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Research Article

SELECTION OF RAIL SYSTEM PROJECTS WITH ANALYTIC HIERARCHY PROCESS AND GOAL PROGRAMMING

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ABSTRACT

Rail systems constitute the body of the public transport in cities. Suburban, tramway, light rail systems, metro and monorail systems are urban rail systems and participate in urban public transportation. In this context, large investments are made in railway systems in urban areas and urban transport is being tried to be improved.
Istanbul Metropolitan Municipality, which realizes its investments with a service concept that can be an example to the world states, also makes and plans big investments in the field of rail systems. Managers aim to increase the quality of life of Istanbul by avoiding the traffic problem brought by the increasing population and urbanization in Istanbul with short, medium and long-term rail system plans. However, it is not possible to make every project. Projects that provide the most benefits within certain constraints and criteria such as the budget should be prioritized or selected. Multicriteria decision making techniques are widely used for project selection. In this context, in this study, the planned rail projects in Istanbul are selected under the different budget scenarios using the analytic hierarchy process and the goal programming method in an integrated manner.
Keywords: Multicriteria decision making, project selection, rail systems, transportation planning.

1. INTRODUCTION

In Istanbul, the existing rail systems are inadequate to meet the transportation demands, the population continues to increase and settlements are expanding. Due to such reasons, the time spent in traffic is increasing. At the same time, this affects the livability of the city. The request of passengers is to realize their daily journeys safely and comfortably in a short time. Highway traffic is increasing due to the fact that most of the journeys are made by road and the number of private cars is increasing. A lot of investment is made public transportation to reduce this density. Most of these investments are investments in rail systems, which are safe, comfortable and fast transport systems. With its short, medium and long-term plans, Istanbul is making and planning big investments in rail systems. It is aimed to reach to many points of the city by rail system such

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as metro, tramway and monorail lines. In this context, there are many activities that are under construction, in the tender stage and in the projecting stage.

To be able to respond to increasing passenger demands with the existing road network and public transportation systems in Istanbul, rail systems are planned on the whole city as efficient, fast, comfortable and safe means of transportation. In this study, the project selection for the planned railway system projects in the following years is discussed with three different budget scenarios. Types of rail transport systems are weighted by analytic hierarchy process (AHP), which is a multi-criteria decision-making method and the most suitable projects to be constructed are selected with the goal programming method.

In the second section of the study, various types of rail systems are mentioned. AHP and goal programming methods are described in the third and fourth sections. In the fifth section, project selection problem is given. In the sixth section, the application and its results are mentioned. In the last section, the results and future works are given.

2. URBAN RAIL SYSTEMS

In urban areas, suburban, tramway, light rail system, subway and monorail systems are preferred for public transport due to their high capacity, reliability and speed. The suburban trains are heavy rail systems that connect long distances with high capacity. Tramway is vehicle with the lowest capacity among rail systems. Metro is a type of urban transportation that provides public transport from underground with high capacity, reliability and speed. The monorail is an eco-friendly and recently popular means of public transport that travels along its own unique route, ascending from the ground atop the columns to the vehicle traffic. There are different monorail types as overlay type, suspension type and console type. The literature on rail systems and urban transport has been given under the section of project selection.

3. ANALYTIC HIERARCHY PROCESS

Multi-criteria decision making (MCDM) methods are approaches that help to determine the most appropriate option among the alternatives in accordance with the determined criteria and targets. In this structure, criteria which are generally independent and expressed in different forms are taken into consideration. MCDA method of AHP and analytic network process (ANP), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), ELECTRE (Elimination meat Choix Traduisant la Reality), PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) are frequently used. The general steps of the AHP method that is based on pairwise comparisons are as follows [1];

Step 1: Identifying the problem and establishing a hierarchy of goals, criteria and alternatives.
Step 2: Pairwise comparisons between criteria and between alternatives according to each criterion
Step 3: Normalize the generated comparison matrices and find the eigenvectors
Step 4: Determine the weights of criteria and calculate a consistency value to determine the suitability of the decisions
Step 5: Matrix multiplication of the importance ratings of the alternatives found for each criterion with the weights of the criterions and find the significance levels of the alternatives.
Step 6: Order or selection of alternatives according to their importance

4. GOAL PROGRAMMING

Problems encountered in daily life often have to be considered multiple objectives. Sometimes we want to accomplish many objectives simultaneously in the decision and sometimes we want to minimization of negative factors. In both cases, we use multi objective mathematical models to achieve g oals in the same direction or conflict situations simultaneously in the realization of our purposes. Goal programming is also a kind of mathematical model and it tries to minimize the deviations from the goals by turning all of the goals into constraints [2].

