical, financial and others aspects. In our analysis we focus on the particular choice of technology for an auxiliary system which is a part of a production line. Such a kind of decision can be considered as independent and the main goal is to find the best suitable alternative. Following the discussions with experts, four important criteria have been found: technical merits, investment cost, operating costs, environmental impact.

A more detailed analysis leads to a decomposition of each criterion to a number of subcriteria which characterize the available solutions more accurately. This part of the decision model is strongly case sensitive, which means that both the meaning and the number of sub-criteria and alternatives depend on the real life problem which is under the consideration. It is shown in Section 3 how this detailed analysis works in practice.

2. Analytic network process as a multiple criteria decision tool [6]

ANP is defined as a multiple criteria theory of measurement used to derive priority scales of absolute numbers from individual judgments which represent the relative influence, of one of two elements over the other in a pairwise comparison process on the third element in the system, with respect to an underlying control criterion. In the ANP one provides the judgment by answering two kinds of questions with regard to strength of dominance:

1. Given a criterion, which of the two elements is more dominant with respect to a criterion?
2. Which of the two elements influences the third element more with respect to a criterion?

It is assumed that there is a system of N clusters, whereby the elements in each cluster interact or have an impact on or are themselves influenced by some or all of the elements of that cluster or of another cluster with respect to a property governing the interactions of the entire system. The cluster is denoted by $C_h, h = 1,..., N$ and it has n_h elements that are denoted $e_{h1}, e_{h2}, ..., e_{hn_h}$.

A priority vector is derived from paired comparisons matrix by normalizing its columns and taking the geometric mean form rows (in the same way as in AHP). It represents the impact of a given set of elements in a cluster on another element in the system. Each priority vector is entered as a part of some column of a supermatrix. The supermatrix (denoted by *W*) represents the influence priority of an element on the left of the matrix on the element at the top of the matrix. The structure of the supermatrix is presented in equation (1). Each element W_{ij} of the supermatrix W is a matrix itself. W_{ij} represents the influence of the elements from cluster *i* on the elements from cluster *j*.

$$W = \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1N} \\ W_{21} & W_{22} & \cdots & W_{2N} \\ \vdots & \vdots & \vdots & \vdots \\ W_{N1} & W_{N2} & \cdots & W_{NN} \end{bmatrix}, \quad W_{ij} = \begin{bmatrix} w_{11}^{ij} & w_{12}^{ij} & \cdots & w_{1n_j}^{ij} \\ w_{21}^{ij} & w_{22}^{ij} & \cdots & w_{2n_j}^{ij} \\ \vdots & \vdots & \vdots & \vdots \\ w_{n_i1}^{ij} & w_{n_i2}^{ij} & \cdots & w_{n_in_j}^{ij} \end{bmatrix} \quad (1)$$

In the next step the supermatrix is transformed into a weighted supermatrix, i.e. to the matrix, whose columns sums to unity. Initially the supermatrix columns are made up of several eigenvectors which, in normalized form, sum to one and hence that column sums to the number of nonzero eigenvectors. The weighted supermatrix (called also 'a column stochastic matrix') can be obtained by weighting the initial supermatrix with a cluster matrix. The cluster matrix contains eigenvectors representing the priorities of clusters with respect to the general control criterion (in most cases it will be a main goal).

In the end the limit matrix is derived by raising the weighted matrix to an arbitrarily high power. This procedure sums up the influences along paths of different length in the underlying network and determines the overall priorities.

3. Illustrative example

3.1. Density measurement technology

As a practical example of technology assessment we have chosen the density measurement of construction material which will be the product of a newly designed production line. Three modern methods of measuring the density of solid state are considered:

- beta-ray based method with the radioactive isotope as the source of beam,
- X-ray based method,
- microwaves based method.

