Economic Comparison of Conventional and Optimum Scheduling of the Electric Transmission/Distribution Substations in Jeddah City Using the Net Present Value

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Abstract: - This paper focuses on the electricity field in Jeddah city. It is devoted to predicting and economically scheduling the needed number of electric transmission/distribution substations for long-term time horizon (10 years). Forecasting is based on predicting the electricity total demand in each year and then finding the needed number of substations for each year.

The forecasting is used to predict the projected annual total consumptions for years from 2009 to 2018 using an artificial Neural Network (ANN) depending on the historical data for six predictor variables for the time period 1979-2008.

Scheduling is based on a dynamic programming model under the constraints of needed demand and budget availability. The objective function is to minimize the total cost; the decision variables are the number of transmission/distribution substations to be built in each year (stage). The state of the system is the number of transmission/distribution substations still required in remaining years.

The optimum schedule for constructing and operating the substations is found and compared with the conventional method of scheduling used by the company. The comparison is based on the net present value for both alternatives.

The net present value (NPV) = 1446.783 and 1748.981 millions Saudi Riyals (SR) for the optimal and the conventional schedules, respectively. So the NPV for the optimal schedule saves SR 302.198 millions, i.e. about 17% over the planning horizon of the next 10 years.

Keywords: **-** Net Present Value, Dynamic Programming, Electric Transmission/Distribution Substations, Scheduling.

1. Introduction

The procedure that Saudi Electricity Company (SEC) now follows depends fully on current immediate actual needs for each area in the city taking into account the budget constraints. The forecasting of needed number of substations is based solely on intuition and on naïve forecasting methods. This may result in either building few substations while the budget permits for more, or building less than required because of the budget constraints. This also has no guarantee to reach an optimum solution over the planning time horizon with respect to total cost. For these reasons, SEC is in bad need to build a systematic procedure for determining the optimal combination of decisions to determine the number of substations to be built in each year during the overall planning time horizon. This is a vital issue for Saudi Electricity Company (SEC). It will help avoid decision problems by building a mathematical model for optimal scheduling under the constraints of needed demand and budget availability.

The main objective of this study is to economically schedule the installation of the needed number of electric transmission/distribution substations in Jeddah city for long-term time horizon (10 years). The scheduling aims to minimize the total cost and to determine the appropriate installation time based on a dynamic programming model. The objective function is to minimize the total cost for establishing these substations under existing constraints of required demand and budget limitations.

Section 2 presents a literature review of similar problems for the Electric Transmission/ Distribution Substations, applications of Dynamic Programming in scheduling, and the economical evaluation of projects based on the net present value (NPV).

Section 3 presents using artificial neural networks to forecast the number of required substations for the planning period. Section 4 illustrates in details the steps for the dynamic programming model to find the optimal scheduling of the substations over the planning horizon.

Section 5 gives an economic comparison for the optimal and the conventional schedules based on NPV. Section 6 is devoted for the main conclusions drawn from this paper, and section 7 introduces some suggestions for future research points.

2. Literature Review

In a recent paper [1], forecasting of the needed number of electric transmission/distribution substations in Jeddah city was performed for the time period (from 2009 to 2018). The forecasting was done using Artificial Neural Networks (ANN). Then a dynamic programming model was formulated to determine the optimum number of substations to be built in each year in the planning horizon. The decision variables are the number of transmission/distribution substations to build in each year (stage) with the objective of minimizing the total cost. The optimal solution was calculated with total cost of 2,085,110,000 SR.

Electricity consumption has increased sharply in Saudi Arabia over the last two decades, mainly due to a rapid economic development and an absence of energy conservation measures. Other contributing factors include a rapidly growing population (with a current annual population growth rate of about 3%) as well as artificially low electricity prices (due to low government-mandated tariffs and heavy consumer subsidies as part of a social welfare program). Several studies have therefore shown a sharp increase in electricity consumption in Saudi Arabia, with an average demand growth of 7% per annum.

According to forecasts provided by the Saudi Ministry of Economy and Planning, approximately 2.2 million new villas and apartments will be required over the period 2010- 2025. Moreover, in a time of global concern over energy and environmental issues, ignorance of efficient building design and the absence of 'time-of-use' electricity rates lead to approximately 80% of electricity being used for air conditioning and refrigeration. Consequently, electricity shortages are acute during the summer season when demand is at its peak [2].

