

Exploring Effectiveness Reserves in Hospitals with the DEA Method

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SUMMARY

In our study, we undertake a relative efficiency analysis of hospitals providing inpatient care, which play a key role in the Hungarian health care system. According to the Competitiveness Report 2020 of the Hungarian National Bank, the Hungarian health care system has a number of reserves, and the sustainability of the system can be improved by using these reserves. In the 2015-2019 period, particular attention has been paid to the identification of achievable and meaningful indicators in the sector under review. The relative effectiveness analysis (DEA) method can be used to address this challenge. The units of our analysis are state-owned institutions in Hungary, typologised by the total number of beds. General profile hospitals with a bed count between 600 and 1200 beds were included in the analysis. The results of running the programme have clearly shown that there are some institutions that do not operate as efficiently as the majority of the organisations included in the study, but further research and refinement of the indicators is needed to determine the practical application of the pilot studies.

KEYWORDS: hospital, effectiveness analysis, DEA method

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The aim of our study is to examine the relative effectiveness of general profile inpatient hospitals with a 600-1200 bed capacity, which play a key role in the Hungarian health care system. Our research question is what results (outputs and outcomes) were achieved by the hospitals in Hungary between 2015-2019, and what and how much resources they used for that.

A key objective of performance-based auditing is the effectiveness-based assessment of the organisations involved (Pulay, Simon, 2020; Veresné Somosi, Hogya, 2011), which allows for the formulation of recommendations to increase operational effectiveness, in addition to relative effectiveness assessment. When comparing different organisations, there is usually no single indicator available that expresses all the key elements of the organisation's performance, and the data included in the analysis cannot always be expressed in the same dimension (Koltai, Tamás, 2019). In the analysis, particular attention should be paid to identifying the indicators that are available and meaningful in the sector/sector under study. This challenge can be addressed by the relative effectiveness analysis (DEA) method, which has a mathematical background in linear programming.

LITERATURE REVIEW

The study of hospital effectiveness is becoming increasingly important, as the effectiveness reserves of hospitals are a central issue. According to the Competitiveness Report of Magyar Nemzeti Bank, the Hungarian healthcare system has a number of reserves that could be exploited to improve the sustainability of the system (e.g. in 2017, bed occupancy was 66 per cent and the average hospital stay is 2 days longer than in the European Union (MNB, 2020).

The improvement of healthcare institutions is based on knowledge and measurement of operational effectiveness (Dénes et al., 2017).

Hospitals in Hungary can be differentiated according to various criteria (Dózsa, Ecseki, 2012):

- central – non-central hospitals,
- hospital groups by owner,
- groups according to progressivity levels (small town, city, county, university hospitals).

Based on these factors, the measurement of performance and effectiveness is a complex task, which requires the use of methods that address the different scales of assessment criteria measured in different dimensions (Dénes et al., 2017; Koltai, Tamás, 2019). This challenge is addressed by the DEA analysis.

The DEA method not only calculates the absolute effectiveness of a given unit, but also gives a ratio, which is a function of the effectiveness of the unit analysed in relation to the data of all the units included in the study (Lapid, 1997).

The DEA method is a performance evaluation technique based on the work of Farrell (1957), formalised by Charnes et al. (1978) and further developed by Banker et al. (1984), which can be identified as a decision support tool for management (Tamás, Koltai, 2020). After a structured screening of the literature, it can be concluded that the application of the relative effectiveness analysis (DEA method) can be extended to a number of areas (restaurant analysis: Reynolds, Thompson, 2007; hotel analysis: Hwang, Chang, 2003; assessment of higher education: Johns, 2006; analysis of simulation games: Tamás-Koltai, 2020), however, the frequency with which the method is used in effectiveness testing of health care providers can be clearly identified. Barnum et al. (2009) examine the performance of hospital pharmacies, while Dénes and colleagues (2017) analyse

the relative effectiveness of musculoskeletal rehabilitation departments in Hungary. *Dózsa and Ecseki* (2012) examine the domestic hospital sector, while *Nepomuceno* (2020) presents an effectiveness study of the evacuation of hospital beds necessitated by the Covid-19 pandemic using the DEA method in response to recent changes.