The above methods differ with respect to all criteria considered. Technically they are different in gauge scale and precision. They are produced by different suppliers and their user interfaces present final data differently. They also have different additional characteristics. For example: both beta-ray and X-ray devices scan the sample locally with the beam according to predefined scheme; the microwave device advantage is that it can make image of the whole sample volume.

In the beta-ray device, the radioactive isotope source should be replaced periodically according to its decay constant (which measures the speed of the decay). A worn out radioactive source must be utilized properly as it is dangerous for the environment. The X-ray source does not produce radioactive waste but it needs a high voltage power supply to produce an X-ray beam. These technical differences influence the environment in different ways and also result in different operating costs.

3.2. ANP Model

As it was discussed in subsection 1.2, the main goal is the choice of the best technological solution for the new production line. This decision requires the analysis of four important criteria which have been found to be: technical merits, investment cost, operating costs, and environmental impact. Following the AHP ideas the main goal is the first hierarchy level. The criteria take place at the second level of the hierarchy. At the next level each criterion has been split into a number of sub-criteria. In the example discussed the following subcriteria have been developed:

- Technical Merits: gauge scale, gauge precision, user interface, additional advantages.
- Investment Cost: purchase price, installation costs, training costs.
- Operating Costs: energy consumption, water consumption, other media consumption, maintenance, guarantee.
- Environmental Impact: labor environment, natural environment.

The bottom level comprises the alternatives considered. They are shortly denoted: Beta-ray, X-ray and Microwave. The overall structure of the ANP model is presented in Fig. 1. The main blocks of the ANP structure (GOAL, OPERATING COSTS, …, ALTERNATIVES) are called clusters (or components). They comprise one or more nodes which are represented in our model by "Technology Assessment" – the only node in the GOAL cluster, subcriteria grouped in the clusters they belong to, and three alternatives contained in the ALTERNATIVES cluster.

At first sight the model looks as it was pure AHP, but the interaction of environmental impact and operating costs cannot be mirrored by the AHP and a more general structure is required. It is not enough to compare the alternatives with respect to their environmental impact and with respect to their operating costs. We need also to judge the water, energy and other media consumption in respect to their environmental impact. And this influence may be different from mere financial assessment.

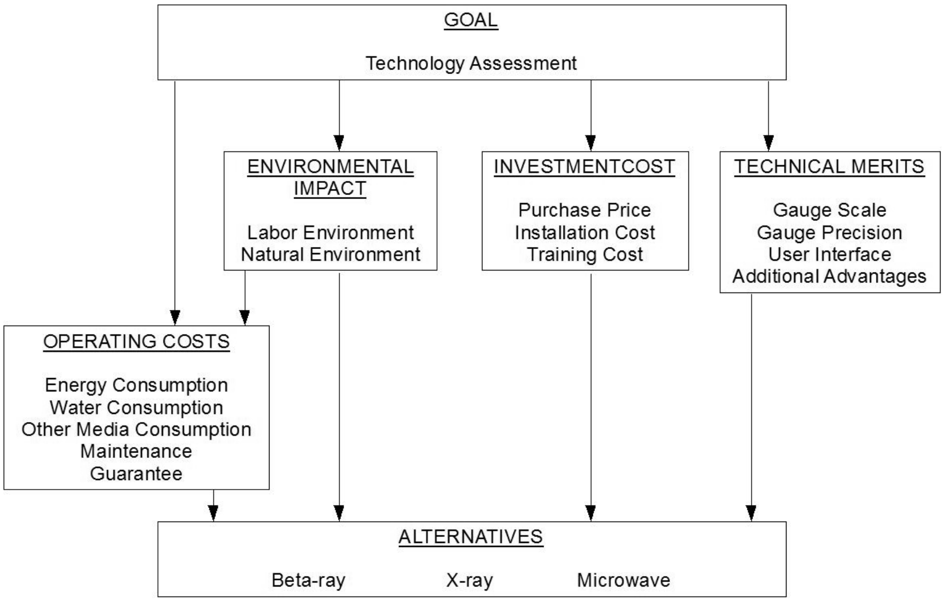

Figure 1. Technology Assessment – the ANP model structure

3.3. Numerical results for the ANP Model

At the beginning the pairwise comparisons of criteria with respect to the goal have been performed. From that data, priorities of criteria have been derived. The eigenvectors representing these priorities form columns of the cluster matrix which is presented in Table 1.