Goal programming formulation as below;

Objective Function:

$$Min\ Z = [P_1 w_1(d_i^+, d_i^-) + \ldots + P_k w_k(d_i^+, d_i^-)] \quad (1)$$

Constraints:

$$\sum_{j=1}^{n} a_{ij} x_j - d_i^+ + d_i^- = b_i \quad (2)$$

$$d_i^+, d_i^-, x_j \geq 0 \quad (3)$$

$$i = 1, \ldots, m \ , \ j = 1, \ldots, n$$

P_i: priority, w_i: weight, d_i^+: Positive deviation d_i^-: Negative deviation, a_{ij}: parameters ve x_j: decision variables.

Goal programming first addressed by Charnes and Cooper [3]. It is used in many areas such as transportation problems [4-7], production planning [8], resource planning in hospitals [9], project selection and management [10-11], marketing [12], menu planning problems [13], investment planning [14], job evaluation [15], media [16].

5. PROJECT SELECTION PROBLEM

Project selection problem is defined as the selection, sorting or weighting of one or several of alternative projects and it is the evaluation period of the most useful, best or least costly project. In selecting a project, we have more than one goal to make the right decisions. Such as, providing the highest benefit, selecting projects that are the shortest time or least costly. In the selection of the project, there is a need for mathematical tools to integrate many objectives into a single objective. At this point, multicriteria decision making methods and goal programming method that provides multi-objective mathematical modeling are at the forefront as analytical methods. In this study, AHP which is a multi-criteria decision-making method, and goal programming as a mathematical model are also used. There are many project selection studies in which these two methods are integrated. AHP and goal programming methods are used together in different areas such as selection of information system projects [17], resource use [18], quality control systems [19], supplier selection [20] and transportation [6], [11].

In urban transport, many studies have been done on project selection. Some of those; Kosijer et al. [21] in the selection of the best railway route, Mohajeri and Amin [22], in the selection of the railway station station, Gerçek et al. [23] assessed the best rail access network, Banai [24], light rail access corridor and alternative routes, Macura et al. [25], order of railway infrastructure investment projects, Abastante and Lami [26] evaluation of transportation infrastructure strategies, Hamurcu and Eren [27-29] selection of monorail projects in Ankara. Taş et al. [30] and Hamurcu et al. [7] selection of monorail projects for urban transport in Ankara, Hamurcu and Eren [31] selection of urban transportation type, Hamurcu and Eren [32] project selection sustainable urban transportation, Kalamaras et al. [33], Piantanakulchai and Saengkhao [34], Piantanakulchai [35], Effat and Hassan [36], the highway route; Zhongzhen and Hayashi [37], rail system route; Yao [38], Farkas [39], Brunner et al. [40], public transportation route; Kim et al. [41] highway network planning.

6. APPLICATION

Istanbul is one of the metropolitan cities with its high population, expanding urban borders and ever-increasing economic development. Many problems arise in the city due to the increase in population and in-city journeys. At the beginning of these problems is the urban transportation problem. Variability in passenger density and population growth in the coming years will require continual addressing of these problems. District-based distributions of the journey are shown in Figure 1 [42].

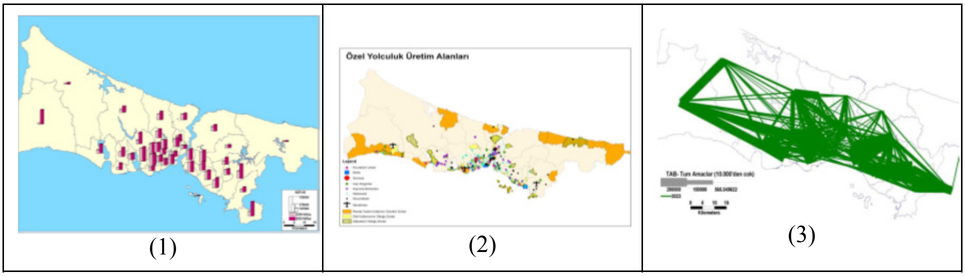

Figure 1. Population by Provinces (1), Special Journey Production Areas by Provinces (2) and District - based (3) Distribution of Journeys, in Istanbul in 2023

