Original Article

Providing performance indicators of solid waste management based on HSE criteria using FAHP

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ABSTRACT

Solid waste has always been one of the main pollutants of the environment. Solid waste management has particular importance due to the population growth and production of more diversified wastes. Therefore, it is very important to collect and dispose solid waste in a suitable way which can directly and indirectly reduce the risks to the health and safety of people and damage to the environment. To achieve this goal, providing performance indicators of waste management assessment in municipalities is useful. Since the main goal of this study was to provide indicators for measuring solid waste management status in Tehran based on HSE criteria, these indicators were identified and presented for the municipality of Tehran as a sample so that the provided framework could be used for evaluating other areas of Tehran. The results showed that the most important problems in the field of solid waste management in Tehran metropolitan area were observed in some of the studied areas with unfavorable conditions

Keywords: Performance indicators, Solid waste management, HSE criteria, Urban management, FAHP.

Introduction

Nowadays, wastes are an integral part of human life [1]. During the past two decades, municipal waste management (MSW) has become one of the major concerns and public issues [2]. Thus, collecting and disposing wastes in a suitable way, which decreases directly or indirectly the risks threating public health and damaging to the environment is important [3]. In this regard, identification and presentation of functional indicators for the evaluation of solid waste management in urban management is necessary. These indicators provide the appropriate tools for urban managers to be able to monitor and evaluate more precisely the contractors and act effectively in their selection and evaluation processes. In fact, these indicators are terse information that illustrates the status of municipal waste management performance in the field of urban management. This information is representative of the performance of solid waste contractors in municipalities and indicates strengths and weaknesses of the system. Providing performance indicators that meet the health and environmental safety standards are the needs of the municipality, which can be used to ensure the health of community and personnel in that area.

Fuzzy logic is a new technique that replaces or largely complements the methods, used to design and model a system by advanced computing, using linguistic values and expert's knowledge. In fact, in fuzzy logic, accurate results can be obtained using a set of inaccurate data, defined by verbal words and values.

Nowadays, wastes are an integral part of human life [1]. Over the past two decades, municipal waste management (MSW) has become one of the major concerns and public issues [2]. Thus, collecting and disposing wastes in a suitable way is important to decrease directly or indirectly the risks threating public health and damaging to the environment [3].

MSW management organizes the steps of control, production, storage, transportation, recycling and disposal of waste. Moreover, the most optimal principals and actions are used in

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this management to adhere to sanitary, economic, social, engineering, protective and aesthetic issues, along with administrative, financial, legal and planning procedures. Therefore, technical solutions should consider sanitary, safety and environmental goals to manage MSW [2].

Available information shows that anyone living in Tehran annually produces waste 6 times as much as his/her weight. Also, this information shows that average per capita waste generation in Tehran is 320 kg, and daily value of this waste is 1800 million IRR. Per capita waste generation is 250-300 g in the world, while this amount is 600 g in Iran and 1200 g in north of Tehran. According to this information, daily per capita waste generation in Iran and Tehran is two and four times as much as that in the world, respectively. On the other hand, environmental problems of these wastes including emission of greenhouse gases and the production of soil, water and air pollutants cause to attract international organizations and officials of countries' attention to waste management and disposal. Despite the waste management and disposal imposes high cost on cities and country budgets, this cost can prevent very larger scale costs, resulting from social, sanitary and environmental side effects due to the lack of proper waste management.

Thus, identifying and providing performance indicators of solid waste management assessment in municipal management is necessary. Using these indicators and selecting contractors with high performance, not only solid waste management performance is assessed in sanitary, safety and environmental fields, but also improvement in the quality of solid waste management is possible in Iran, especially in Tehran, through spending the least cost.

Introducing the district 1 of Tehran municipality

This district is located in Tehran heights with vastness of 64 km^2 and population of 379962. On the other hand, a large numbers of new and under construction buildings would increase the population of this district to the border of 500,000. The geographical coordinates of this area are limited on the north side to the altitude 1800m of the southern slopes of Alborz Mountains, on the south side to Shahid Chamran highway, intermediate between the Azadi Hotel and Modarres highway and Ayatollah Sadr bridge, and on the west side to the Derekeh River, and on the east side to the end of Artesh highway - cement factory and oil supply in north east of Tehran. In terms of urban design, it has a rural texture and can be called the garden-city. Shemiranat County, which is located on the southern slope of Alborz Mountains, has more potential for constructive activities, due to being semi-mountainous, old site with important climatic features, and special structure, which is a mixture of modern and traditional urban design, in spite of some problems in developmental activities.

