Mathematical Modeling of the Planning of Measures to Improve Road Safety

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***Abstract*—In this study, a mathematical model for planning of measures taken to improve road safety by using Qualimetry methods was developed. The problem was modelled as One-Dimensional Integer Bounded Knapsack Problem where the variables are bounded above and bounded below. A greedy algorithm was proposed in order to solve the problem and a software was developed in C# programming language, then computational experiments were performed. The results show the that the proposed algorithm is efficient. The exact solution of the problem was obtained by using WinQSP package program. The prepared mathematical model was applied to road data of Aliaga-Izmir and the results were presented.**

***Keywords*—mathematical modeling, integer programming, knapsack problem, highways, road safety, planning, Qualimetry**

I. Introduction

In today's economic conditions, organizations need to make timely and healthy decisions that may affect their lives in order to survive. For this, the authorities of the establishment need information systematically. Organization officials make use of the information they have in their decision-making processes and apply to mathematical methods and models [1].

Although "analysis of systems" is an important subject in our age, the mathematical tools required for this analysis are limited. Solving a system of equations with several hundred unknowns is very easy with computers. More difficult problems arise in the analysis of large systems. Mathematical modeling techniques, which can be a solution to all these difficulties, have proven to be useful in wide areas in a short time and have become a promising tool for the future [2].

Traffic accidents have taken thousands of lives in the world for years and this problem has not been solved to a significant extent yet [3]. There are three main factors in the formation of traffic accidents: human (driver or pedestrian), environment and road. Although the fault is mostly caused by the human factor in accidents, road and environment are important factors. It is possible to reduce accidents and increase traffic safety by making changes in some geometric features of the road or in the marking [4].

Many measures can be taken to increase road safety, the important thing is to take the measures that can increase traffic safety the most within the possibilities available. Road safety for any road or part of it in road networks is determined by the required safety conditions and the suitability of the road's characteristics [5].

Within the scope of this study, mathematical models of the planning of measures in the form of integer programming models were prepared in order to increase road safety, and the prepared models were solved with discrete optimization methods and computer software. New solution methods and computer software have been developed and implemented on some of the roads in Izmir [6]. In this way, what kind of measures should be taken to increase road safety using the available constraints has been determined and contributed to the literature on traffic safety.

With the obtained data, it has been determined which road features can be improved in order to increase road safety with the budget possibilities available. In this way, traffic safety can be increased and accidents can be reduced.

II. Knapsack Problem

The knapsack problem is a problem in combinatorial optimization: Given a set of items, each with a weight and a value, determine the number of each item to include in a collection so that the total weight is less than or equal to a given limit and the total value is as large as possible [7]:

w_j: the weight of the j.th item,
p_j: the benefit of the j.th item,
c: Total capacity of the knapsack

$$x_i = \begin{cases} 1, & \text{if item } j \text{ is selected} \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

$$\sum_{j=1}^{n} w_j x_j \le c\,, \quad (2)$$

$$x_j \in \{0,1\}, \quad j = 1,\ldots\ldots,n \tag{3}$$

$$Max\ Z^* = \sum_{j=1}^{n} p_j x_j \tag{4}$$

In addition to the standard knapsack problem defined in the model (2)-(4), the Knapsack Problems have expanded and each of them has become a standard problem on its own, with the addition of many additional constraints to the model in industrial applications [2].

III. QUALIMETRY

Qualimetry is a science that deals with the measurement methods of the quality of any object with things like relations or processes, natural or man-made objects, natural or inanimate, etc. deals [8]. Qualimeter is the scientific theory of quantification assessment of the 'USSR' formerly written by G.G.Azgaldov and is currently used in the development of Russian standards [9].

IV. ROAD SAFETY AND EXPLANATION OF ROAD PARAMETERS

Traffic accident occurs when a vehicle collides with another vehicle, pedestrian, animal, road debris, or other stationary obstruction, such as a tree, pole or building. Traffic collisions often result in injury, disability, death, and property damage as well as financial costs to both society and the individuals involved [11].