In [3], a dynamic programming is used to solve the optimization problem of optimal matrix parenthesization problem. The results and their analysis reveal that there is considerable amount of time reduction compared with simple left to right multiplication, on applying the matrix parenthesization algorithm. Time reduction varies from 0% to 96%, proportional to the number of matrices and the sequence of dimensions. Foremost improvement of the parallel algorithm used is its independency on the number of matrices. Moreover, work has been uniformly distributed between processors, besides its confirmation to single processor algorithm results.

Net present value (NPV) is one of the best financial tools to establish the value of a project or investment. NPV is used for capital budgeting, and widely throughout economics, it measures the excess or shortfall of cash flows in present value (PV) terms, once financing charges are met. All projects with a positive NPV are profitable; however this does not necessarily mean that they should be undertaken since NPV does not account for opportunity costs. Assuming a firm aims to maximize profit, projects should only be undertaken if their NPV is greater than the opportunity cost.

In [4], two economic analyses of investments for integrated waste water collection and treatment in selected area are presented. The methods of Net present value (NPV) and capitalized costs (CC) have been used to compare economic efficiency of construction of central waste water treatment plant with collecting system and construction of decentralized waste water treatment plants with belonging collecting system for each settlement separately. Two possible solutions have been selected to cover the extraordinary maintenance costs in the life time of each construction solution.

In [5], the authors explain how government officials can solve the problems surrounding municipal solid waste management in Metropolitan-Manila. A crucial related issue is how the expert group can better evaluate municipal solid waste (MSW) management solutions and select favorable ones using a series of criteria. MSW solution selection is a multi-criteria decision-making problem, which requires considering numerous complex criteria. The study applies cost-benefit analysis (CBA) and data envelopment analysis (DEA) to determine the benefits and cost / input and output technical efficiency of alternative projects, which affords financial data information that evaluators can use for economic decision-making regarding MSW projects. To solve this problem, the measurement of the monetary value of benefits and costs could be translated into the total net benefit or net present value (NPV) of a project.

In [6], the authors present a management model to deal with the problem of tracking missing features during long image sequences using computational vision. Some usual difficulties related to missing features are that they may be temporarily occluded or might even have disappeared definitively. The proposed Net Present Value (NPV) model, based on the economic Theory of Capital, considers the tracking of each missing feature as an investment. Thus, using the NPV criterion, with adequate receipt and outlay functions, each occluded feature may be kept on tracking or it may be excluded of the tracking process depending on its historical behavior.

It [7], the authors found that an essential element of electric utility resource planning is forecasting of the future load demand in the service area. Based on the outcome of such forecasts, utilities coordinate their resources to meet the forecasted demand using a least-cost plan. In general, resource planning is performed subject to numerous uncertainties. Expert opinions indicate that a major source of uncertainty in planning for future capacity resource needs is the forecasted load demand.

In [8], the authors investigate the reactive power/voltage control in a distribution substation. The purpose is to properly dispatch the shunt capacitors and on load tap changers at the distribution substation based on the forecast hourly loads of a main transformer and its primary bus voltage. The aim is to minimize the voltage deviations from the desired values in the reactive power flows through the main transformer, and the transformer secondary bus. An approach based on dynamic programming is presented to reach the desired dispatching schedule.

In [9], the authors use the spatial load forecast to forecast the distribution load demand in the planning area in future years. The planning area was divided into lots of small sectors (areas). A forecast approach based on classification of the small sectors is selected. The basic data can be easily obtained, and it is rather flexible to the changes of city planning. The obtained loads at different years inside each sector are different in distribution network planning, such that the optimal planning of substation locations and sizes is a dynamic programming problem.

3. Forecasting Number of Substations

Saudi Electricity Company (SEC) is the single national company responsible for generation, transmission and distribution of electricity all over the kingdom of Saudi Arabia. The Strategic Goals of SEC [10] include working on developing its programs to improve the performance of power transmission systems that includes the quality of electricity supply, performance and preventive maintenance indicators, expansion plans, and the construction of new projects. The objective of the power distribution system is to deliver electrical power to customers in safe, reliable and most economical way.

Data collection consisted of three tasks, namely identification of data requirements, data sources and determination of the volume of data. It is also important to make a reasonable estimation of how much data will be needed to achieve the objective of this study.

Data of the annual total electricity consumption in Jeddah city from 1979 to 2008 were collected. The different input variables (factors) thought to be influencing total electricity consumption were also collected for the same period.

