system is to meet bridge network requirements, using available resources and implementing the most effective method. Lack of prioritizing credits lead to an imbalance between the requirements of a bridge network and the current resources [4].

The main objective of the system is to allocate current credit and resources to the repair projects and maintenance operation as well as determining the best possible time for their execution. The effects of repair projects on the maintenance activities shall be considered in this system.

Operational measures will help decision-makers to allocate a proper budget to bridge repair and maintenance activities in order to comply with level of service standards. BMS reduces the need for delayed repair and maintenance programs.

The first objective is to present a prioritization plan which could optimize the efficiency of the system in order to allocate sufficient funds to the repair projects, as well as specifying the best possible time of implementin. This includes the formulation of a network optimization model for bridge repair operation, using a dynamic programming method [5, 6]. The second objective is to investigate the effects of repair projects on maintenance plans. To achieve this objective, an optimum maintenance model was developed in this research.

4. OPTIMIZATION MODEL FOR REPAIR PROJECTS

Allocation of limited finance to bridge repair projects includes a multi-phase optimization, process. An optimum method which leads to an optimal decision may be applied over a period of time. In this paper a model for multi-phase optimization has been proposed. In this approach the restricted budgets are allocated to repair projects through minimizing the system profit loss [7].

This modelling process is based on: time and network dimensions. The model consists of two mixed external and internal models.

The internal model carries out the annual optimization, while the external model optimizes the system profit based on the analysis period. Both models are formulated, using the dynamic programming method [8,9]. A computer software program has also been developed for simulation of the network optimization model.

4.1. Model Formulation

The allocation of the budget to the bridge projects includes selecting the best modifying alternative for every bridge in the network along with determining the optimal time for its implementation. The objective function is defined as follows:

Minimize

$$Z=\sum_{t=1}^{T}\sum_{B=1}^{N}\sum_{A=0}^{m(t,B)} BL(t,B,A)*X(t,B,A) \qquad (1)$$

In which:

Z= total profit loss of the system,

T= number of years in the analysis period,

N= total number of the bridges,

m(t,B)= number of repair alternatives for bridge (B) in the year (t).

BL(t,B,A)= the level of profit loss in system if alternative (A) for bridge (B) is chosen in year (t); and,

X(t,B,A)= it would be one if alternative (A) is selected, otherwise it would be zero.

If the bridge is repaired in any year of the analysis period, all primary costs and system profit loss must be estimated for all possible alternatives [10]. The profit loss is related to the application of any modifying alternative and determined by using the following equation [11].

$$BL(t,B,A)=[(LCC(t,B,A)-LCC(t,B,E))+(UC(t,B,A)-UC(t,B,E))]*(P/F,r,t) \qquad (2)$$

In which:

LCC(t,B,A)=total life time of the selected alternative (A) for Bridge (B), in the year t,

UC(t,B,A)= expenses imposed on users for alternative (t,B,A),

E= An alternative for bridge (B) in the year t, which has the least amount of (LCC+UC), and,

(P/F,r,t)=present fund value coefficient for the real output rate in the year t.

The formulated model uses the dynamic programming method. In fact, two dynamic programming models have been mixed together. The external model in its phases deals with the years of the analysis period, while different phases of the internal model deal with the bridges.

4.1.1. External Model

It should be noted that there is no specific algorithm for solving the problems of the dynamic programming such as simplex method,

which is used for solving linear programming problems. However, Equation 1 indicates the objective of the model. There is a specific budget (BD) based on {currency per year}. The total budget (TBD) is calculated for an analysis period of (T) years by summing up the annual budgets over (T) years. The consumption of the budget in each year should not exceed the credit of the same year plus the invested credit from the previous years. This can be shown by the following equation:

$$\sum_{j=1}^{j=t} \sum_{B=0}^{N} \sum_{A=0}^{m(B,A)} IC(j,B,A) * X(j,B,A) \leq \sum_{j=1}^{j=t} BD_j$$

for all t (3)

In which:

IC(j,B,A)=initial cost of alternative (A) for bridge (B) if carried out in year (j),

X(j,B,A)= it shall be one if alternative (A) for bridge (B) is chosen for year (j) , and otherwise it shall be zero, and

BDj= the current budget for year (j)

The problem is Formulated by using dynamic programming as it follows:

Phases (t): years from the first year up to year (T)

Decision making in one phase and reaching optimal consumption in each phase, in achieving the system profit loss is at minimum level.