The DEA method can be defined in two approaches: input-oriented (cost-oriented) and output-oriented (result-oriented). When measuring effectiveness, we also have to take into account that not all inputs are utilised in the same way: if we expect the same level of resource incorporation, we should expect a constant rate of return (CRS - Constant Return to Scale), if not, we should expect a variable rate of return (VRS - Variable Return to Scale) (Gál, Komlósi, 2010).

METHODOLOGY

The DEA (Data Envelopment Analysis) method defines the effectiveness values (ratio) and the effectiveness frontier as a linear programming task. It has the advantage of being non-parametric, because knowledge of the production function is not a prerequisite (Dózsa, Ecseki, 2012).

In the analysis, the effectiveness scores of the decision-making units are compared, with the unit with the highest effectiveness scoring 1 (100 per cent). The procedure is used to calculate an effectiveness threshold (*best practice*), which is used to determine an effectiveness ranking (each unit is ranked in percentage terms).

The analysis compares organisations performing the same activity on the basis of the outputs of each organisation and the weighted share of inputs used. Input is the quantity of resources that is decisive for the evaluation. Output is any significant

operational result for which the organisation uses resources. The amount of resource used is an autonomous decision of the organisation, so the organisation can be identified as a Decision Making Unit (DMU). The comparison of DMUs is based on the ratio of the weighted sum of outputs to the weighted sum of inputs. Weighting can be determined objectively, using mathematical tools, based on the characteristics of the organisations. Determining the ratio of weighted inputs to outputs can be done for two purposes:

- maintaining the current value of outputs with fewer inputs (input-oriented approach, relative effectiveness index between 0 and 1),
- higher output at the current value of inputs (output-oriented approach, relative effectiveness ratio between 1 and infinite).

The effectiveness function is the weighted sum of outputs divided by the weighted sum of inputs (Ragsdale, 2007; Iberhalt, 2017):

$$E_i = \frac{\sum_{j=1}^{n_o} O_{ij}w_j}{\sum_{j=1}^{n_i} I_{ij}v_j} \quad (1)$$

where:

- E_i : effectiveness of the i -th unit
- O_{ij} : weighted value of the j -th output factor of the i -th unit
- n_o : number of outputs
- w_j : evaluation of a unit of the j -th output
- I_{ij} : weighted value of the j -th input factor of the i -th unit
- n_i : number of inputs
- v_j : evaluation of a unit of the j -th input

The formula can be used to determine the effectiveness of the “ i ”-th unit, based on the weighted output and input components of the unit. This function is the basis for the DEA, which is run for all hospitals in the analysis.

In connection with the run, the balance

sheet conditions for the DEA analysis are defined (Ragsdale, 2007; Iberhalt, 2017). The balance conditions of the analysis are constraints that ensure that maximum effectiveness can be identified.

BALANCE CONDITIONS:

1 No unit tested can have an effectiveness greater than 100 per cent. The effectiveness of each hospital is thus less than or equal to 1.

$$\sum_{j=1}^{n_o} O_{kj} w_j \leq \sum_{j=1}^{n_i} I_{kj} v_j \tag{2}$$

(k=1, 2, ... , number of units analysed),
i.e.,

$$\sum_{j=1}^{n_o} O_{kj} w_j - \sum_{j=1}^{n_i} I_{kj} v_j \leq 0 \tag{3}$$

2 Output evaluations (w_1, w_2, w_3, w_4) and input evaluations (v_1, v_2, v_3, v_4) can be used to maximise effectiveness at the “i”-th unit (effectiveness indicator value 1).

3 It is necessary to ensure that input costs and output valuations are strictly positive. Because if, e.g., $w_j = 0$ then DEA cannot find those non-effective solutions, which contain the j-th output; and if $v_j = 0$, then DEA is unable find non-effective solutions that contain the j-th input (Iberhalt, 2017).

Based on the effectiveness measurement function and the balance conditions, a linear programming exercise can be performed for each hospital under study, with the aim - in the context of this study - to minimise the weighted inputs of each unit.

The objective function of the model:

$$\sum_{j=1}^{n_i} I_{ij} v_j \rightarrow MIN \tag{4}$$

Based on the literature (Barnum et al., 2009; Dózsa, Ecseki, 2012; Dénes et al., 2017; Iberhalt, 2017; Koltai, Tamás,

2019; Nepomuceno et al., 2020) and the methodology developed, input and output indicators can be identified to support the measurement of relative effectiveness, which also allow the development of a relative effectiveness ranking for the hospitals under study.

