METHODOLOGY FOR EXTERNAL STORAGE SELECTION

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Abstract

The temporary external storage of Fully Build Units is currently a standard part of the outbound logistics of many car manufacturing companies. This problem arises mainly from the contradiction between the significant disruptions of supply chains caused by, for example, COVID-19, the chip crisis, the Ukraine war, and the reluctance to lose the production capacity of the assembly lines and related manufacturing operations. To effectively manage the given process, selecting the provider and location where the external storage will take place is vital. The aim of this article is to create a methodology based on multi-criteria decision-making, which will enable this selection.

Keywords: External storage, parking area, service providers, automotive, multi-criteria decision-making

1. INTRODUCTION

The storage of Fully Build Units (FBUs) that are not yet ready for final sale is a problem faced by many car manufacturing companies in the current crisis and dynamic times. This problem arises mainly from the contradiction between the significant disruptions of supply chains caused by, for example, COVID-19, the chip crisis, the Ukraine war, and the reluctance to lose the production capacity of the assembly lines and related manufacturing operations. For small volumes, internal storage areas can be used, but if they are exhausted, it is necessary to store FBU externally. Finding the most suitable provider of such parking areas is not a trivial task. Different providers offer a different mix of services at different price levels. Other associated costs must also be taken into account, in particular logistics costs. In addition to these cost parameters, parameters such as overall capacity, payment terms, etc. must also be taken into account. Taking a holistic view, this creates a rather complex problem that must be addressed across the multiple departments. Multi-criteria decision-making (MCDM) methods seem to be a suitable tool. The aim of this article is to create a methodology based on MCDM, which will enable this selection.

2. LITERATURE REVIEW

The literature review is divided into two main parts: (1) Multi-criteria decision-making methods; and (2) Most similar selection problems.

2.1 Multi-criteria decision-making methods

MCDM is a process of finding the most suitable (so called compromise) solution (alternative) with respect to the given set of criteria and preferences of a decision-maker. There are various MCDM methods available, providing different settings and working under different assumptions (see [1]). For instance, we can distinguish: (1) Ranking methods (revealing the order of the alternatives), like Weighted sum method [2], AHP [3], and sorting methods (assigning the alternatives into pre-defined groups), like TOPSIS-SORT [4]; (2) Methods based on measuring the utility of the alternatives (WSM, AHP), methods based on measuring of distances among alternatives (TOPSIS [5]), or methods using special evaluation measures and functions (PROMETHEE

[6]); (3) Deterministic methods (AHP, WSM), stochastic methods (SMAA [7]), or fuzzy methods (Fuzzy TOPS [8]); (4) Methods requiring strictly numerical inputs (quantitative or quantified criteria), like WSM, methods allowing qualitative evaluation of criteria (AHP).

Weighted sum method (sometimes also called Simple Additive Weighting) is one of the MCDM methods which is popular especially for its simplicity, (see [1,2]). This method calculates the total utility for each alternative. Let us have a problem with k criteria and n alternatives. The utility function is expected to be linear, dependent on the performance of an alternative i in terms of each criterion j and its weight. Both, performance value x_{ij} and weight w_j are assumed to be normalized (i.e., their sum across all criteria is equal to 1). The utility of alternative i is calculated using (1).

$$U_i = \sum_{j=1}^{k} x_{ij} \cdot w_j, for \ \forall \ i. \quad (1)$$

In (1), it is assumed that the performance values x_{ij} are benefit-like (the greater values, the better). In case that a decision problem contains the cost-like criteria too, it is necessary to swich their direction using the inverse values. The normalization of the input (not normalized) values $\bar{x}_{ij}$ to x_{ij} can be simply done using (2).

$$x_{ij} = \bar{x}_{ij} / \sum_{i=1}^{n} \bar{x}_{ij}\,, for \ \forall \ j. \quad (2)$$

The greater utility of the alternative U_i, the better ranking.