Situations (d): all possible levels of the budget, which could be transfered to the next year.

Decision-Making: supposing that the level of the budget consumption is W_2 {curreney/year}, which bridge projects will be implemented.

Return equation:

$f_t(d_t)$ = Minimum $[g(t,d_t, w_t)]$ for all w_t (4)

$g(t,d_t, w_t) = BL(t,d_t, w_t) + f_{t-1}(d_t + w_t - BD)$ (5)

In which:

$f_t(d_t)$= the minimum loss of the profit which could be achieved till phase (t) in (d_t) situation,

$g(t,d_t,w_t)$= the profit loss till phase (t) in (d_t) situation, when the level of the budget consumption is w_t {currency/year}.

BL(t. d_t,w_t)= the loss of the profit for phase (t) in (d_t) when the level of the budget consumption is w_t { currency/year }.

In each phase (t), there is a matrix with (d_t) of the line and w_t of the column. The matrix particulars include g(t, d_t,w_t). Any information in this matrix requires two parts indicated in Equation (6). The second part is derived from (t-1) of the previous phase, while the first part is resolved with the internal model.

Selecting the internal model Dec ((t,d_t,w_t)) for this information guarantees and includes three parts:

D(t, d_t,w_t)= all completed bridge projects in phase (t) and situation (d), provided that the level of budget consumption is W_t.

BL (t,d_t,w_t)= the system profit loss resulting from the completion of all D (t, d_t,w_t) projects, and

IC(t, d_t,w_t)= initial costs for completion of all D(t, d_t,w_t) projects.

Each bridge is illustrated by one vector (B,A,K), in this vector B is the bridge specification, A is the applied alternative and, K is the year in which the bridge can be reinvestigated for another revision and is equal to (t+v).

Parameter V is the number of years after the reinvestigation. If alternative (A) is chosen it will be included in the model.

It is necessary to point out that the model shall start with all of the bridges in the road network in phase (1), and in each phase (t), all P(t, d_t,w_t) bridges, applied by the internal model to solve the cell (t, d_t,w_t), could be identified as follows:

$$P(t,d_t,w_t) = P\left(t-1, d_t + w_t - BD, w_{t-1}^*\right) - D\left(t-1, d_t + w_t - BD, w_{t-1}^*\right) \quad (6)$$

In which:

W_{t-1}=the level of budget consumption complying with $f_{t-1}(d_t+w_t-BD)$.

In fact, P(t,d_t,w_t) is calculated through applying specific amounts of K for all bridges. If (k≤t), so the bridge is to be considered in total bridges (P).

After solving the internal model, the quantities of k are to be placed in D(t,d_t,w_t) as it is specified in two following cases.

If the alternative " do nothing" is chosen, k=k and otherwise, k=t+v

The alternative "do nothing" always causes the maximum profit loss but it has zero initial cost.

4.1.2. Internal Model

This model is used for any (t,d_t,w_t) member of the external model, so that it effects an optimal decision to be made for that member of Dec(t,d_t,w_t). The model input includes full information of all bridges p(t,d_t,w_t), plus the current budget which is w_t. The objective function as well as its constraints, are defined as follows:

Minimize

$$Z = \sum_{B=1}^{N} \sum_{A=0}^{m(B)} BL(B,A) * X(B,A) \qquad (7)$$

Subject to:

$$\sum_{B=1}^{N} \sum_{A=0}^{m(B)} IC(B,A) * X(B,A) \leq W \qquad (8)$$

$$\sum_{A=0}^{m(B)} X(B,A) = 1 \qquad for\ all\ B \qquad (9)$$

X (B,A) = 1,0 (10)

In which:

Z= profit loss for each phase of (t) in any situation of (d_t) of the external model, when budget consumption level or current budget is equal to W (currency/year),

N= number of total bridges,

M(B)= number of modifying alternatives for bridge (B),

BL(B,A)= loss of system profit when alternative (A) is selected for bridge (B),

X(B,A)= would be equal to 1, if alternative (A) is selected for bridge (B), otherwise it is zero; and

W= current yearly budget.

The internal model is also formulated using dynamic programming as follows:

Phases (B): the bridges from the first bridge to bridge N,

Decision in one phase: what is the suggested alternative for that bridge (phase) to keep the loss of the system down to a minimum.

Situations: current finances.

Making decision: supposing alternative (A) is selected, what is the system profit loss?