SURVEY

In the framework of this study, we present the main results of the survey conducted between 2015 and 2019.

For the institutions included in the analysis, difficulties such as limited resource management can be identified, so it is worth identifying a *best practice* in effectiveness and benchmarking against it. This step will support the institutions to become aware of a good practice that can be used to model effectiveness processes and implement them in their own institutions.

The study was conducted using an input-oriented approach, where we aimed to minimise inputs for a given level of output. The scale-insensitive CRS model assumes the same rate of resource incorporation (output/input ratio unchanged). The method presented in this study assumes a constant return on scale factor, i.e. perfect substitutability of outputs at a fixed rate. In the literature, this condition is referred to as CRS (Constant Return on Scale) or CCR (Charnes-Cooper-Rhodes) (EIF). A major advantage of the method is that the determination of reduced input values is not arbitrary (Dózsa, Ecseki, 2012).

As a starting step, we looked for input and output indicators (potential indicators are described in *Table 1*). The indicators have been selected primarily to test the method, but more research is needed to select the right indicators before the actual effectiveness study. In this selection, we have identified as a main objective

Table 1

**POTENTIAL INDICATORS TO BE INCLUDED IN THE ANALYSIS
(TO TEST THE METHOD)**

Input	Output
<ul style="list-style-type: none"> • number of beds (number) • number of physicians (persons) • number of nurses (persons) • non-medical staff (administrative staff) • total staff (persons) • tools (number) • total cost (HUF) • other cost (HUF) • health expenditure per capita (HUF) 	<ul style="list-style-type: none"> • outpatient (persons) • number of nursing days (number) • other case (care, number) • total cases (care, number) • number of surgeries (number) • inpatient care (HUF) • per capita surgical care (HUF) • other service (number) • income (HUF)

Source: own edited

both to ensure that the indicators used are significant and to avoid multicollinearity. In addition, the selection criteria are availability, appropriateness for the purpose and relevance. Many of the variables identified as a result of the international outlook are available only to a limited extent in national central statistics, which is also a limitation of the analysis.

Taking these factors into account, limitations of the effectiveness analysis for domestic hospitals can be identified:

- the small number of variables that can be included based on available statistical data,
- the lack of standardisation (e.g. job classification),
- the performance volume limit (the limit on how much of a given health service a hospital can provide in a month. Each year, the state determines how much a hospital can receive per month for different types of care, and how much of the excess the hospital will be paid by NEAK if it exceeds the limit),

- the complexity of ownership (public and private).

The indicators included in the study are shown in *Table 2*.

To support effectiveness audits of hospitals, a set of indicators can be defined, which can be broken down into input and output indicators, following the DEA methodology. In the analysis of hospitals, 4 indicators were included in each indicator group.

As a first step, we looked for indicators in each area and made the following suggestions:

- the source of the indicators is the database of the Central Statistical Office (2015-2019) and the budget reports of the individual institutions (the budget reports are processed from the CrefoPort database),
- for the indicators, an average of 5 years has been included in the analysis, allowing year-to-year fluctuations to be filtered out (while taking structural changes into account),
- the analysis looked for a link between

Table 2

INDICATORS INCLUDED IN THE ANALYSIS

Input indicators	Output indicators
<ul style="list-style-type: none"> • number of active hospital beds (number) • total staff (persons) • number of nursing days that can be completed (number) 	<ul style="list-style-type: none"> • number of beds actually in operation (number) • number of patients discharged (persons)* • number of nursing days completed (number) • total income (HUF)

Remark: * total of patients discharged, transferred to another ward and patients who died.

Source: own edited

performance and actual performance (the difference between the expected maximum and the actual performance in relation to the organisation’s capabilities).

The list of hospitals included in the analysis is presented in *Figure 1*. The units of the DEA analysis are state-run institutions in Hungary, and each unit is typologised according to the total number of beds. County hospitals with between 600 and 1200 beds were included in the analysis. The list of hospitals is not exhaustive, as we have not looked at institutions that typically serve one area (e.g. psychiatry). Next to the names of the hospitals, the number of beds is stated, which was determined on the basis of the CSO database (for the year 2019). In the database, hospitals have been processed out of order and not by name to ensure anonymity, which is why the institutions are indicated by letters (A-P) when presenting the results of the study.