There are a number of economic and demographic variables that could have a considerable impact on electricity consumption. Depending on the effect of these variables, they would lead towards the increase or decrease of total electricity consumption. The variables found to have significant effect, using the best subsets regression among the 14 affecting factors, are only 6. These will be used in the proposed model, and they are [1]:

1- Total Number of Subscribers (TNS).
2- Population Size (PS).
3- Oil Gross Domestic Product (OGDP).
4- Private Non-Oil Gross Domestic Product (PNOGDP).
5- Government Non-Oil Gross Domestic Product (GNOGDP).
6- Per Capita Income (PCI).

There are several Neural Network (NN) models that can be used. The one appropriate for our study is multilayer perceptrons (MLPs) feed forward NN. Their main advantage is that they are easy to use, and they are very powerful pattern classifiers. With one or two hidden layers they can approximate virtually any input-output map [11].

Based on the forecasts, the projected annual total consumptions for years from 2009 to 2018 are calculated [12].

The electrical annual total consumption (recorded energy) can be converted to recorded demand load.

The load factor can be calculated from the energy records (0.6 – 0.65).

Losses occurring at various stages of transformation and transmission system at 380 /132 kV are transmission losses, losses occurring on 132 /13.8 kV are sub transmission system losses and losses occurring on 13.8/0.4/0.22 kV are distribution losses. Losses can be divided into two categories: Technical losses and non-technical losses (commercial losses). Technical losses are losses which occur due to inherent characteristics of the equipment used in the transmission and distribution system, while commercial losses occur due to pilferage of power on account of theft and malpractice adopted by customers, defective meters etc.

The international figures for the losses are:

- Transmission losses are in the range 0.5% to 2.6%,
- Sub transmission losses are: 1.5% to 4%,
- Distribution losses are in the range of 8 % to 10%.

It is assumed that a loss factor in the range of 10% is quite a good figure, which will cover the technical losses in the distribution system as well as commercial losses if any.

Total MWh to be provided to Jeddah city are calculated using the following formula:

$$Eng.T = \{\frac{1}{1000.(1 - Loss\ Factor)}\}.ETC$$

Where:

Eng.T = Total energy to be provided during the year (MWh).

ETC = Total energy consumed by customers within the year (KWh).

Loss Factor = 10%.

The demand loads in MVA in Jeddah city are calculated using the following formula:

$$MVA = \frac{Eng.T}{(8760.LF.PF)}$$

Where:

LF = Load Factor = 0.6,

PF = Power Factor = 0.87.

The results of demand load for each year from 2009 to 2018 are calculated, and the number of required substations in Jeddah city in each year is obtained depending on the calculated demand load and the capacity of the current substations in the city. The current total capacity of substations in Jeddah = 6356 MVA. Each substation contains 3 transformers, each transformer has a capacity of 40 MVA, this means that each substation requires 120 MVA. The maximum load for each substation must not exceed 85% of the available capacity in that substation as a safety factor for the distribution sector.

Defining the number of required substations in each year can be calculated using the formulas:

$$MVA(WSF) = \frac{MVA}{0.85}$$

Where **:** *MVA (WSF) = MVA* (with safety factor)

$$MVA(TBA) = MVA(FCY) - MVA(FPY)$$

Where **:** MVA (TBA) = MVA (To Be Added)

MVA (FCY) = MVA (For Current Year)

MVA (FPY) = MVA (For Previous Year)

The number of required substations

$$= \frac{MVA(TBA)}{120}$$

Results for the number of required substations for years 2009 to 2018 are as follows: (2, 1, 3, 3, 1, 3, 3, 3, 2, and 3).

4. The Dynamic programming Model

4.1. Basic Features of the Model

The basic features that characterize the dynamic programming formulation of the problem are presented as follows:

1- The problem is divided into consecutive years (stages), a policy decision is required at the beginning of each stage, and accordingly a number of possible states (number of remaining substations to be built) will be associated at the beginning of the next stage.

2- The problems is interpreted in terms of networks, each node corresponds to a state. The network consists of columns of nodes; each column corresponds to a stage. The links from a node to nodes in the next column correspond to the possible decisions. The value assigned to each link is interpreted as the immediate contribution to the objective function by making that policy decision.

3- The objective corresponds to finding the shortest path through the network. The solution procedure is designed to find an optimal policy for the overall problem, i.e., a prescription of the optimal policy decision at each stage for each of the possible states (optimal sequence of decisions).

4- Given the current state, an optimal policy for the remaining stages is independent of the policy decisions adopted in previous stages. Therefore, the optimal immediate decision depends only on the current state and not on how we got there (the principle of optimality for dynamic programming).

5- The solution procedure begins by finding the optimal policy for the last stage (backward procedure). It prescribes the optimal policy decision for each of the possible states at that stage.

The solution of this one-stage problem is usually trivial.