Return equation:

$f_B (S_B)$ = Minimum [$v(B, S_B , A_B)$] for all A_B (11)

$v(B, S_B, A_B) = BL (A_B) + f_{B-1} (S_B - IC(A_B))$ (12)

In which:

$F_B(S_B)$= the minimum profit loss, till phase (B) in the situation (S_B) is obtained,

$V(B,S_B,A_B)$= the profit loss till phase (B) in the situation (S_B) when alternative (A_B) is selected,

$BL(A_B)$= profit loss if alternative (A_B) is chosen for the bridge (B), and,

$IC(A_B)$= initial cost of the alternative (A_B).

In each phase, the situations start from zero and increasingly develop, untill they reach the current budget W_t. This increase must be selected in a manner that a relationship between the project and its cost would exist. In each phase (B), there shall be a matrix with (S_B) rows and (A_B) columns. The matrix particulars include amounts of $v(B, S_B, A_B)$.

5. THE OPTIMUM MAINTENANCE MODEL

The effects of the renovation and renewal on the maintenance planning have been considered in the optimization model of maintenance activities. The optimal maintenance resources are allocated to maintenance activities. Methodology of presenting a model for organizing maintenance activities includes 3 phases.

Phase 1, is the determination of the maintenance activities, in which it is necessary to suspend them in order to deal with repair and renovation projects [12]. This phase is investigated in a so-called suspension sub-model; then, a priority index has been estimated for any maintenance activity to determine the obtained profit from accomplishing the activity [13]. Phase 2, is carried out in the priority index sub-model. Phase 3, is carried out through a dynamic programming model for allocation of maintenance resources to the necessary activities [14]. This model aims at maximizing total priority index throughout the network and is carried out by the optimization sub model.

The maintenance resources are defined as total current man/hours in a full year-period. A computerized program has also been developed for the simulation of the optimum maintenance.

5.1. MODEL FORMULATION

The objective function for the optimization problem for each year can be stated by the following equation:

$$Maximize \quad Z = \sum_{i=1}^{n} A_i * PF_i \qquad (13)$$

Subject to:

$$\sum_{i=1}^{n} A_i * ch_i \leq CH \qquad (14)$$

$A_i = 1, 0$ (15)

In which:

Z= total priority index obtained,

n= total maintenance activities proposed for the study year,

A_i= if maintenance activity (i) is proposed, it would be one, otherwise it is zero;
PF_i= priority index for maintenance activity (i);
Ch_i= number of "man/hours" required for implementation of maintenance activity (i),
CH= total number of current "man/hours" during the analysis year.
This problem can be solved using the integer programming, provided that there are few decision-making variables or specific maintenance activities. Unfortunately, in most transportation departments these activities might include thousands of activities. so it is impossible to solve these huge problems by integer programming. Hence, the dynamic programming is applied to solve the problem.
As already explained, the dynamic programming is a very powerful method for solving great optimization problems having few constraints.
The model is formulated using dynamic programming as follows:
Phases (M): maintenance activities, situations (s): all levels of possible existing "man/hours",
Decision in one phase: implementation or non-implementation of the activity so that the total priority index is maximized.
Making decision: what is the total (PF), when the activity is carried out, and what if it is not?
Return equation:

$$f_M (S_M) = \text{Max } [U(M, S_M, A_M)] \quad \text{for } A_M = 0, 1 \tag{16}$$

$$U (M, S_M, A_M) = PF(A_M) + f_{M-1} (S_M - ch_M) \tag{17}$$

In which:
$F_m(S_m)$= the maximum total (PF) which can be obtained till Phase (M) in Situation (S_m),
A_m= would be one if alternative (M) is chosen, and otherwise it is zero;
$U(M,Sm,A_m)$= total (PF) up to phase (M) when (A_m) is selected,
$PF(A_m)$= activity priority index (M) if A_m=1, otherwise it is zero, and;
ChM= (man/hour)s required for the activity (M).
It is presumed that the model are based on maintenance activities, so, there would be (n) phases. Cases in each phase, shall take all possible levels of man/hours. Thus, they start from zero and progressively increase, until it is equal to total current man/hours of (CH) during the full year time at the final phase.In each (M) phase, there would be a two-column matrix, indicating implementation or non-implementation of activity (M). The rows of the matrix correspond to the possible cases. The matrix particulars are quantities of $U(M,Sm,A_m)$.