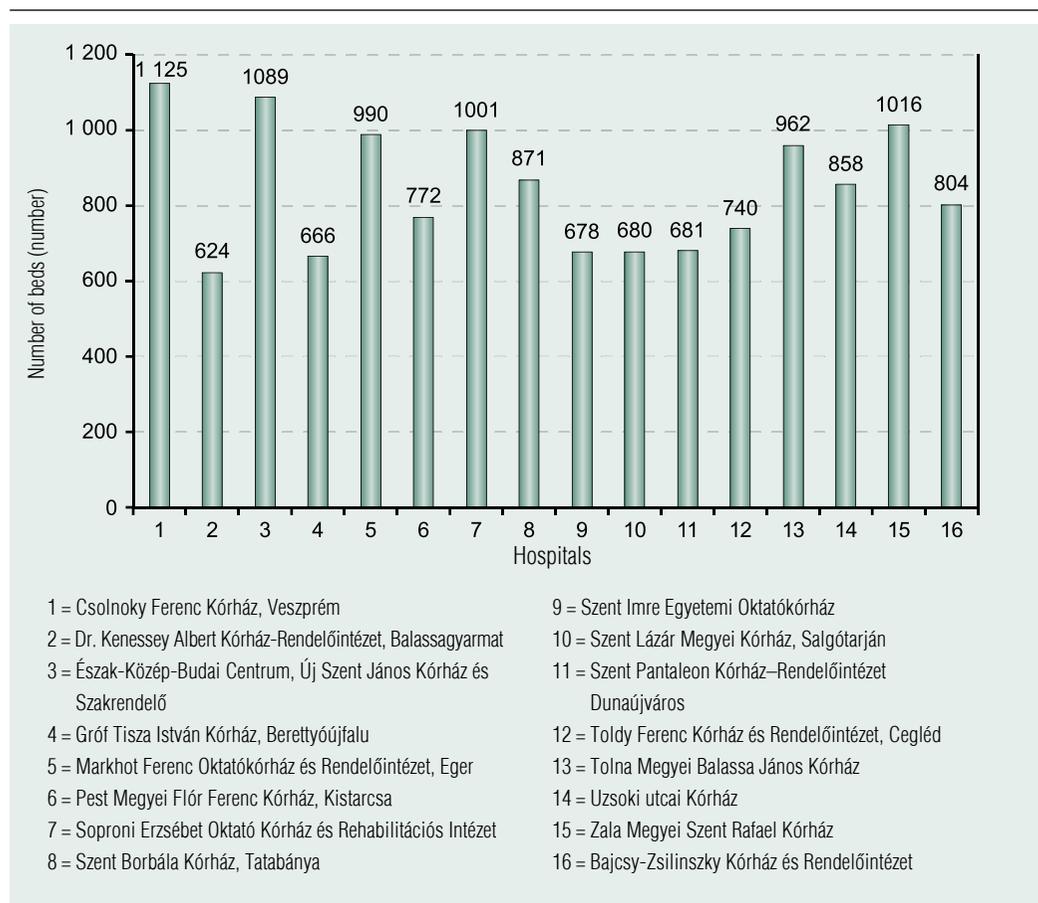
Our DEA analysis was based on a database defined on the basis of pre-defined indicator values. The analysis focuses primarily on efficient operation, where the maximum value assigned to each unit is 1 (100 per cent). The procedure calculates best practice threshold based on the data of the best performing decision-making units, i.e. those with an effectiveness score of 1, and then

gives a percentage of the effectiveness reserves of the poorest performing hospitals. This suggests that institutions with an effectiveness index of 1 are operating with a reliable level of effectiveness. For hospitals that do not achieve the maximum value relative to the best value of the indicator, it is worthwhile to conduct a more in-depth analysis, as there is a difference in their operations compared to other institutions.