Istanbul, which is the locomotive for other cities along with Ankara in the transportation area in our country, competes with and sometimes pioneers the metropolitan cities of the world with its huge projects. Managers who have signed many projects in urban transportation as well as many other areas, are planning to establish a rail system network throughout the city with various types and features of railed system projects. The railed systems in Istanbul on the basis of periods are shown in Figure 2 [42]. The goal of the Metropolitan city is to reach a rail system network about 1000 km of rail systems after 2019 with new projects.

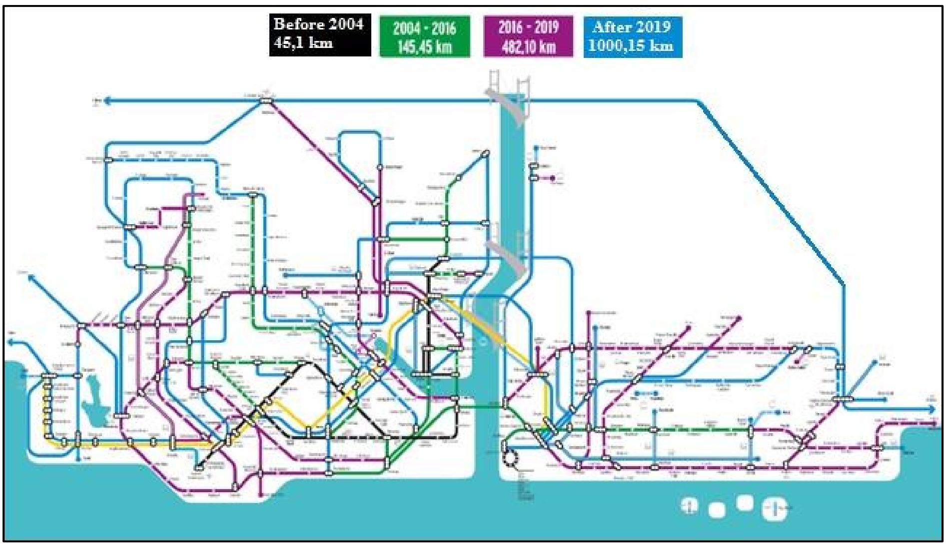

Figure 2. The railed systems in Istanbul

6.1. Research Methodology

When the problem of project selection is considered, firstly alternatives are determined and classified according to transportation type. Projects are divided into groups according to the transportation method by using opinion of urban transport planning department experts and literature. Each group is weighted according to the criteria of capacity, safety, speed, prestige and cost. The AHP method is used for weighting. Goals are set as the budget goal, maximum benefit, linking the most points, combining the longest distances, least travel time and high AHP weighting.

Determinated our aims are rail system and urban transport goals of Istanbul Metropolitan Municipality that are maximum benefit, access to most stations, access to the longest areas, providing minimum travel time and using minimum budget. Three different scenarios are solved with the goal programming method using the specified goals and the best projects were selected. The process flow chart is given in Figure 3.