Many factors with different characteristics can be effective in the occurrence of traffic accidents. In a study conducted in the United States, 289 different factors were found to be effective in 68 accidents. Accident factor, accident-related, accident; can be defined as the condition without which it cannot occur. Essentially, there are many accident factors:

- Factors related to road users,
- Vehicle related factors,
- Road related factors; as 3 main groups [3].

The complex quality assessment of a built and suitable road is described below [11]:

K_t – target,

K_p-process,

K_h- non-hazardous motion,

K_{er}-ergonomics,

K_s-Indicators of road safety

K_{tec}-technology,

K_{es}-aesthetics

Target control indicators (K_t)

P_1 – Road category,

P_2 – Pavement type and Flexibility modulus,

P_3 – Width of the road,

P_4 – Road types in the plan,

P_5 – Profile of the road length ,

P_6 – Equipment of the road

Ergonomics Indicators (K_{er})

This group characterizes the indicators (driver, car, road and environment) criteria.

P_{16} – Psychophysical states,

P_{17} – Polishing properties of the road surface,

P18 – Evaluation of air pollution,

P_{19} – Level of road noise at the time of departure,

P_{20} – Vibration

Technological indicators (K_{tec})

P_{16} - continuity of repair,

P_{17} - content of repair work,

P_{18} - quality of repair work

Indicators of road processing (K_p)

P_8 – With level of continuity,

P_7 – Density of movement,

P_9 – Durability of road goods,

P_{10} – Smoothness of pavement,

P_{11} – Coupling coefficient of pavement

Non-hazardous Indicators (K_h)

P_{12} – Non-hazardous indicator of road movement

Indicators of road safety (K_s)

P_{13}– Infallibility (continuous operation without faults on the road),

P_{14}– Long-term operation,

P_{15} – Repairability

Indicator of the aesthetics of the road (K_{es})

P_{21} – Aesthetics

The complex quality assessment of worked roads can be represented by the following expression.

$$K_k = 0.1\ K_t + 0.3K_p + 0.15K_h + 0.25K_s + 0.15K_{er} + 0.05K_{es} \quad (5)$$

When evaluating quality with simple features, the above expression can be shown as the following expression.

$$K_k = 0.01(P_1+P_2+P_3+P_5+P_{18}) + 0.02(P_4+P_{17}+P_{19}) + 0.03(P_3+P_{20}) + 0.04\ (P_6+P_7) + 0.08\ P_9 + 0.09(P_{10}+P_{14}) + 0.06(P_{11}+P_{15}) + 0.15\ P_{13} + 0.07\ P_{16} + 0.05\ P_{21} \quad (6)$$

It depends on the conditions of non-hazardousness and whether the characteristics of the road are suitable or not, which measures should be planned in order to increase the non-hazardousness of vehicles moving on the road. Considering the entire budget allocated for the repair and reconstruction of the road, the K equation is established, then a Qualimeter model of the non-hazardousness of the road is established according to the appropriate P_1-P_n plain indicators in order to increase the non-hazardousness of the road. The aim here is to determine the maximal value of the complex demonstrator of the non-hazardousness of the movement designed without exceeding the allocated financial costs.

V. Mathematical Modeling of the Planning of Measures to Improve Road Safety

The methodology of planning measures to increase the safety of movement by means of road-maintenance services depends on the following situations. The non-hazardousness of movement for any road or part of it in the road network is determined by the required non-hazardous conditions and whether the road features are suitable. According to the methodology, the value of the K_k determined before the beginning of the planned period is characterized by the non-hazardousness of the movement and the suitability of the planned levels [10].

Considering all the financial resources allocated for the repairing and reconstruction of the road, after determining the current value of the K_k variable, a Qualimetric model of the safeness of the movement is established according to the appropriate Π_1 -Π_{19} plain pointers in order to increase the risklessness of the road (i.e., the improvement of the Π_1 is appropriate for the widening of the crossing part of the road, the bridges). expansion – Π_3 denoter etc.) [10, 11].