6- A recursive relationship that identifies the optimal policy for stage *n*, given the optimal policy for stage *n*+1, is to be calculated. The notations are summarized as:

N = number of stages.

n = label for current stage (n = 1, 2, …, N).

S_n = current state for stage *n*.

x_n = decision variable for current stage *n* and state S_n.

x_n^* = optimal value of x_n (given S_n).

$f_n(S_n, x_n)$ = contribution of stages *n*, *n*+1, . . ., and N to the objective function if system starts in state S_n at stage *n*, immediate decision is x_n, and the optimal decision can be made therefore.

$f_n^*(S_n) = f_n(S_n, x_n^*)$ ……..……………… (1)

The recursive relationship is of the form:

$f_n^*(S_n) = \min_{x_n} \{f_n(S_n, x_n)\}$ ……………… (2)

Where:

$$f_n(S_n, x_n) = P_n(x_n) + (24 - S_n).w_n + f_{n+1}^*(S_n - x_n)$$

……..………… (3)

Where:

$P_n(x_n)$ = Total cost of establishing x_n substations in stage (year) *n*,

w_n = Operating cost for one substation in stage *n*.

7- The solution procedure starts at the end and moves backward stage by stage (considering all states), each time finding the optimal policy for the current stage and state until it finds the optimal policy starting at the initial stage. This optimal policy immediately yields an optimal solution for the entire problem, namely, x_1^* for the initial state S_1, then x_2^* for the resulting state S_2, and so on to x_N^* for the last stage S_N.

8. The problem is considered to be a deterministic one, where the state at the next stage is completely determined by the state and policy decision at the current stage. At stage *n*, the process from some state S_n, making policy decision x_n, will move the process to some state S_{n+1} at stage *n*+1, where the contribution to the objective function under the optimal policy has been calculated to be $f_{n+1}^*(S_{n+1})$ [13].

9. The problem requires making ten interrelated decisions, namely, how many substations to build in each year of the coming ten years (stages). The decision variables x_n (n = 1, 2, 10) are the number of substations to be built in year (stage) *n*. The "state of the system" S_n is the number of substations still required in the remaining years.

10. The states for the network can be calculated as follows: At stage 1 (year 1), where none of the required stations are built, then S_1= summation of the total number of required substations in all the stages (D_N). At the second stage, S_2 is just D_N minus the number of substations built at the preceding stage, and so on: $S_n = S_{n-1} - x_{n-1}$, n = 2, 3, ..., N. So the sequence of states is:

$S_1 = D_N$,

$S_2 = D_N - x_1$,

$S_3 = S_2 - x_2$,

....

....

$S_{10} = S_9 - x_9$.

11. The decision variables are the number of substations to be built in each year $x_1, x_2, x_3, \ldots\ldots., x_N$ subject to:

$$\sum_{n=1}^{N} x_n = D_N \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

x_n are nonnegative integers, n = 1, 2, …, N ….. (5)

12. The objective is to choose $x_1, x_2, x_3, \ldots\ldots., x_N$ so as to

$$Minimize \sum_{n=1}^{N} p_n(x_n) + \sum_{n=1}^{N} x_n \cdot (\sum_{i=n}^{N} w_i)$$

…………………….…………... (6)

13. The problem has two constraints, the demand and the budget constraints. The demand constraint says that the number of substations in each year must be greater than or equal to the required number to cover the load. The budget constraint says that the total expenses for establishing the new substations in each year should not exceed the allocated budget in same year.

The budget constraints can take the form:

$x_n \leq x_{n_{\max}}$, n = 1, 2, …, N ……….……… (7)

Where $x_{n_{\max}}$ = the maximum number of substations that can be build during year *n* due to the available budget constraints. The demand constraints can take the form:

$$\sum_{j=1}^{n} x_j \geq D_j,\ n = 1, 2, \ldots, N \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where: $D_j = \sum_{j=1}^{n} d_j$, $d_j =$ required number of substations in a year *j* to cover the demand.

4.2 Model Constraints

The establishing cost is assumed to start from 50 millions Saudi Riyals at year 2009 for one substation. This cost is increased yearly by an amount of 7% of the previous year. Operation and maintenance costs start from 3 millions and are increased by 7% yearly.

1. Budget Constraints

$x_n \leq 3,\ n=1,2,\ldots,10$.