Based on municipal divisions, Tehran city is divided into 22 districts. At the present, district 1 includes 11 region as the following:

District 1: regions in Tehran municipality

District	Regions
1	Hesar-e Boali- Farmanieh
2	*Zafaranieh- Velenjak- Mahmodieh*-Evin-Darakeh
3	*Golabdareh*- Emamzadeh Ghasem- Darband
4	Niavaran- *Jamaran*- Dezashib
5	*Kashanak*- Darabad
6	*Shahrak*-e *Naft*- Shahrak-e-Daneshgah
7	Ferdows Garden-Tajrish - *Gheytariyeh*
8	Hekmat- Chizar
9	Araj- Ozgol
10	*Shahrak*-e *Shahid Mahalati*- Sohanak

Figure 1: The range of district 1 of Tehran municipality

The main goal of this research was to provide indicators for measuring solid waste management status in Tehran with HSE criteria and include the following sub-goals:

1. Identifying and providing environmental safety performance indicators in solid waste management
2. Identifying and providing environmental health performance indicators in solid waste management
3. Identifying and providing environmental performance indicators in solid waste management
4. Identifying and providing personnel safety health performance indicators in solid waste management
5. Identifying and providing personnel health performance indicators in solid waste management
6. Providing suggestions for the promotion of solid waste management in the three areas of health, safety and environment.

Since the main objective of this research was to provide indicators for measuring solid waste management status in Tehran based on HSE criteria, these indicators were identified and presented to district 1 of Tehran municipality as a sample, so that the obtained framework could be used to evaluate other areas of Tehran.

Dr. Seyyed Hossein Bahraini and Manouchehr Tabibian have carried out a research in line with the second five-year development plan of the Islamic Republic of Iran, and suggested twelve indicators in three groups to assess the quality of the environment in cities. These indicators are shown in the following figure:

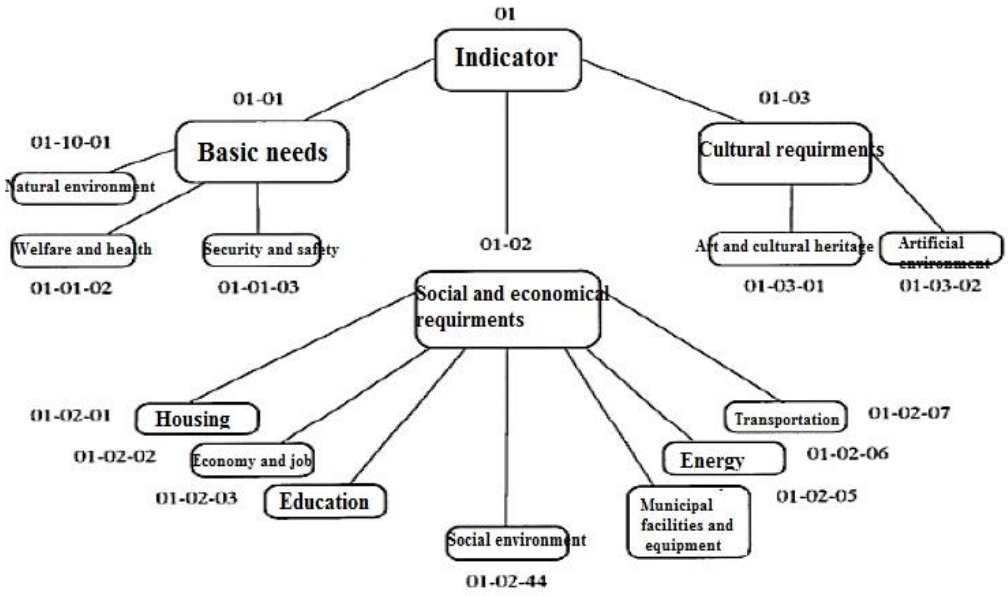

Figure 2: Categorizing 12-time indicators into 3 groups to evaluate urban environment

Each city is the best place to define the most important indicators of that city. For instance, Leicester Brown considers "the proportion of parks to parking lots" as a good indicator to assess a city in terms of habitability (Brown), or in the Seattle city, " the number of wild salmons returning to the city" (City Of Seathele, 1993), while in Copenhagen, "the number of benches for public use in city streets" was considered as a good indicator in an urban environmental assessment. [4].