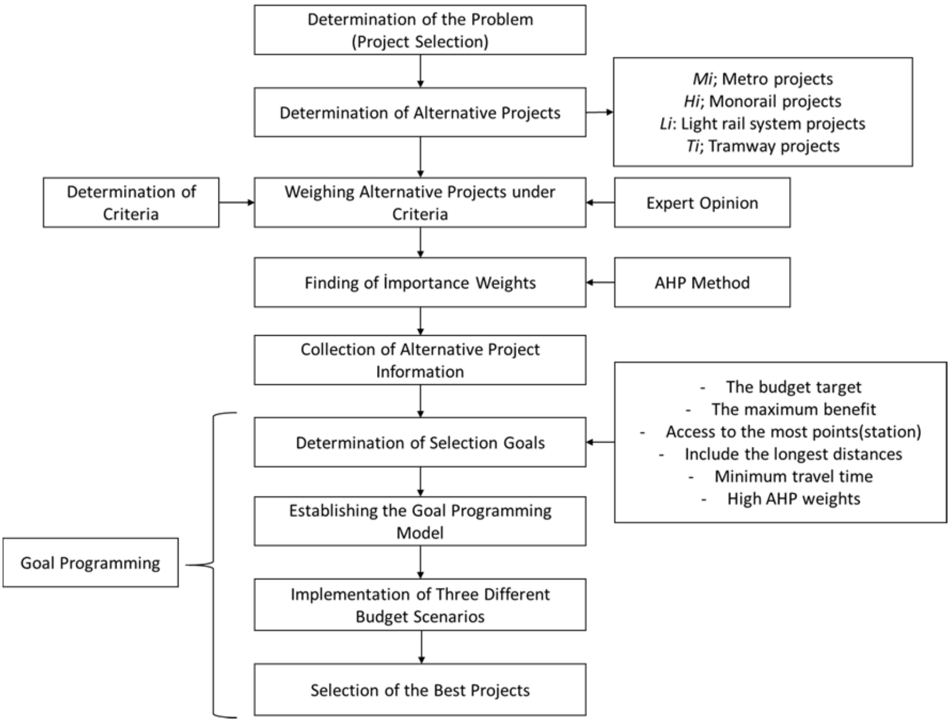

Figure 3. Research Methodology

6.2. Determining Alternative Projects

The projects to be planned are the subway, tramway, monorail and light rail system projects considered within the borders of Istanbul Metropolitan Municipality. Alternative projects and properties are shown in Table 1.

Table 1. Planned Rail System Projects for Istanbul

Nu.	Year	Name of Line	Rail System Type	Station Number	Distance (km)	Travel Time (dk)	Approximate Cost (Million $)	Benefit
1	2018	M1	Metro	19	24.5	37	1835	949
2	2018	M2	Metro	9	9	13.5	435	330
3	2018	M3	Metro	38	63.5	115.5	3521	259
4	2018	M4	Metro	5	7.4	11.5	370	5072
5	2019	M5	Metro	12	14.3	22	810	88
6	2019	M6	Metro	4	14.3	22	808	622
7	2019	M7	Metro	12	13	19.5	710	1021
8	2019	T1	Tramway	14	10.1	30	888	150
9	2019	H1	Monorail	17	15	40	240	92
10	2019	M8	Metro	5	6,2	10	320	99
11	2019	M9	Metro	10	9.7	15	450	97
12	2019	M10	Metro	7	7.6	12	380	444
13	2019	M11	Metro	2	4.1	6	240	63
14	2019	L1	Rail system	9	10.9	16.5	1280	240
15	2019	M12	Metro	6	6,9	10.5	350	403
16	2019	M13	Metro	11	13	19.5	720	82
17	2019	M14	Metro	10	16.24	25	980	51
18	2019	M15	Metro	11	14	21	942	87
19	2019	L2	Rail system	5	32	32	2340	260
20	2019-…	M16	Metro	11	18	27	1085	622
21	2019-…	M17	Metro	4	5.5	8.5	350	403
22	2019-…	M18	Metro	13	28	42	1420	444
23	2019-…	M19	Metro	14	55.5	166.5	3025	742
24	2019-…	M20	Metro	5	9.7	14.5	1030	68
25	2019-…	M21	Metro	5	5.5	8.5	341	267
26	2019-…	L3	Rail system	9	12,3	19	1475	578
27	2019-…	L4	Rail system	7	33	33	2380	250
28	2019-…	H2	Monorail	9	7.25	12.5	175	587
29	2019-…	T2	Tramway	6	3	9	202	120
30	2019-…	L5	Rail system	13	22.3	34	2400	785

6.3. The Weighting of Transport Types

Rail system projects are selected from 4 different transportation types. These types of transportation are metro, monorail, light rail system and tramway. These systems, which have different characteristics, are weighted according to safety, capacity, speed, cost and prestige criteria. Table 2 shows the pairwise comparison matrix of the criteria. The criterion weights obtained as a result of pairwise comparisons are given in the weight column in table 2. For each type of transportation, pairwise comparisons are made according to each criterion and their weights are shown in Table 3 on a criterion basis.