2. Load Constraints

$x_1 \geq 2$

$x_1 + x_2 \geq 3$

$x_1 + x_2 + x_3 \geq 6$

$x_1 + x_2 + x_3 + x_4 \geq 9$

$x_1 + x_2 + x_3 + x_4 + x_5 \geq 10$

$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 \geq 13$

$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 \geq 16$

$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 \geq 19$

$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 \geq 21$

$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10} \geq 24$

4.3 Model Graphical Representation

Figure 5 shows the states to be considered at each stage. The links (line segments) show the possible transitions in states from one stage to the next by building a feasible number of substations in the year involved. In stage 1 (first year), the initial state equals 24, the demand constraint is to build at least two substations ($x_1 \geq 2$), and the budget constraint dose not allow to build more than three substations ($x_1 \leq 3$). This means that there are two choices, that is to build two or three substations, thus bringing the number of remaining substations (state) = 22 or 21 respectively as shown in second column in the figure, and so on for the other stages. The overall problem is to find the path from the initial state 24 (stage1) to the final state 0 (after stage 10) that minimizes the sum of the number along the path.

An Excel program is used for the calculation during the solution procedure. With S_{10} substations still required to be built in the last year $(n = 10)$, the decision should be "to build those remaining stations". And as there is only one branch from each state, then $x_{10}^* = S_{10}$, and $f_{10}^* = P_{10}(S_{10}) + (25 - S_{10}) * w_{10}$. The calculations for different states are computed using the Excel worksheet, and the results are recorded in a corresponding table for further use in the following tables, where the recursive equation for the last stage is:

$$f_{10}(S_{10}, x_{10}) = P_{10}(x_{10}) + (24 - S_{10}).w_{10} + f_{11}^*(S_{10} - x_{10})$$

Now by moving backward to start the next-to-last stage (*n*=9). Here, finding x_9^* requires comparing $f_9(S_9, x_9)$ for the alternative values of x_9, namely, $x_9 = 0,1,2,3$ taken into account the budget and demand constraints in the ninth year (stage 9).

Recursive equation for that stage is:

$$f_9(S_9, x_9) = P_9(x_9) + (24 - S_9).w_9 + f_{10}^*(S_9 - x_9)$$

The solution procedure will continue to move backward till reaching the first stage (*n*=1). In this case, the only state to be considered is the state $S_1 = 24$ where the feasible solutions are x_1^* = 2 or 3 respectively.

The optimal solution which gives the number of substations to be built in each year can be known by getting the values of all x_n^* for n = 1, 2, …, 10 which are respectively: (3, 3, 3, 3, 3, 0, 3, 3, 0, 3). The results of the dynamic programming model is summarized in figure 5.

5. Comparison By Net Present Value

Managers in the Saudi Electricity Company (SEC) rely only on intuitive and naïve methods to forecast of the needed substations for the planning period. According to their idea, they plan to construct 3 electric transmission/distribution substations each year for the following 10 years. Their logic depends on the fact that 3 substations were required for each of the foregoing 4 years.

Net present value (NPV) or net present worth (NPW) [15] is defined as the total present value (PV) of a time series of cash flows. It is a standard method for using the time value of money to appraise long-term projects. Used for capital budgeting, and widely throughout economics, it measures the excess or shortfall of cash flows, in present value terms, once financing charges are met.

A future amount of money converted to its equivalent value now has a present worth (PW) that is always less than that of the actual cash flow, because for any interest rate greater than zero, all P/F factors have a value less than 1.

P = value or amount of money at a time designated as the present. Also *P* is referred to as present worth (PW), present value (PV), net present value (NPV), discounted cash flow (DCF), and capitalized cost (CC).

The net present value can be calculated using the following formula [15]:

$$P = F\left[\frac{1}{(1+i)^n}\right] \qquad \text{..................... (9)}$$

Where:

F = value or amount of money at some future time. Also *F* is called future worth (FW) and future value (FV), and

i = interest rate.

The two alternatives are evaluated over the planning horizon upon the prognosis that a reasonable Rate of Return (ROR) can be expected, this reasonable rate is called the Minimum Attractive Rate of Return (MARR), for simplicity we will consider the MARR to be equal to the interest rate expected from a safe investment that involves minimal investment risk (*i*). Figure 1 represents the steps for the economical comparison for the two alternatives using the net present value.

The NPV for the optimal schedule is calculated to be equal to 12,821millions SR (Saudi Riyals), while the NPV for the conventional schedule is 15,419 millions SR. The total NPV for the optimal schedule saves 2,598 millions SR, i.e. about 17% over the planning horizon of the next 10 years. Figures 2 and 3 represent the building and operating costs for the optimal and the traditional schedules respectively, while figure 4represents the total costs for the two alternatives.