Considering the issues discussed in the urban environment and the indicators studied above, the following indicators can be considered in the evaluation of solid waste management in Tehran:

Table 1. Performance indicators of urban environment

Row	Sections	Indicators	Sub-indicators
1	Waste	Waste production	The ratio of urban solid waste recycling to total waste
			Per capita waste generation
		Percentage of separation of waste at the origin	
		Influence coefficient of mechanization of urban services in district	
		The ratio of constructive waste recycling to total production in district	
2	Sanitary, safety and environment	Quality of air and voice	The ratio of highway in region to total highway in city
			equivalent sound level in district
			Number of stations measuring noise pollution
			Number of received complaints in district
			Number of industries and factories having noise pollution
			Per capita neighborhood in district
			Per capita worker settlement in district
			Amount of rodenticide use compared to district area
			Percentage replacement for environment improvement and mechanical methods for coping with rodents
			The amount of green space pesticide use compared to the space of district
3	Environmental governance	Empowerment of the environment in the structure of the municipality	The number of occupations at the bachelor level in the environment and the establishment of environmental agencies in the districts, organizations and related companies
		Legalism and the rule of law	Progress in the implementation of the urban environmental law
		Participation	Number of council meetings on environmental issues to the whole sessions
		Legalism and rule of law	Number of non-governmental organization in district level
		Education and culture	The number of educational and cultural activities in all environmental issues in district level
		Clarity	The number of environmental and related contracts clarified for the community over the whole project in the district
		responsibility	Providing the necessary services to the stakeholders within the specified time frame
		Responsiveness	The ratio of the number of municipal employees to the every 2,222 people covered

Research Methodology

This research was carried out in two parts. In the first part, the performance indicators of solid waste management were defined, and in the second stage presented indicators were analyzed and investigated as a case study, in one of the largest districts of Tehran municipality, which had encountered environmental problems.

In the first step, using expert`s opinion[1], who were theoretician in urban environment and management issues, health safety and environmental indicators were identified in solid waste management, and were classified into 3 categories. Then in each category, sub-indicators were determined, so that these sub-categories were determined and defined at two levels. Three main groups and two subgroups of indicators are presented in table 1. For better understanding of the conditions of the indicators and how it is grouped, the schematic design of the hierarchical structure has been shown in Figure 1:

Table 2. Criteria at the first level of performance evaluation

First level criteria	symbol
Waste	A
Sanitary, safety and environment	B
Environmental governance	C

Table 3. The second level of indicators (first sub-criteria)

The second level criteria	Symbol	The second level of criteria	Symbol
Waste production	A1	The amount of green space pesticide use compared to the space of district	B6
Percentage of separation of waste at the origin	A2	Empowerment of the environment in the structure of the municipality	C1
Influence coefficient of mechanization of urban services in district	A3	Legalism and rule of law	C2
The ratio of constructive waste recycling to total production in district	A4	Participation	C3
Quality of air and voice	B1	Legalism and rule of law	C4
per capita neighborhood in district	B2	Education and culture	C5
Per capita worker settlement in district	B3	Clarity	C6
Amount of rodenticide use compared to district area	B4	responsibility	C7
Percentage replacement for environment improvement and mechanical methods for coping with rodents	B5	Responsiveness	C8

Table 4. The third level criteria of indicators (second sub-criteria)