Table 1

Cluster Matrix for Density Measurement Technology Assessment

	Goal	Operating Costs	Investment Costs	Environmental Impact	Technical Merits	Alternatives
Goal	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Operating Costs	0.225353	0.000000	0.000000	0.500000	0.000000	0.000000
Investment Costs	0.178104	0.000000	0.000000	0.000000	0.000000	0.000000
Environmental Impact	0.094196	0.000000	0.000000	0.000000	0.000000	0.000000
Technical Merits	0.502346	0.000000	0.000000	0.000000	0.000000	0.000000
Alternatives	0.000000	1.000000	1.000000	0.500000	1.000000	0.000000

Then a substantial number of pairwise comparisons should be performed. First of all they comprise assessment of all alternatives with respect to all sub-criteria which makes altogether $14 \times 3 = 42$ comparisons. With addition of 3 comparisons of media consumption with respect to natural environment there are 45 comparisons in total. The resulting priority eigenvectors are placed in columns of the unweigted supermatrix (Tables 2-4).

Table 2

Unweighted Supermatrix for Density Measurement Technology Assessment

	Choice of Technology	Energy Con-sumption	Guarantee	Maintenance	Other Media Consumption	Water Con-sumption
Choice of Technology	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Energy Consumption	0.322192	0.000000	0.000000	0.000000	0.000000	0.000000
Guarantee	0.077448	0.000000	0.000000	0.000000	0.000000	0.000000
Maintenance	0.341793	0.000000	0.000000	0.000000	0.000000	0.000000
Other Media Consumption	0.101721	0.000000	0.000000	0.000000	0.000000	0.000000
Water Consumption	0.156846	0.000000	0.000000	0.000000	0.000000	0.000000
Installation Costs	0.199991	0.000000	0.000000	0.000000	0.000000	0.000000
Purchase Costs	0.600012	0.000000	0.000000	0.000000	0.000000	0.000000
Training Costs	0.199997	0.000000	0.000000	0.000000	0.000000	0.000000
Labor Environment	0.500000	0.000000	0.000000	0.000000	0.000000	0.000000
Natural Environment	0.500000	0.000000	0.000000	0.000000	0.000000	0.000000
Additional Advantages	0.087717	0.000000	0.000000	0.000000	0.000000	0.000000
Gauge Precision	0.462131	0.000000	0.000000	0.000000	0.000000	0.000000
Gauge Scale	0.293755	0.000000	0.000000	0.000000	0.000000	0.000000
User Interface	0.156396	0.000000	0.000000	0.000000	0.000000	0.000000
Beta-ray	0.000000	0.238476	0.310814	0.428567	0.249299	0.249299
Microwave	0.000000	0.625026	0.195800	0.142851	0.593647	0.593647
X-ray	0.000000	0.136498	0.493386	0.428582	0.157054	0.157054