2.2 Most similar selection problems

The selection of an external storage provider is an issue that, to the authors' knowledge, has not yet been addressed in the literature. One of the closest areas is supplier evaluation and selection problem. A wide range of MCDM methods can be used in this area, as shown for example in [9], or [10]. These sources define the most used methods as DEA, Mathematical Programming, and AHP. However, these methods are in many cases unnecessarily complex for practical implementation, which is the focus of the proposed methodology. Regardless of the MCDM method chosen, the main difference between the supplier selection and evaluation process and the external storage provider selection process is the nature of the collaboration (supply of goods vs. provision of a specific service) and the resulting set of criteria, which is significantly different. Standard sets of criteria for selecting and evaluating suppliers are defined, for example, by the sources [11], or [12]. However, the analysed lists of criteria are not usable for the development of the methodology.

The other closest area is the selection of a logistics provider. Also in this area, MCDM methods are most often used for selection, for example [13], or [14]. However, as with the selection and evaluation of suppliers, the concept and mostly the set of criteria is very different. In the authors' view, this is mainly due to the difference in the content and scope of the services provided.

It can be said that there is inspiration to be drawn from both investigated areas in the development of the methodology, but the differences are significant. There is a need to develop a methodology that reflects the specifics of the defined problem and the unique list of criteria associated with it.

3. METHODOLOGY FOR EXTERNAL STORAGE SELECTION

The proposed methodology consists of 7 basic steps: (1) definition of the objectives and boundaries; (2) selection and definition of criteria; (3) definition of alternatives; (4) weights determination; (5) determination of the criteria values for the considered alternatives; (6) alternatives prioritization; and (7) managerial interpretation of the results.

1. Definition of the aim and boundaries

The decision-making process begins with the occurrence of a problem. In this case, the problem is the lack of internal parking spots for FBU at the manufacturer site. In other words, the number of spots is not sufficient to cover the needs caused by the various facts mentioned in the introduction. The aim of the decision is to assess the suitability of external parking storage providers and find the optimal mix of locations. The boundaries of the solution are determined by the sensible location and the providers' application to the relevant tender.

2. Selection and definition of criteria

The car manufacturing company should select a manageable set of criteria. In developing a set of criteria, the added value offered by providers and the associated costs should be given the greatest consideration. For each criterion it is necessary to define the unit in which it is monitored and the direction. The following two types of direction are most commonly used: (1) the greater the better type ('max'); and (2) the smaller the better type ('min'). Some criteria can also be of Boolean type.

3. Definition of alternatives

The alternatives are determined by the set of registered providers that meet the basic conditions of the specific tender and the locations they offer (one provider can offer multiple locations). The authors recommend creating a clear list of input information that individual providers must provide for each location. The list of required information is based on the criteria defined in step two. If the selected information is not of the required quality, it must be refined individually with the given provider. There may also be situations where some provider does not provide the selected service. In this case, it is necessary to define an internal process and its costs to replace the requested service. When setting the internal prices, all related costs (transport, material, labour) and the issue of efficient utilisation of internal staff must be taken into account.

4. Weights determination

The weighting of the criteria may be done by any method defined for this purpose. In practice, rather simpler methods that do not require deeper mathematical knowledge of managers are most often implemented (like Direct rating or Point allocation).

5. Determination of the criteria values for the considered alternatives

The basic input data is already provided by each provider in step three. Now it is necessary to edit them into a suitable form. There may be some challenges in this step, including: (1) the selected providers have different methodologies for determining the value of a certain criterion; (2) selected providers use a different currency for cost criteria; (3) the selected providers do not provide certain services that the car manufacturer must source internally; (4) selected criteria are Boolean in nature; and (5) the selected criteria are unsuitable for multi-criteria decision making without adjustment (for example, those that can take the value 0). In addition, it is necessary to unify the direction of the indicators and normalize them so that they can be further processed in the next step.

6. Alternatives prioritization

A fairly wide range of selected multi-criteria methods can be used to prioritise alternatives. For realistic use in practice, especially when dealing with a large number of variants, it is advisable to use basic (simpler) methods that are immediately familiar and acceptable to managers in practice. For this reason, the authors propose to use the basic multi-criteria decision-making method WSM.