A unit is non-effective if the value of the effectiveness indicator is less than 1, so the study concludes that five hospitals are non-effective (institutions marked with the letters B, D, H, N, P). The lowest score went to the hospital marked with N (0.9797), so there is room for improvement for this institution as well. *Figure 2* shows a predominance of values of 1 or close to 1, which requires a demonstration of the practical side of the methodology. The DEA analysis has a mathematical background, but it also performs a comparison, so that the best value is selected from the given indicators. This highlighting provides the basis for comparison with the best value of the indicator under the DEA method. This comparison allows differences to be identified, so that effectiveness can be assumed on the basis of the relative values. *Table 3* presents the comparisons based on

Figure 1

GENERAL PROFILE HOSPITALS WITH 600-1200 BEDS INCLUDED IN THE ANALYSIS



Source: own edited (based on CSO database)

the institutions for which the DEA method calculated a value of 1 (effectiveness) based on the indicators provided by our database, and which institutions were given a different score (non-effective). Those institutions for which effectiveness cannot be assumed on the basis of a comparison with the best institution have been compared with other institutions.

The table shows that the highest number of comparisons (5 associations) were made between D- and H-marked hospitals, which supports the results in Table 3. In a detailed

study, it is worthwhile to make and analyse a comparison that shows which input values need to take on a different value to achieve the desired effectiveness. For this question, it is necessary to examine the non-effective hospitals described in Table 4. Our tests were input-oriented, i.e. we aimed to minimise the input for a given level of output. The method assumes a constant return on scale factor, i.e. perfect substitutability of outputs at a fixed rate. Table 4 and Table 5 show the input and output values, respectively.

Figure 2

RELATIVE EFFECTIVENESS ANALYSIS (COUNTY HOSPITALS)



Source: own edited (based on CSO data and budget reports)

Overall, after reviewing the tables, it can be concluded that the input and output values are correlated. It is worth noting that the targets in *Table 4* take a different value from the actual value (this is in bold italics in the table for non-equivalence). The target value represents the indicator that can be identified as the optimal value in relation to the indicators of the institution with high effectiveness. This can be explained by the fact that the programme is proportionate to the indicators of efficient operation. All this suggests that if the target were met, each institution would operate more effectively than at present.

It is more interesting to observe the output values, since, as shown in *Table 5*, no correction from the output side is needed for the hospital marked H, and therefore it is not marked separately in the table (this is also reflected in the effectiveness, since its value

is 0.999). For this hospital, full effectiveness could be assumed if no corrections were needed in the input rows. For the other institutions, the correction is reflected in the number of patients discharged, which typically took a value below the target value, and the evolution of the number of nursing days and the value of the income needs further examination (area in bold italics in *Table 5*). All this suggests that there are institutions, where 3 indicators are below target on the output side, but there are also institutions (D and P labelled institutions) where only 1 indicator can be identified, indicating non-appropriateness. In the cases outlined above, it is worth analysing the results of the survey in more detail, and for these indicators within the institution, we recommend a deeper analysis to help the organisation achieve a higher level of effectiveness. It should be stressed, however,

Table 3

PROCEDURAL METHOD FOR COMPARING HOSPITALS

Column1	Matching 1	Matching 2	Matching 3	Matching 4	Matching 5
Hospital A	Hospital A	-	-	-	-
Hospital B	Hospital E	Hospital J	Hospital K	Hospital M	-
Hospital C	Hospital C	-	-	-	-
Hospital D	Hospital C	Hospital J	Hospital K	Hospital M	Hospital O
Hospital E	Hospital E	-	-	-	-
Hospital F	Hospital F	Hospital M	-	-	-
Hospital G	Hospital G	-	-	-	-
Hospital H	Hospital E	Hospital F	Hospital J	Hospital K	Hospital M
Hospital I	Hospital I	-	-	-	-
Hospital J	Hospital J	-	-	-	-
Hospital K	Hospital K	-	-	-	-
Hospital L	Hospital L	-	-	-	-
Hospital M	Hospital M	-	-	-	-
Hospital N	Hospital E	Hospital J	Hospital K	-	-
Hospital O	Hospital O	-	-	-	-
Hospital P	Hospital A	Hospital J	Hospital K	Hospital O	-

Source: own edited (Based on DEA software)

that there is no significant difference between the effectiveness values based on this analysis.

The deviations found by the DEA model only shed light on certain problems of non-effective units, the causes of non-effectiveness and the extent to which critical factors deviate from optimal. Accordingly, the information revealed by this analytical method can serve as a useful exercise for organisational management to plan and implement changes in which areas and in which direction to improve effectiveness.