Table 3

Unweighted Supermatrix for Density Measurement Technology Assessment

	Installation Costs	Purchase Costs	Training Costs	Labor Environment	Natural Environment
Choice of Technology	0.000000	0.000000	0.000000	0.000000	0.000000
Energy Consumption	0.000000	0.000000	0.000000	0.000000	0.625013
Guarantee	0.000000	0.000000	0.000000	0.000000	0.000000
Maintenance	0.000000	0.000000	0.000000	0.000000	0.000000
Other Media Consumption	0.000000	0.000000	0.000000	0.000000	0.136500
Water Consumption	0.000000	0.000000	0.000000	0.000000	0.238487
Installation Costs	0.000000	0.000000	0.000000	0.000000	0.000000
Purchase Costs	0.000000	0.000000	0.000000	0.000000	0.000000
Training Costs	0.000000	0.000000	0.000000	0.000000	0.000000
Labor Environment	0.000000	0.000000	0.000000	0.000000	0.000000
Natural Environment	0.000000	0.000000	0.000000	0.000000	0.000000
Additional Advantages	0.000000	0.000000	0.000000	0.000000	0.000000
Gauge Precision	0.000000	0.000000	0.000000	0.000000	0.000000
Gauge Scale	0.000000	0.000000	0.000000	0.000000	0.000000
User Interface	0.000000	0.000000	0.000000	0.000000	0.000000
Beta-ray	0.139642	0.249310	0.527836	0.249299	0.113002
Microwave	0.332525	0.157056	0.139648	0.593647	0.651929
X-ray	0.527833	0.593634	0.332516	0.157054	0.235069

Table 4

Unweighted Supermatrix for Density Measurement Technology Assessment

	Additional Advantages	Gauge Precision	Gauge Scale	User Interface	Beta-ray	Microwave	X-ray
Choice of Technology	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Energy Consumption	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Guarantee	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Maintenance	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Other Media Consumption	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Water Consumption	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Installation Costs	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Purchase Costs	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Training Costs	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Labor Environment	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Natural Environment	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Additional Advantages	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Gauge Precision	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

Gauge Scale	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	Additional Advantages	Gauge Precision	Gauge Scale	User Interface	Beta-ray	Microwave	X-ray
User Interface	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Beta-ray	0.166667	0.189711	0.319618	0.330897	0.000000	0.000000	0.000000
Microwave	0.666667	0.547216	0.121957	0.288919	0.000000	0.000000	0.000000
X-ray	0.166667	0.263073	0.558425	0.380184	0.000000	0.000000	0.000000

According to the ANP procedure described in Section 2 cluster matrix has been used to produce the weighted (column stochastic supermatrix). As there is not enough room here the presentation of this matrix is omitted. The last step in ANP is to derive the limit supermatrix by taking arbitrarily high power of the weighted supermatrix. This matrix comprises in its columns the final priority eigenvectors of the problem. The content of the limit supermatrix is presented in Tables 5-7.

Table 5

Limit Supermatrix for Density Measurement Technology Assessment

	Choice of Technology	Energy Consumption	Guarantee	Maintenance	Other Media Consumption	Water Consumption
Choice of Technology	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Energy Consumption	0.043155	0.000000	0.000000	0.000000	0.000000	0.000000
Guarantee	0.008625	0.000000	0.000000	0.000000	0.000000	0.000000
Maintenance	0.038064	0.000000	0.000000	0.000000	0.000000	0.000000
Other Media Consumption	0.012917	0.000000	0.000000	0.000000	0.000000	0.000000
Water Consumption	0.020243	0.000000	0.000000	0.000000	0.000000	0.000000
Installation Costs	0.017602	0.000000	0.000000	0.000000	0.000000	0.000000
Purchase Costs	0.052811	0.000000	0.000000	0.000000	0.000000	0.000000
Training Costs	0.017603	0.000000	0.000000	0.000000	0.000000	0.000000
Labor Environment	0.023275	0.000000	0.000000	0.000000	0.000000	0.000000
Natural Environment	0.023275	0.000000	0.000000	0.000000	0.000000	0.000000
Additional Advantages	0.021776	0.000000	0.000000	0.000000	0.000000	0.000000
Gauge Precision	0.114724	0.000000	0.000000	0.000000	0.000000	0.000000
Gauge Scale	0.072925	0.000000	0.000000	0.000000	0.000000	0.000000
User Interface	0.038825	0.000000	0.000000	0.000000	0.000000	0.000000
Beta-ray	0.131134	0.238476	0.310814	0.428567	0.249299	0.249299
Microwave	0.189201	0.625026	0.195800	0.142851	0.593647	0.593647
X-ray	0.173847	0.136498	0.493386	0.428582	0.157054	0.157054