7. Managerial interpretation of the results

For practical managerial interpretation of the results, tabular or graphical outputs are defined that contain at least the following two results: (1) the idealized result of the evaluation; (2) the ranking of the alternatives. Only ranking is not sufficient as it is important to see the size of the difference between individual providers. Especially if not only one is chosen, but it is necessary to choose the most suitable mix. Idealized values also make it easier to deal with the situation where other various benefits of individual providers that cannot be captured in the decision-making process itself need to be added to the consideration.

If certain assumptions need to be made in a given decision, it is also possible to create a sensitivity analysis that examines the impact of these assumptions on the overall outcome.

4. CASE STUDY

The explanatory case study from the automotive industry was used to verify the developed methodology and to identify critical points for its implementation. The subject of the study is a model manufacturer of passenger cars of masstige (volume) brands, where the problem of lack of storage capacity for FBUs has been defined. The model company and the problem are based on a real situation that has been dealt with in practice. The structure of this section follows the seven steps of the developed methodology described in previous section.

1. Definition of the objectives and boundaries

The model manufacturer under review lacks approximately 5 to 8 thousand parking spaces for the FBU. The FBUs will be transported to the external areas from two different production sites. There is also a reverse flow which transports the FBUs back to the two production sites. The aim of the decision-making process is to find the best mix of providers and locations to satisfy the required capacity gap. The solution boundary is set at a maximum location distance of 500 km from both plants.

2. Selection and definition of criteria

For decision-making purposes, the criteria set out in **Table 1** have been established. In the right-hand column are the "care" criteria, which, according to internal guidelines, are carried out at set time intervals on FBUs.

Table 1 Selected criteria

Criterion	Unit	Direction	Criterion	Unit	Direction
Staff provision (for Handling)	Boolean	x	Refuelling (without fuel)	EUR per car	min
Capacity (FBU)	pcs	max	Low voltage battery check	EUR per car	min
Possibility of transport by train	Boolean	x	High voltage battery check	EUR per car	min
Price of storage per day	EUR per car	min	Charging low voltage battery	EUR per car	min
Handling cost (in)	EUR per car	min	Charging high voltage battery	EUR per car	min
Handling cost (out)	EUR per car	min	Brake disc cleaning	EUR per car	min
Price of transport plant 1	EUR per car	min	Car wash - exterior	EUR per car	min
Price of transport plant 2	EUR per car	min	Car wash - interior	EUR per car	min
Rental of indoor winter hall	EUR per day	min	Tyre pressure check	EUR per car	min
Rental of indoor summer hall	EUR per day	min	Tyre pressure top-up	EUR per car	min
Minimum billing	EUR per day	min	Foil removal	EUR per car	min

3. Definition of alternatives

Five providers (each with one location) have applied for the model tender and have met the relevant conditions and provided the required information. A summary of these is given in **Table 2**.

Table 2 Selected Providers

Criterion	Unit	Provider 1	Provider 2	Provider 3	Provider 4	Provider 5
Staff provision (for Handling)	Boolean	yes	no	yes	yes	no
Capacity (FBU)	pcs	3,500	3,000	2,000	5,300	4,000
Possibility of transport by train	Boolean	no	no	no	yes	no
Price of storage per day	EUR per car	0.9	1	1	1.2	1.5
Handling cost (in)	EUR per car	4	5	5,5	9	6
Handling cost (out)	EUR per car	4	5	4	9	7
Price of transport plant 1	EUR per car	100	70	80	150	100
Price of transport plant 2	EUR per car	150	200	75	30	90
Refuelling (without fuel)	EUR per car	8	9	7	8.5	10
Low voltage battery check	EUR per car	3	2	2	3	1.5
High voltage battery check	EUR per car	3	2	4	4	1.5
Charging low voltage battery	EUR per car	8	10	15	13	9
Charging high voltage battery	EUR per car	12	10	18	13	11
Brake disc cleaning	EUR per car	5	4	5	8	4
Car wash - exterior	EUR per car	10	20	15	10	11
Car wash - interior	EUR per car	15	20	18	15	13
Tyre pressure check	EUR per car	3	2,5	3	4	3
Tyre pressure top-up	EUR per car	3	3	4	4	3
Foil removal	EUR per car	10	8	5	10	11
Rental of indoor winter hall	EUR per day	300	250	400	325	280
Rental of indoor summer hall	EUR per day	300	150	300	300	100
Minimum billing	FBU per day	0	1,000	400	300	1,000