6.MODEL EVALUATION

6.1. Repair Optimum Model

Using the data from 25 bridges including modifying alternatives for each bridge as well as initial costs and the net profit from implementation of each alternative, dynamic programming model was compared with the method of increasing profit/cost ratio. Following the comparison of 11 different levels of budgeting, the net profit through execution of proposed alternatives showed the superiority of dynamic programming model. Figure 1 shows that in all budgeting levels (except the last one), the dynamic programming model offers more profit to the network as compared with the method of increasing profit/cost ratio. The two methods are similar in delivering results only in the highest level of budgeting. This shows that the optimal solution in the method of increasing profit/cost ratio is only completed when unlimited or adequate budgets are provided for executing the best economic alternative for each bridge.
Meanwhile, in lower levels, the dynamic programming model generates a profit almost three times more than the net profit gained from the second method. Figure 1 shows that, following a small change in the level of budgeting, a double boom in net profit resulted from the method of increasing profit/cost ratio is achieved. This is an indicative of inconsistency of this method as well as how the method is deviated by some modifying alternatives and also a proof of the consistency of the dynamic programming model.

6.2. Optimum Maintenance Model

Using the data from 25 maintenance activities including priority indices and the quantity of man/hour required for the execution of the activity, a comparison was made between the presented model and the classification model based on resources allocated to the maintenance activities arranged according to the priority indices of each activity in a descending manner.
In this comparison, regarding the 9 levels of

man/hour and the total priority indices resulted from the two methods; the superiority of dynamic programming model over the classification method was proved. In the presented model most resources are totally allocated to the maintenance activities and more activities are done comparing the classification method.

In Fig. 2, the total priority resulted from the two methods for 9 different levels of the current resources have been shown. Fig. 2 shows that the profit gained from the application of presented model is much higher than the classification method, when the existing resources are less than what is required. In the last level, which the adequate resources exist for implementing necessary activities, the resuts of two methods are similar.

7. THE COMPUTER SOFTWARE DEVELOPMENT

7.1. Simulation of Optimum Repair Model

The main aim is to allocate restricted budgets to the repair projects of a bridge network within a specific time period. The budget is allocated to each bridge in the network along with specifying an optimal time for its implementation, through selection of the best modifying alternative.

Data entry into the program include number of bridges, the analysis period, the existing budget for each year of the analysis period, and also the initial costs and the profit loss related to all possible alternatives for all bridges.

The output information of the program include; a schedule for spending the budget for each year of the analysis period, selection of a modifying alternative for each bridge in each year of the analysis period, total budgets required for the implementation of the alternatives selected in each year as well as the balance credit for each year.

7.2. Simulation of Maintenance Model

The function of this software is to allocate limited maintenance resources to maintenance activities required by a network of bridges.

Input data of the program include; total number of maintenance activities, the essential resources on the man/hour basis required for execution of each activity, every existing maintenance activity in each year and also the priority index of each maintenance activity.

The outputs of the program includes; proposals for maintenance activities to be done in this year, total priority indices gained through implementing selected alternatives, as well as resources unexploited.