Table 6

Limit Supermatrix for Density Measurement Technology Assessment

	Installation Costs	Purchase Costs	Training Costs	Labor Environment	Natural Environment
Choice of Technology	0.000000	0.000000	0.000000	0.000000	0.000000
Energy Consumption	0.000000	0.000000	0.000000	0.000000	0.208338
Guarantee	0.000000	0.000000	0.000000	0.000000	0.000000
Maintenance	0.000000	0.000000	0.000000	0.000000	0.000000
Other Media Consumption	0.000000	0.000000	0.000000	0.000000	0.045500
Water Consumption	0.000000	0.000000	0.000000	0.000000	0.079496
Installation Costs	0.000000	0.000000	0.000000	0.000000	0.000000
Purchase Costs	0.000000	0.000000	0.000000	0.000000	0.000000
Training Costs	0.000000	0.000000	0.000000	0.000000	0.000000
Labor Environment	0.000000	0.000000	0.000000	0.000000	0.000000
Natural Environment	0.000000	0.000000	0.000000	0.000000	0.000000
Additional Advantages	0.000000	0.000000	0.000000	0.000000	0.000000
Gauge Precision	0.000000	0.000000	0.000000	0.000000	0.000000
Gauge Scale	0.000000	0.000000	0.000000	0.000000	0.000000
User Interface	0.000000	0.000000	0.000000	0.000000	0.000000
Beta-ray	0.139642	0.249310	0.527836	0.249299	0.118512
Microwave	0.332525	0.157056	0.139648	0.593647	0.421729
X-ray	0.527833	0.593634	0.332516	0.157054	0.126425

Table 7

Limit Supermatrix for Density Measurement Technology Assessment

	Additional Advantages	Gauge Precision	Gauge Scale	User Interface	Beta-ray	Microwave	X-ray
Choice of Technology	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Energy Consumption	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Guarantee	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Maintenance	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Other Media Consumption	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Water Consumption	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Installation Costs	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Purchase Costs	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Training Costs	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Labor Environment	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Natural Environment	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Additional Advantages	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Gauge Precision	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000

Gauge Scale	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	Additional Advantages	Gauge Precision	Gauge Scale	User Interface	Beta-ray	Microwave	X-ray
User Interface	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Beta-ray	0.166667	0.189711	0.319618	0.330897	0.000000	0.000000	0.000000
Microwave	0.666667	0.547216	0.121957	0.288919	0.000000	0.000000	0.000000
X-ray	0.166667	0.263073	0.558425	0.380184	0.000000	0.000000	0.000000

The final ranking of alternatives with respect to main goal can be found in the “Choice of Technology” column (the numbers in parentheses represent the normalized scores of alternatives):
1. Microwave (0.3829) 2. X-ray (0.3518) 3. Beta-ray (0.2654)

Conclusions

The important and complicated problem of technology assessment was analyzed in the particular case of arrangement of a new production line. Analysis shows that four main important criteria should be taken into account in the decision process: technical merits, investment cost, operating costs, environmental impact. Usually these criteria are subject to further analysis and several subcriteria are derived. At this stage the problem becomes case sensitive and specific features of the problem determine the content of analysis.

To help the decision process, the technology assessment problem was structured with the aid of Analytic Network Process. The advantage of ANP is that it models interactions of different aspects of the problem while most popular methods usually treat them as independent. In the case of technology assessment an example of such an interaction is the interaction of environmental impact and operating costs. They are connected by energy, water and other media consumption. The use of resources can be evaluated differently from the financial and the environmental points of view.

ANP includes also several pairwise comparisons of criteria, subcriteria and alternatives. These comparisons result in a number of priority vectors organized in a supermatrix and give a numerical assessment of alternatives. Finally, a ranking of alternatives is achieved which reflects the whole analysis process.

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