6. Conclusions

1. A dynamic programming model has been formulated to determine the number of substations to be built in each year (from 2009 to 2018). The decision variables are the number of transmission/distribution substations to build in each year (stage) with the objective of minimizing the total cost.
2. The optimal solution is to build the following number of substations (3, 3, 3, 3, 3 0, 3, 3, 0, and 3) respectively in each year from 2009 to 2018 with total net present value of 1,282 millions SR.
3. The net present value (NPV) for the conventional schedule based on intuitive judgment is calculated to be equal to 1,542 millions SR. So, the total NPV for the optimal schedule saves 260 millions SR, i.e. about 17% over the planning horizon of the next 10 years

7. Points for Future Research

1. To generalize the solution method for other regions of the kingdom, and then to try to build a comprehensive model for the whole kingdom.
2. To build a decision support system to help the decision maker in obtaining the optimal solution for such problems.
3. This study can be used as a scientific basis for making similar decisions in planning and scheduling the basic structure stations of cities (water, electricity, wastewater, communication, etc.) depending on a scientific basis.

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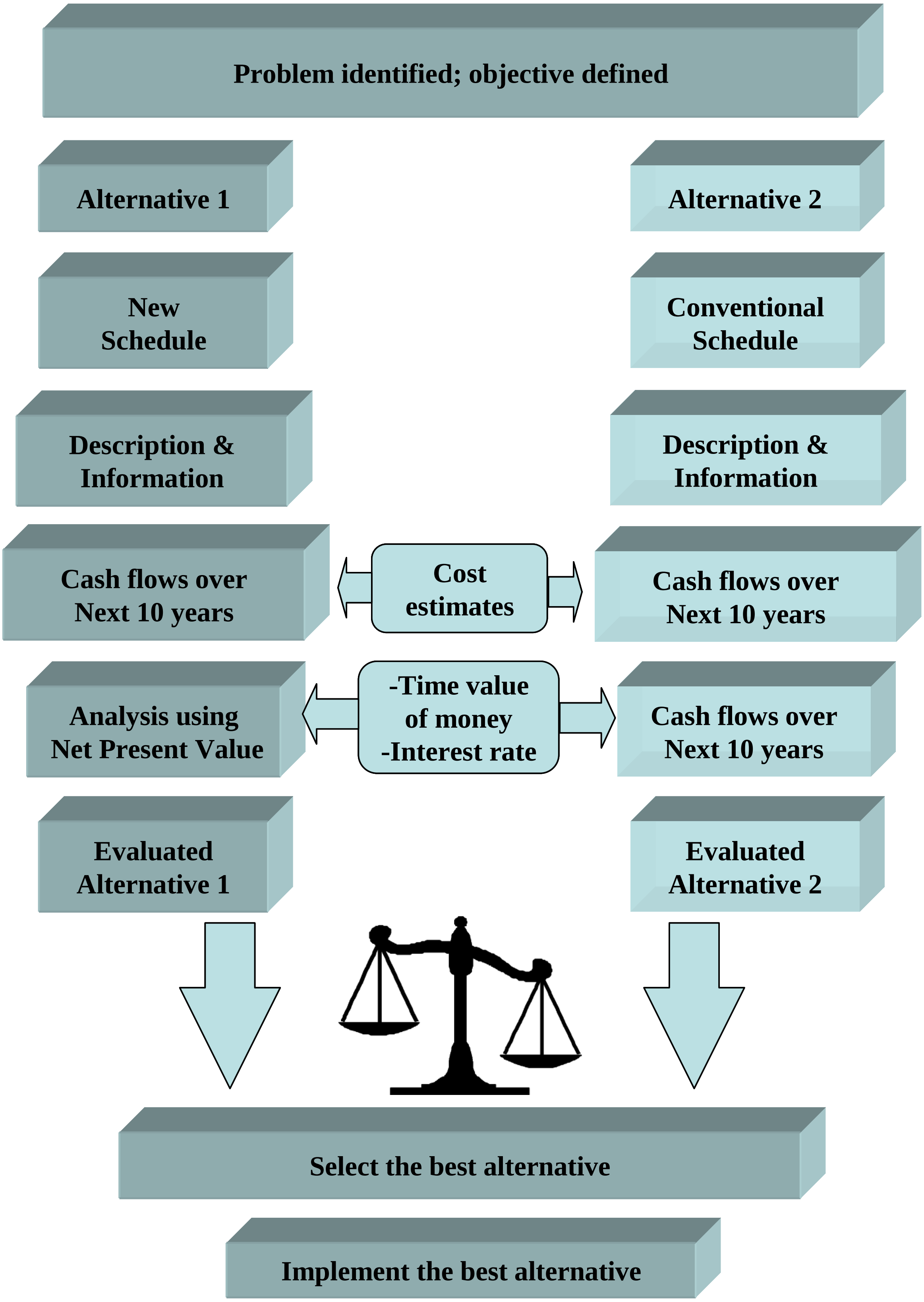