The third level criteria	Symbol	The third level criteria	Symbol
The ratio of urban solid waste recycling to total waste	A1.1	The number of occupations at the bachelor level in the environment and the establishment of environmental agencies in the districts, organizations and related companies	C1.1
Per capita waste generation	A1.2	Progress in the implementation of the urban environmental law	C2.1
The ratio of highway in region to total highway in city	B1.1	Number of council meetings on environmental issues to the whole sessions	C3.1
equivalent sound level in district	B1.2	The number of environmental messages 286 and 2333 to total messages	C3.2
Number of stations measuring noise pollution	B1.3	The extent to which city authorities communicate with people, including meeting and visiting	C3.3
Number of received complaints in district	B1.4	Number of non-governmental organization in district level	C3.4
Number of industries and factories having noise pollution	B1.5	The number of educational and cultural activities in all environmental issues in district level	C4.1
Number of industries and factories having noise pollution	B1.4	The number of environmental and related contracts clarified for the community over the whole project in the district	C5.1
Equivalent sound level in district	B1.5	Providing the necessary services to the stakeholders within the specified time frame	C6.1
The level of changing gardens to non-green areas in the area	B2.2	The ratio of the number of municipal employees to the every 1000 people covered	C7.1

[1] Center for municipal studies in Tehran- Tehran Municipal Solid Waste Organization - Department of Urban Services of Tehran municipality - Department of Environment and Waste of the Organization of Municipalities of Iran

The AHP method was used to determine the weight of each of the indices and sub-criteria influencing the environmental performance. In this method, the decision was based on the criteria provided by the experts and approved. The priority of these criteria relative to each other was determined according to the paired comparison table (Table 4), and the questionnaire set for this purpose was completed. In the next step, entering the numbers resulting from the pairwise comparison in the software Expert Choice, the importance and weight of each indicator was determined.

Table 5. Paired comparison of indicators in the method of AHP

Preferred value	The situation of comparison I to j	Explanation
1	Equal importance	Indicator i has the same important as j, or don't have preference to each other
3	Relatively more important	Indicator I is relatively more important than j
5	More important	Indicator i is more important than j
7	Very more important	Indicator I is more preferred than j
9	Completely important	Indicator i is completely more important than j
2,4,6,8		Shows median values between preferred values. For instance, 8 shows more importance compared to 7 and less importance compared to 9.

In this research, considering the uncertainty conditions and the range of changes governing the criteria of the problem, the multi-criteria decision-making method was considered in fuzzy mode, and fuzzy logic numbers and calculations were used. The more the decision-making process involved manpower and complex systems, the fuzzier phenomenon dominated the explanation of these systems more. AHP method was used in fuzzy mode to solve this problem, which is the main objective of the evaluation of solid waste management in Tehran. The criteria which was weighted by Expert Choice software showed that measurement criteria did not have the same degree of significance to evaluate Tehran city, and the range was determined for fuzzy calculations. The objective of using the fuzzy hierarchy analysis process was to identify reference options to determine the rank of criteria by simultaneously considering all decision-making criteria. In this method, based on the answers given by the decision makers to the questions, fuzzy national numbers replaced obscure data, and for a certain level of the hierarchy, the matrix of paired comparisons was formed. Therefore, after determining the levels of importance of the criteria by the means of the questionnaire, the selected options were converted to the following scales (table 5), containing triangular fuzzy numbers and were generalized for computing and analyzing the results.

Table 6: Fuzzy numbers corresponding to preferences in paired comparisons

Intensity of Importance	Definition	TFN	Reciprocal TFN
1	Equal Importance	(1,1,1)	(1,1,1)
2	Intermediate Values	(1/2,3/4,1)	(1,4/3,2)
3	Moderate Importance	(2/3,1,3/2)	(2/3,1,3/2)
4	Intermediate Values	(1,3/2,2)	(1/2,2/3,1)
5	Strong Importance	(3/2,2,5/2)	(2/5,1/2,2/3)
6	Intermediate Values	(2,5/2,3)	(1/3,2/5,1/2)
7	Very Strong Importance	(5/2,3,7/2)	(2/7,1/3,2/5)
8	Intermediate Values	(3,7/2,4)	(1/4,2/7,1/3)
9	Extreme Importance	(7/2,4,9/2)	(2/9,1/4,2/7)

As mentioned above, we use the triangular fuzzy numbers represented as A = (a1, a2, a3). Because some deviations in judgments of decision makers (especially in large matrices with a large number of judgments) are natural, threshold must be defined and small amounts should be considered as accepted [5]. Thus, Saati produced a large number of randomly matched matrices for each size to compare the CI index for them, as shown in the table 7:

Table 7. Random incompatibility index (RI)

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.51	1.51	1.48	1.56	1.57	1.59

Saati suggests that if the matrix inconsistency index was not more than 10% of the value of the random inconsistency index, the weights produced by that matrix could be assured. Therefore, if the conflict rate (CR) was less than 0.1, then the matrix was considered consistent.