The justification of measures to increase the non-hazardousness of the movement is brought to determine the maximal value of the designed complex demonstrator of the non-hazardousness of the movement without exceeding the capacity of the allocated financial costs. The mathematical model of the problem is shown in (7)-(9):

$$\sum_{i=1}^{19} c_i(x_i - \Pi_i) \le C \quad (7)$$

$$\Pi_i \le x_i \le 5,\ i=1,2,\ldots,19 \quad (8)$$

$$Max\ K_k = \sum_{i=1}^{19} a_i x_i \quad (9)$$

Here, x_i and Π_i are the input and output values of the simple parameters of the qualimetric model that show the effectiveness of road conditions on the non-hazardousness of the movement:

a_i, the valence coefficients of the parameters given above;

c_i, the unit value of measures to increase the value of demonstrators by one point;

C, the planned capacity of financial resources allocated to measures to increase the security of movement for one year.

The problem can be written more clearly:

$$C_1(x_1-\Pi_1) + C_2(x_2-\Pi_2) + \ldots + C_{19}(x_{19}-\Pi_{19}) \le C, \quad (10)$$

$$\Pi_i \le x_i \le 5,\ (i=1,2,\ldots,9,11,\ldots 19), \quad (11)$$

$$C_{10} = 0 \quad (12)$$

$$C_{\Pi k} = 0 \quad (13)$$

The objective function (14) with its constraints is considered.

$$\text{Max}\ K_k = 0{,}15x_1 + 0{,}06\,x_2 + 0{,}05x_3 + 0{,}11x_4 + 0{,}13x_5 + 0{,}2x_6 + 0{,}03x_7 + 0{,}03x_8 + 0{,}03x_9 + 0{,}06\Pi_{10} + 0{,}09x_{11} + 0{,}08K\Pi_k + 0{,}10x_{16} + 0{,}03x_{17} + 0{,}01x_{18} + 0{,}02x_{19} \quad (14)$$

This model is a one-dimensional Knapsak problem with integers whose variables are limited on both sides [7].

The indicators used in this study are summarized according to the coating type, flexibility model, polishing of the coating surface, Noise, Roughness and repair continuity.

According to the information received from the General Directorate of Highways of Turkish Republic, the construction cost for the 10 km road section and the cost of each indicator for the 10 km road section were obtained [4].

Considering the budget of one year, the program for the knapsack problem with limited variables was implemented in C# language and calculations were made (DSKP Program). "The program used the method suggested by one of the authors in his study [12].

VI. WINQSB PACKAGE PROGRAM

WinQSB is a package program that contains the operations literature. It contains 19 modules. Each module contains algorithms and solution methods in the literature. LP-ILP Module, This module solves linear (LP) and integer linear (ILP) programming problems.

Among the previously explained road criteria, P_2 flexibility model is according to the pavement type (mpa), P_{17} is the shine of the pavement surface (lk), P_{19} is the noise level on the road (db), P_{11} is the friction coefficient of the road surface, P_{15} is the continuity of the repair made on the road, and its values are measured (Pn), scores between 1 and 5 (d_i) and costs (tl) are determined (w_n) for a 10 km road section. A budget of 10,000 TL has been allocated for all expenditures for the road surface.

VII. CONCLUSION

In this study, integer programming models of the planning of measures to increase road safety have been prepared. Qualimeter methods were used while preparing the models. The prepared model variables are expressed as the Knapsack Problem, which is limited from the bottom and the top. To solve this problem, a heuristic algorithm is proposed and a program system called DSKP (Knapsack Problem with Limited Variables) is implemented in C# programming language.

Calculation experiments were made on the test problems with the prepared program and the LP-ILP program of the WinQSB system was compared. According to this comparison, the results found by DSKP were always the same as those found by the LP-ILP program.

Prepared Mathematical Model and Program System was applied on Izmir's Aliaga highway data and the results are presented in [6].

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