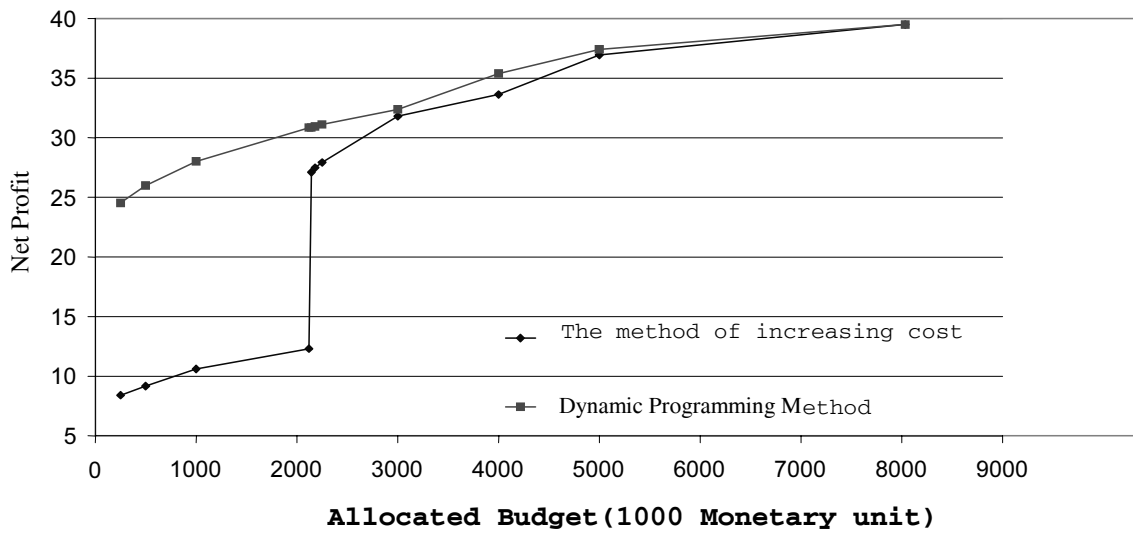

Fig. 1: Comparison between the net profit realized from the method of increasing cost ratio and the dynamic programming model

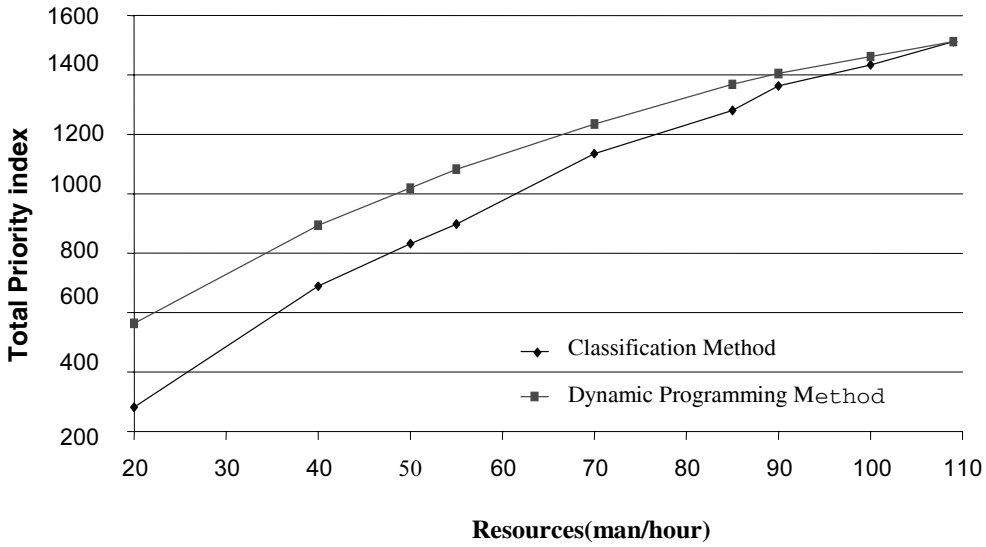

Fig. 2. Comparison between total priority indices gained from the classification method and the dynamic programming model

8. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drown from this research:

1) The prioritization method presented for bridge repair projects, which indicate the bridge management system, is capable of optimizing on a multi-phase basis, and if applied, an optimal decision can be made for allocation of limited credits to the bridge projects.

2) For a one-year optimization, comparing the presented internal model with the method of increasing profit to cost ratio is widely used. The superiority of internal dynamic programming model over the method of increasing profit to cost ratio is shown. The internal model can essentially find the optimal solution with a restricted budget for a period of one year. The optimal solution in the method of increasing profit to cost ratio is applied when unrestricted or sufficient funds is provided for accomplishing the best economic alternative for every bridge.

3) The external model's function might be realized by none of the existing methods. This model is able to determine the best optimal repair time for each bridge and the quantity of optimal expenditure of the fund available for each year of the analysis period.

4) Combining internal dynamic programming model with external model creates a new prioritization method for bridge repair projects. One could make optimal decisions with regard to the restricted finances. The use of proposed method in bridge management systems leads to a huge savings in system profit loss.

5) Upon the implementation of multi-phase optimization for allocation of limited funds to the bridge network, the consequences revealed the fact that prioritization of bridge projects is affected by the internal rate of return and deterioration rate of the projects.

6) Comparing the presented maintenance model with the method of maintenance activities classification, it was revealed that when the existing maintenance resources are less than the required resources, the profit gained from application of the presented model is by far more practical than the classification method. When there are enough maintenance resources, the results of the methods are similar.

Finally, some of the models were tested using the suppositional information due to the lack of real data. Collecting these information allow the users of the bridge management systems to examine the system strength by applying the real information.More research is required to investigate the impact of traffic volumes, highway classification type as well as weather forcasting in the prediction model. Application of neural networks for predicting the condition of the bridge is also recommended.

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