Table 2. Pairwise Comparison Matrix of Criteria and Weights of Criteria

	Security	Capacity	Speed	Cost	Prestige	Weight
Security	1,0000	3,0000	3,0000	5,0000	3,0000	2,2922
Capacity	0,3333	1,0000	3,0000	3,0000	3,0000	1,4030
Speed	0,3333	0,3333	1,0000	3,0000	3,0000	0,9030
Cost	0,2000	0,3333	0,3333	1,0000	0,3333	0,3181
Prestige	0,3333	0,3333	0,3333	3,0000	1,0000	0,5678
The Consistency Ratio: 0,08044						

Table 3. Criteria Weights of Transportation Types

	Security	Capacity	Speed	Cost	Prestige
Metro	0,5230	0,5081	0,3889	0,0473	0,1480
Light rail system	0,0819	0,1932	0,1535	0,0927	0,0596
Monorail	0,3132	0,2289	0,3889	0,6609	0,6845
Tramway	0,0819	0,0699	0,0687	0,1991	0,1079
The Consistency Ratio	**0,0572**	**0,0433**	**0,0163**	**0,0693**	**0,0915**

The criterial weights of each transportation type are multiplied by the criterion weights in Table 2 and these values are summed to obtain final weights of transportation systems (Table 4).

Table 4. Importance Weights of Transportation Types

Type of Transport	**Importance weights(%)**
Metro	0,42641
Light rail system	0,11950
Monorail	0,36745
Tramway	0,08664

6.4. Mathematical Model of Problem

The goal programming model is established that collects different objectives under one objective for the problem. There are multiple goals in the problem, such as achieving the budget goal, making the most of the benefits, linking the most points, combining the longest distances, and achieving the minimum travel time objectives. Maximization of the weights obtained with AHP is also one of the goal. Goal programming model of the problem is given in Table 5.

In the mathematical model, the objective function of which deviations from the targets are minimized is defined as meeting mandatory objectives, ensuring high AHP weights and ensuring budget constraints. The constraints consist of providing the most benefit, accessing the most stations, combining long distances, ensuring minimum travel time, mandatory selection of M3 and M19 metro projects, and selection of all alternative projects.

6.5. Solution Results

The mathematical model is solved separately for three different budget scenarios with IBM ILOG CPLEX 12.6.2 program and the solution results are given in Table 6.

Table 5. Mathematical Formulation

Mathematical Model	
Model formulation	Goals
Minimize Z= $pl_1\,(d_1^- + d_2^- + d_3^- + \ldots\ldots + d_5^- + d_6^-)$	Satisfy all obligatory goals
$Pl_2\,(0{,}3674(d_7^- + d_8^-) + 0{,}1195(d_9^- + .. + d_{13}^-) + 0{,}0866(d_{14}^- + d_{15}^-) + 0{,}4264(d_{16}^- + \ldots + d_{36}^-))$	Select highest AHP weighted projects
$Pl_3\,(d_{35}^- + d_{35}^+)$	Ensuring the budget constraint
Constraints	
$\sum_{i=1}^{2} h_{1i}H_i + \sum_{i=1}^{5} l_{1i}L_i + \sum_{i=1}^{21} m_{1i}M_i + \sum_{i=1}^{2} t_{1i}T_i + d_1^- - d_1^+ = 15275$	Maximum benefit
$\sum_{i=1}^{2} h_{2i}H_i + \sum_{i=1}^{5} l_{2i}L_i + \sum_{i=1}^{21} m_{2i}M_i + \sum_{i=1}^{2} t_{2i}T_i + d_2^- - d_2^+ = 302$	Access to most stations
$\sum_{i=1}^{2} h_{3i}H_i + \sum_{i=1}^{5} l_{3i}L_i + \sum_{i=1}^{21} m_{3i}M_i + \sum_{i=1}^{2} t_{3i}T_i + d_3^- - d_3^+ = 203{,}4$	Access to the longest areas
$\sum_{i=1}^{2} h_{4i}H_i + \sum_{i=1}^{5} l_{4i}L_i + \sum_{i=1}^{21} m_{4i}M_i + \sum_{i=1}^{2} t_{4i}T_i + d_4^- - d_4^+ = 150$	Providing minimum travel time
$M_3 + d_5^- = 1$	Select obligatory metro project
$M_{19} + d_6^- = 1$	Select obligatory metro project
$H_1 + d_7^- = 1$	Select Project H_1
$H_2 + d_8^- = 1$	Select Project H_2
$L_1 + d_9^- = 1$	Select Project L_1
$L_2 + d_{10}^- = 1$	Select Project L_2