4. Weights determination

The weights were determined using Direct rating. To improve the overall efficiency of the model, the set of criteria was simplified, but in such a way that no information was lost. First, a unit cost criterion was developed that integrates all costs of transport, handling, average storage (30 days) and average car care (according to internal rules of car manufacturer). This criterion was defined for three transport options: (1) FBUs are transported from both production sites equally; (2) FBUs are transported from production site 1 only; (3) FBUs are transported from production site 2 only. The reason for creating these variations is a situation where it is necessary to provide multiple parking areas that can be used separately from the individual production sites. Also, rental criteria that represent the same issue were combined in determining the weights. The last adjustment was to split the Minimum billing (FBU per day) criterion into two Minimum billing (EUR per day) and Minimum utilization (%). This view better reflects the real impact of the issue. The final weights for the adjusted criteria are shown in **Table 3**.

Table 3 Weights for adjusted criteria

Criterion	Unit	Weights	Weights
Staff provision (for Handling)	Boolean	10	10
Capacity (FBU)	pcs	10	10
Possibility of transport by train	Boolean	5	5

Unit costs (Plant 1 and 2: 50 %)	EUR per car	50	50
Unit costs (Plant 1: 100 %)	EUR per car		
Unit costs (Plant 2: 100 %)	EUR per car		
Rental of indoor winter hall	EUR per day	5	2.5
Rental of indoor summer hall	EUR per day		2.5
Minimum utilization	%	20	10
Minimum billing	EUR per day		10

5. Determination of the criteria values for the considered alternatives

All criteria have been normalized. The minimization criteria were converted to maximization criteria using the inverse values. Scoring scales were created for criteria with a Boolean unit (1 point for a „no“ answer and 3 points for a „yes“ answer). A five-point scoring scale has been defined for the minimum billing and minimum utilization criteria (see **Table 4**).

Table 4 A five-point scoring scale for minimum billing and utilization

Minimum billing scale	Points	Boundary	Minimum utilization scale	Points	Boundary
above 400 EUR	1	∞	above 50 %	1	100
300.1 - 400 EUR	2	400	35.1 - 50 %	2	50
200.1 - 300 EUR	3	300	20.1 - 35 %	3	35
100.1 - 200 EUR	4	200	5.1 - 20 %	4	20
up to 100 EUR	5	100	0 - 5 %	5	5

Finally, the uniform normalized values were multiplied by the appropriate weights. The resulting set of values can be seen in **Table 5**.

Table 5 Final criteria values

Criterion	Unit	Provider 1	Provider 2	Provider 3	Provider 4	Provider 5
Staff provision (for Handling)	Boolean	0.0273	0.0091	0.0273	0.0273	0.0091
Capacity (FBU)	pcs	0.0197	0.0169	0.0112	0.0298	0.0225
Possibility of transport by train	Boolean	0.0071	0.0071	0.0071	0.0214	0.0071
Unit costs (Plant 1 and 2: 50 %)	EUR per car	0.0889	0.0822	0.1224	0.1048	0.1018
Unit costs (Plant 1: 100 %)	EUR per car	0.1001	0.1276	0.1127	0.0674	0.0923
Unit costs (Plant 2: 100 %)	EUR per car	0.0680	0.0525	0.1115	0.1739	0.0941
Rental of indoor winter hall	EUR per day	0.0051	0.0061	0.0038	0.0047	0.0054
Rental of indoor summer hall	EUR per day	0.0031	0.0063	0.0031	0.0031	0.0094
Minimum utilization	%	0.0263	0.0158	0.0211	0.0211	0.0158
Minimum billing	EUR per day	0.0385	0.0077	0.0231	0.0231	0.0077

6. Alternatives prioritization

Since in the previous step all the necessary transformations have already been performed on all individual values, it is possible to simply add them up to obtain the final result. The result of the decision will be produced in three variants, depending on which unit costs are selected (see **Table 6**).