Fig. 1: Economical comparison for the two alternatives

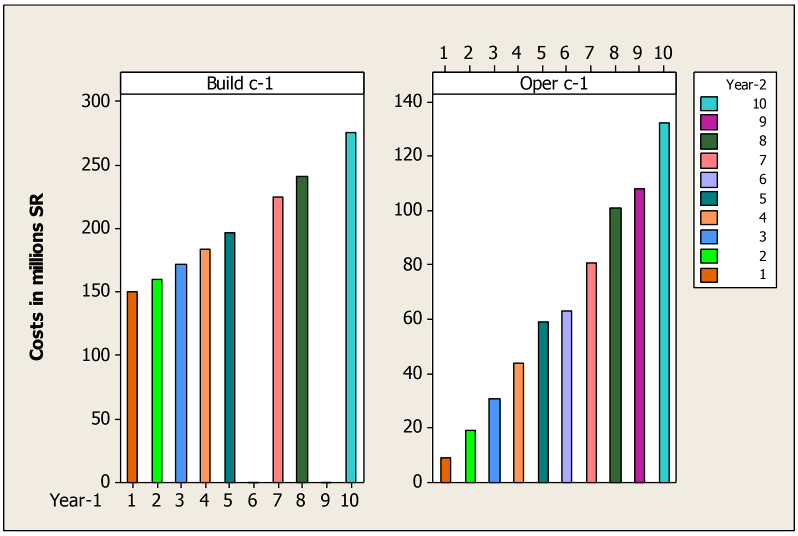

Fig. 2: Building and operating costs for the optimal schedule

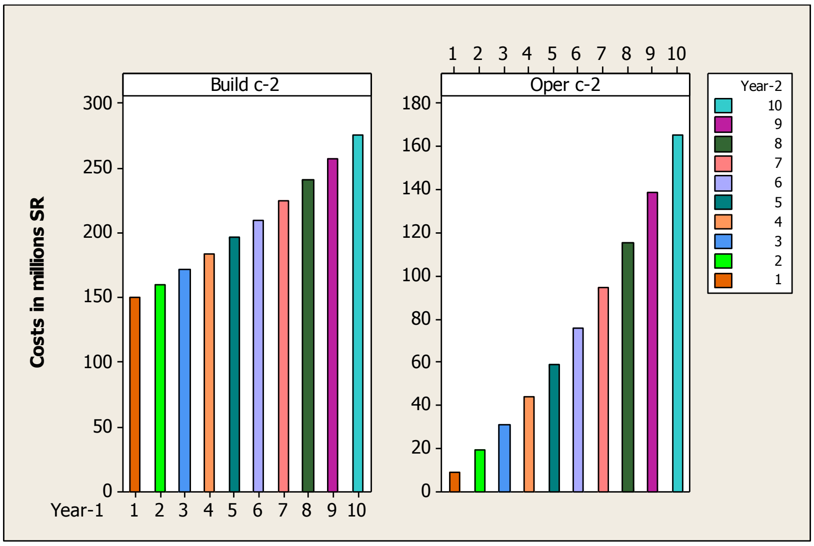