$L_3 + d_{11}^- = 1$	Select Project L_3
$L_4 + d_{12}^- = 1$	Select Project L_4
$L_5 + d_{13}^- = 1$	Select Project L_5
$T_1 + d_{14}^- = 1$	Select Project T_1
$T_2 + d_{15}^- = 1$	Select Project T_2
$M_1 + d_{16}^- = 1$	Select Project M_1
…..	Select Projects
$M_{21} + d_{34}^- = 1$	Select Project M_{21}
$\sum_{i=1}^{2} h_{5i} H_i + \sum_{i=1}^{5} l_{5i} L_i + \sum_{i=1}^{21} m_{5i} M_i + \sum_{i=1}^{2} t_{5i} T_i + d_{35}^- - d_{35}^+ = Budget$	The budget constraint(Scenarios)
H_i=0 veya 1 (i=1,2)	
T_i=0 veya 1 (i=1,2)	
L_i=0 veya 1 (i=1,2,3,4,5)	
M_i=0 veya 1 (i=1,2,3,…,21)	

Table 6. The Three Different Budget Scenarios and Results of Solution

Projects		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		M1	M2	M3	M4	M5	M6	M7	T1	H1	M8	M9	M10	M11	L1	M12
The budget scenarios (Billions $*100)	150	✓	✗	✓	✓	✗	✓	✓	✗	✓	✓	✓	✓	✗	✗	✓
	100	✗	✓	✓	✓	✗	✓	✓	✗	✓	✓	✗	✓	✗	✗	✓
	80	✗	✗	✓	✓	✗	✗	✓	✗	✗	✗	✗	✓	✗	✗	✓
Projects		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
		M13	M14	M15	L2	M16	M17	M18	M19	M20	M21	L3	L4	H2	T2	L5
The budget scenarios (Billions $)	150	✗	✗	✗	✓	✓	✓	✗	✗	✗	✓	✓	✗	✗	✓	✗
	100	✗	✗	✗	✓	✗	✓	✗	✗	✗	✗	✗	✗	✗	✓	✗
	80	✗	✗	✗	✓	✗	✓	✗	✗	✗	✓	✗	✗	✗	✗	✗

According to the $ 15 billion budget scenario, 12 metro projects, 1 tramway project, 1 monorail project and 2 light railway system projects are selected. According to the $ 10 billion budget scenario, 9 metro projects, 1 tramway project and 1 light rail system project are selected. Finally, according to a budget scenario of $ 8 billion, 7 metro projects and 1 light rail system project are selected.

6.6. Conclusions and suggestions

In this study, railed system projects which are planned in Istanbul are selected by establishing the goal programming model under certain constraints. The types of rail system are weighted with AHP from multicriteria decision making methods. According to the criteria of security, capacity, speed, cost and prestige, the types of rail systems are weighted with AHP. The metro, monorail, light rail system and trolley preference order emerged with the safety criterion considered to be the highest weight. Subsequently, the best projects were selected to improve urban transport among the planned transportation projects with the mathematical model established at the point of achieving the specified objectives.

Urban transportation planning is one of the most difficult decision-making processes of transportation planning. Using mathematical calculations has become compulsory in order to achieve the highest profit by using available resources. The use of mathematical methods makes it possible to achieve many goals at the same time. Solving the problem with a mathematical model will ensure that projects are best selected for a more liveable city and less traffic. These methods, which are used in many areas, also have an effective use in transportation planning. In urban transport projects, many factors must be taken into consideration and scarce resources should be used effectively. These methods can be used in the selection of vehicle type in urban transportation, in the selection of investment projects, in route setting, prioritization of infrastructure projects, transportation network planning, and allocation of resources to projects. Thus, the projects and activities that will be the most beneficial will be selected and prioritized by providing the resource utilization activity.

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