Table 6 Variants of result

Variant of result	Provider 1	Provider 2	Provider 3	Provider 4	Provider 5
Unit costs (Plant 1 and 2: 50 %)	0.2159	0.1510	0.2191	0.2352	0.1787
Unit costs (Plant 1: 100 %)	0.2271	0.1965	0.2094	0.1978	0.1693
Unit costs (Plant 2: 100 %)	0.1950	0.1214	0.2082	0.3043	0.1711

7. Managerial interpretation of the results

For practical interpretation of the results, the obtained results were converted to idealized values. For quick orientation, especially with a larger set of alternatives, it is advisable to add a ranking (see **Table 7**).

Table 7 Idealised values and ranking

Unit costs (Plant 1 and 2: 50 %)	**Provider 1**	**Provider 2**	**Provider 3**	**Provider 4**	**Provider 5**
Basic assessment result	0.2159	0.1510	0.2191	0.2352	0.1787
Idealised assessment result (%)	92	64	93	100	76
Ranking	3	5	2	1	4
Unit costs (Plant 1: 100 %)	**Provider 1**	**Provider 2**	**Provider 3**	**Provider 4**	**Provider 5**
Basic assessment result	0.2271	0.1965	0.2094	0.1978	0.1693
Idealised assessment result (%)	100	87	92	87	75
Ranking	1	4	2	3	5
Unit costs (Plant 2: 100 %)	**Provider 1**	**Provider 2**	**Provider 3**	**Provider 4**	**Provider 5**
Basic assessment result	0.1950	0.1214	0.2082	0.3043	0.1711
Idealised assessment result (%)	64	40	68	100	56
Ranking	3	5	2	1	4

The best option when the FBU flow is evenly distributed is provider 4. This provider also ranked first for plant 2. For plant 1, the best is provider 1. Provider 4 has a capacity of 5 300 FBU, which could be sufficient overall. If the capacity needs to be increased, provider 1 could be recommended and primarily transport FBUs from plant 1 to it. Provider 1 also does not require minimum billing and therefore there is no need to manage the utilization of this site extensively. All results were based on the premise that the average storage time would be 30 days. The question is whether providers' ratings will change if this assumption is fundamentally changed. For this purpose, it is possible to use a sensitivity analysis whose results for the balanced FBU flow are shown in **Table 8**.

Table 8 Sensitivity analysis

Average number of storage days	Provider 1	Provider 2	Provider 3	Provider 4	Provider 5
30	91.82	64.23	93.18	100.00	76.01
40	92.45	64.75	93.20	100.00	75.56
50	93.05	65.24	93.22	100.00	75.17
60	93.60	65.69	93.23	100.00	74.81
70	94.13	66.12	93.24	100.00	74.48
80	94.63	66.53	93.25	100.00	74.18
90	95.10	66.91	93.26	100.00	73.91

It can be seen from the **Table 8** that the advantage of Provider 1 increases with increasing stock days, but even at 90 days it does not move to first place. The results of providers 2 and 3 also improve but only marginally. On the other hand, a slight drop in ranking is observed for provider 5. Overall, providers 4 and 1 are still the most suitable to be included in the final selection.

5. CONCLUSION

This paper responds to research and mostly practical needs of developing a methodology for selection of suitable external storage (parking) areas for FBUs in automotive industry. The developed methodology, together with the case study, defines the basic decision-making process, highlighting the challenges that can arise in the decision-making process. It also provides a list of appropriate criteria and shows how they can be approached. The methodology does not aim to use sophisticated methods of multi-criteria decision making but seeks to be well implementable in practice. Based on the implementation, the ranking of the suitability of providers as well as their mutual differences can be determined, even if the producer is allocated to multiple production sides.

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