Fig. 3: Building and operating costs for the optimal schedule

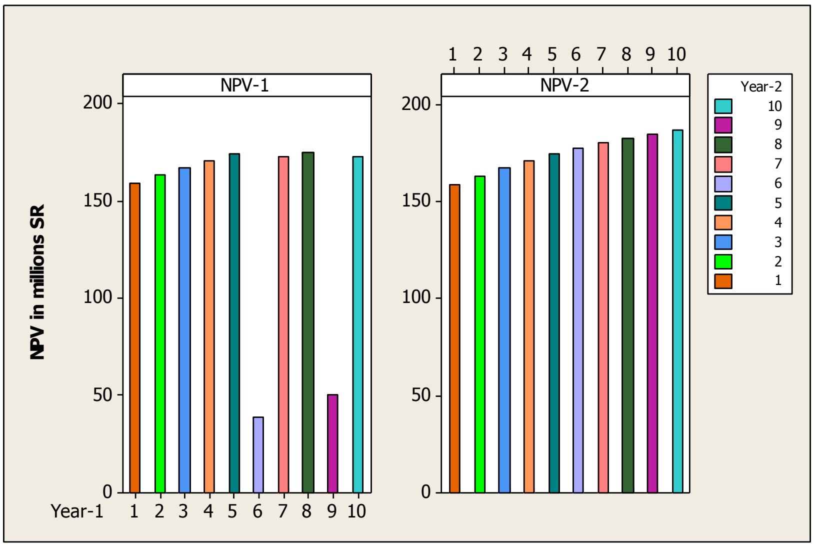

Fig. 4: Total costs for the two alternatives

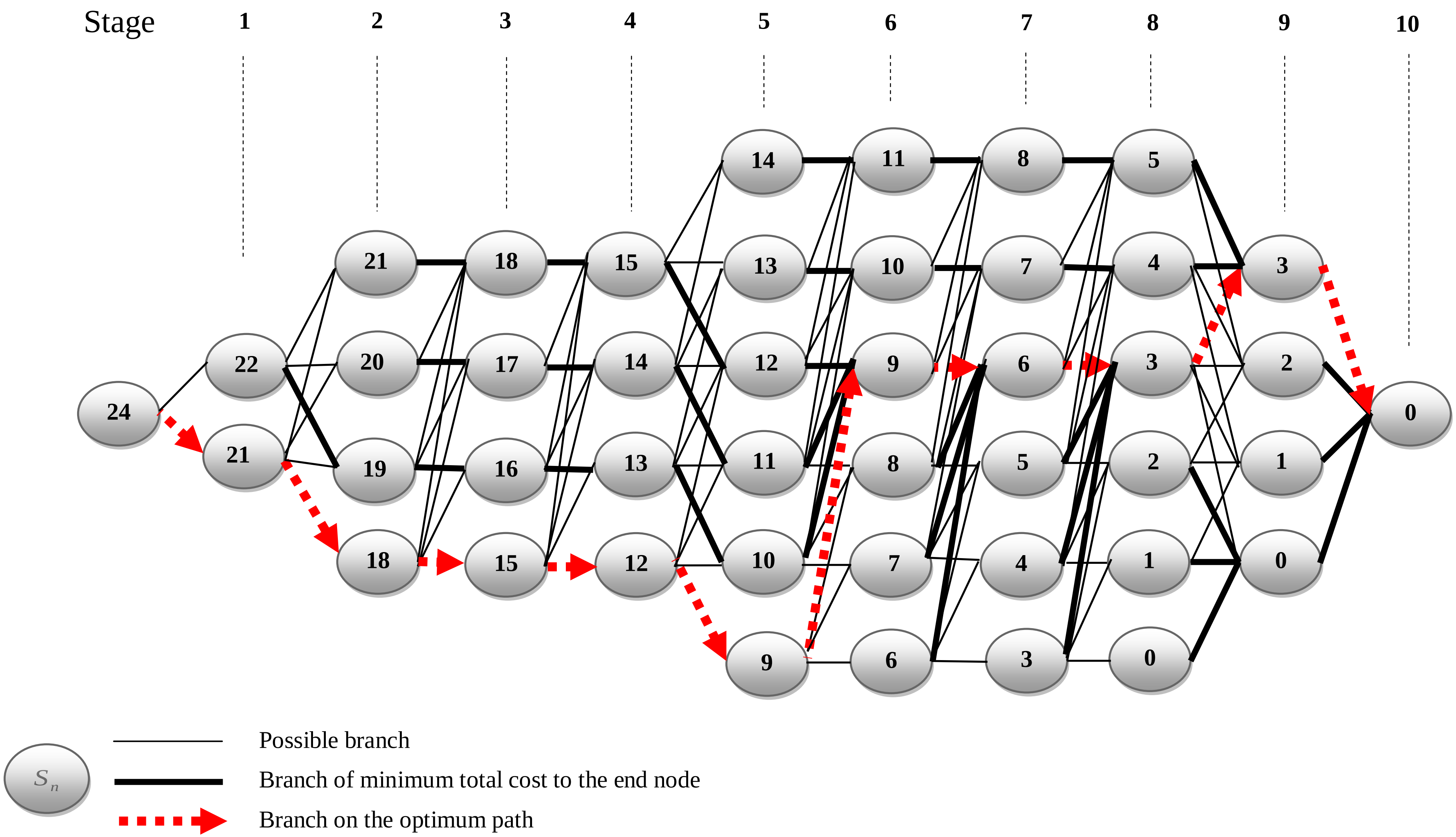

Fig. 5: Backward Network Formulation for the problem