In view of the above, it is worth mentioning that implementing and running the DEA methodology is a necessary step for an organisation, as it enables the organisation to measure whether the strategic objectives previously set have been met, i.e. whether the

organisation is operating effectively or not. However, it is not sufficient to fully test an organisation, because if an organisation does not get the desired results, it is necessary to incorporate additional models and methods to correct these errors. However, the DEA is a very flexible methodology for identifying or defining failures, as it is able to compare institutions and highlight good practices based on specific indicators.

SUMMARY

The effective functioning of organisations and the measurement of their effectiveness is a key issue in all healthcare institutions. In our study, we have presented a methodology

Table 4

COMPARISON OF THE INPUT INDICATOR VALUES OF THE HOSPITALS IN THE STUDY THAT WERE FOUND TO BE NON-EFFECTIVE WITH THE TARGET VALUES

Values	Hospitals	Total number of active hospital beds (number)	Staff (total, persons)	Number of nursing days (possible to complete, number)	Expenditure (HUF)
Actual	Hospital B	1,119	1,903	404,161	13,693,839,288
Target value		1,107	1,516	399,869	13,548,428,381
Actual	Hospital D	1,120	1,551	398,645	14,784,318,386
Target value		1,097	1,529	393,067	+14 577 463 943
Actual	Hospital H	1,001	1,398	354,536	9,205,194,672
Target value		975	1,230	354,358	9,200,591,188
Actual	Hospital N	966	1,789	343,932	11,761,291,112
Target value		946	1,320	336,957	11,522,783,033
Actual	Hospital P	1,026	1,671	368,716	15,160,298,225
Target value		1,016	1,506	363,185	15,016,175,232

Source: own edited (based on CSO data and budget reports)

Table 5

A NEMHATÉKONYNAK BIZONYULT KÓRHÁZAK VIZSGÁLATBA BEVONT OUTPUTMUTATÓI ÉRTÉKEINEK ÖSSZEHASONLÍTÁSA A CÉLÉRTÉKEKKEL

Values	Hospitals	Number of beds actually in peration (number)	Number of patients discharged (persons)	Number of nursing days (completed, number)	Income (HUF)
Actual	Hospital B	1,106	33,252	29,3622	13,457,844,430
Target value		1,106	34,288	29,3622	14,622,864,098
Actual	Hospital D	1,094	37,561	286,362	15,172,882,313
Target value		1,094	37,704	286,362	15,172,882,313
Actual	Hospital N	943	29,390	200,753	11,491,490,934
Target value		943	33,716	250,836	11,625,131,778
Actual	Hospital P	1,008	36,872	240,308	15,819,782,283
Target value		1,008	36,872	251,407	15,819,782,283

Source: own edited (based on CSO data and budget reports)

that could be a solution for measuring effectiveness. The DEA method is based on the definition of input and output indicators for organisations (indicators that contribute to the operation on the one hand, and indicators that are created after the operation on the other hand). Our study clearly supports the view of Lapid (1997) that the DEA method has the advantage of not only calculating the effectiveness of a particular unit, but also of displaying comparative figures. The focus of the method is the definition of *best practice*, which represents 100 per cent, i.e. 1 effectiveness, and thus forms the basis for comparison (Dózsa, Ecseki 2012). In developing the methodology, pairs of input and output indicators were formulated for easier comparability and quantification. Examples of indicator pairs are revenue and expenditure, or the number of active beds and the number of beds actually in operation. Furthermore, in order to avoid bias, the typologisation of

health institutions has become a necessity. We selected general profile hospitals with between 600 and 1200 beds for the analysis, as their size allowed for comparability. The results of running the DEA programme have clearly shown that there are some institutions that do not operate as efficiently as the majority of the organisations included in the study. The methodology is highly recommended for comparing the operational effectiveness of institutions with a similar profile, subject to certain limitations. Current research is still testing and piloting the methodology, and further research and refinement of the indicators are needed to put it into practice. Quality is a key factor in competitiveness, which is also a determining factor when assessing healthcare providers. Based on the current testing, it can be concluded that the institutions are comparable in this sector as well, and the DEA method provides a good basis for effectiveness testing. ■

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