Data analysis

The results of the Expert Choice software outputs

As described in the previous chapter, in the AHP method which was based on the paired comparison matrix, after completion of the questionnaire by the experts, the paired comparison matrices were formed and the criteria were weighted by the MATLAB software. The results of the calculations were as the following:

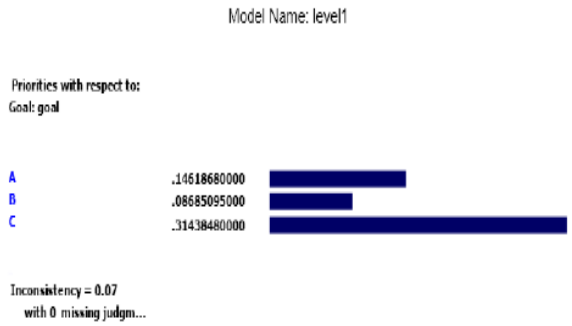

Figure 3. Prioritizing the criteria at the first level

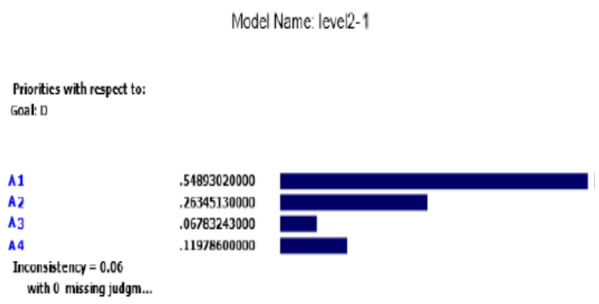

Figure 4. Prioritizing the criteria at the second level

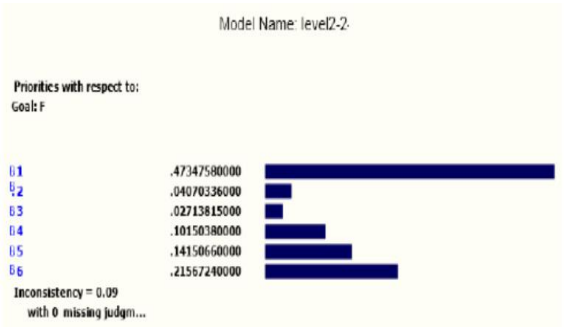

Figure 5. Prioritizing the criteria at the second level

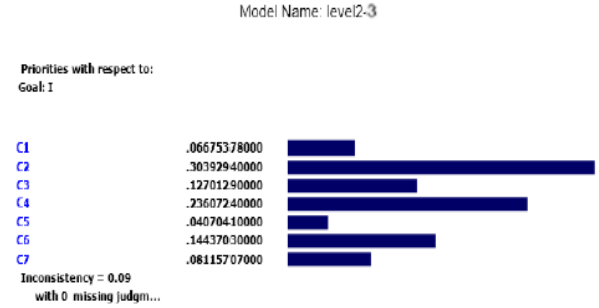

Figure 6. Prioritizing the criteria at the third level

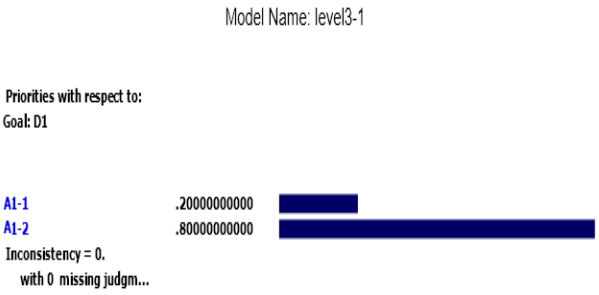

Figure 7. Prioritizing the criteria at the third level

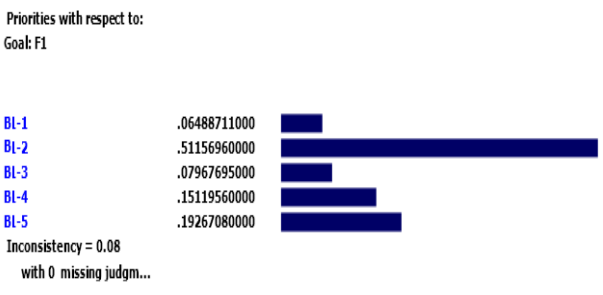

Figure 8. Prioritizing the criteria at the third level

Paired comparison matrices are defined using the experts' comments in the form of triangular numbers in MATLAB software as the following:

Table 8: Results of Fuzzy AHP method in MATLAB software

Chat = [1	1	½	1/3	½	½	½	2	1/6
0	2	1/3	¼	1/3	½	2	2	1/7
0	0	1	1	3	2	3	3	1/3
0	0	0	1	2	2	2	5	1/3
0	0	0	0	1	½	½	4	1/5
0	0	0	0	0	1	1/3	4	1/3
0	0	0	0	0	0	1	3	¼
0	0	0	0	0	0	1	1	1/6
0	0	0	0	0	0	1	0	1] ;

The final weight of performance indicators of environment using FAHP algorithm has been shown as table 9:

Table 9. The final weight of each indicator using FAHP algorithm

Indicator	A	B	C
Final weight of indicator	0.1092	0.1104	0.1881

The results showed that the "environmental governance" indicator with the highest score of 2.2332 was identified as the most important criterion for evaluating the performance. The criteria of "waste" and "health and safety and the environment" were prioritized with weights of 0.1092 and 0.1104, respectively.

The results of the checklist for the evaluation of the district 1 of Tehran municipality

In the next step, to conduct a case study in the district 1 of a municipality, one of the largest areas in Tehran, the evaluation of identified indicators was implemented whose environmental issues were of particular importance,. The results of the evaluation are presented using the checklist in the following table:

Table 10. the results of checklist in district 1

Region criteria	Weight D	Weight F	Weight I	Final weight
1	0.146	0.044	0.291	0.708
2	0.146	0.044	0.291	0.758
3	0.146	0.044	0.291	0.790
4	0.146	0.044	0.291	0.786
5	0.146	0.044	0.291	0.770
6	0.146	0.044	0.291	0.852
7	0.146	0.044	0.291	0.786
8	0.146	0.044	0.291	0.724
9	0.128	0.044	0.291	0.788
10	0.146	0.044	0.291	0.774

According to above table, region 6 with final weight of 0.852 had better performance compared to other districts. On the other hand, region 1 with the weight of 0.708 had the weakest performance. Regions 3, 9, 4, 7, 10, 5, 2, 8 with the weights of 0.790, 0.788, 0.786, 0.786, 0.774, 0.770, 0.752, 0.724 were

ranked, respectively. Also, Harim indicator (H) was only evaluated in region 9.

Discussion and Conclusion

Nouri et al. discussed in their article that in assessing the performance in crisis situations, the combination of the AHP model and risk can be used to obtain better assessment conditions without having effect on personal judgment [6]. Also, Nouri (2010) provided a risk assessment model with the combination of AHP and the FMEA model. In this article, it has been pointed out that the use of the AHP method could minimize the problem of personal judgment of assessors in risk assessment [6]. Also, Afsharkia introduced the use of the VIKOR approach, which was based on multi-criteria agreement planning, in the evaluation of performance. The use of MCDM models created the opportunity to have useful prioritizing to deal with the problems of organization.

Regarding the results of this research, it seems that the improvement of solid waste management is possible. The use of AHP method in "providing performance indicators of solid waste management based on health, safety and environmental criteria in urban management "(and generally to choose best option in performance), has high performance. This performance is due to the potential of comparison and evaluation of different criteria and choosing the best criterion. Because AHP is a logical way to compare, evaluate and finally choose options, it creates a good framework for participating in decision making. Additionally, due to its flexibility, low cost, and quick access to results, it is a good way to solve such problems. On the other hand, in AHP, the conscious and correct selection of weights is really helpful in determining the target. One of these weighting methods is the use of expert. Using the experience and knowledge of the experts in the field of application and considering the characteristics of the studied area, useful factors are determined and weighted. Although this method was simple and documented, it had some disadvantages, such as the probability of experts' mistake in determining the weight and standardizing the mental unit of measurements. Using fuzzy logic in this process, more precise results at the time of the uncertainty of the indicators could be achieved.

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