Strategic Implementation of Infrastructure Priority Projects: Case Study in Palestine

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Abstract: A strategy was developed for implementation and management of multisector urban infrastructure projects. The strategy includes risk-based analytical hierarchy process (AHP) for project prioritization that is based on project deliverables and project life-cycle and implementation guidelines. The expert-opinion elicitation process used for this study consists of a variation of the Delphi technique, scenario analysis, civil works, and nuclear industry recommendations. The AHP methodology utilizes a multicriteria decision-making technique that allows the consideration of both objective and subjective factors in obtaining cardinal priority ranking of infrastructure projects. The methodology, which deals with different fields of infrastructure, can incorporate uncertainty in the process and can be implemented using simple spreadsheet format. The methodology was developed for a group of players (methodology implementers) involved in implementation and management of urban infrastructure projects. These include the decision makers, the stakeholders who can influence the decision and/or be affected by it, and the analysts. The methodology was demonstrated in this paper using real-life applications for effectiveness in prioritizing infrastructure projects from mixed infrastructure sectors in Palestine.

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Introduction

Urban infrastructure management includes a vast range of activities that are essential to the efficient working of city utilities and services. It can include many activities, such as provisions for water and sewage facilities, highways, transport facilities, energy distribution networks, telecommunications facilities, and other networked services. It also includes the provision of the types of social facilities regarded as essential for the maintenance of public health and welfare. The multisector nature of infrastructure management involves a variety of institutions in the process of selection, execution, and operation of projects. Decision makers involved in infrastructure management often include national and/or cabinet committees, heads of involved agencies (e.g., ministries, local government, banks, execution agencies, governmental and nongovernmental organizations, beneficiary institutions, etc.), executive directors within each of the involved agencies, planners, engineers, contractors, and others.

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The involvement of this large number of decision makers adds to the constraints in making priority decisions. In developing countries, the constraints may include inefficient institutional structures, lack of motivation, lack of sector data, and external or internal political influences. The timely completion and proper utilization of resources and operation of a project are further hampered by lack of technical and managerial experience and proper project documentation. Moreover, incomplete design and contractual documents, incorrect project cost assessment, inadequate allocation of technical and financial resources, inadequate public cooperation, and inadequate coordination among the involved parties complicate the decision situation. These factors become important constraints that require serious attention when prioritizing the projects. Kessides and Ingram (1997) reported that improvement in performance of the infrastructure has the potential to produce 50 billion U.S. dollars per year in efficiency gains for developing countries and $123 billion per year in fiscal revenue savings to these developing countries. Such amounts constitute a large fraction of the $200 billion per year developing countries currently invest in new infrastructure facilities.

This paper proposes a methodology for strategic implementation of urban infrastructure priority projects that allows the consideration of both objective and subjective factors in obtaining cardinal priority ranking of infrastructure projects. The paper starts by defining the problems and needs, followed by a presentation of the methodology, the data needs and data collection method, and ends with a real-life application of the methodology in Palestine.

Strategy for Urban Infrastructure Priority Projects

There are growing demands, especially in countries of limited resources, to provide more services with fewer resources. Governments have been responsible for managing urban infrastructure in many countries worldwide. At the moment, there is a growing belief that the provision of infrastructure needs to be conceived and run jointly with the private sector as a service industry responding to customer demand. Some vital infrastructure investment projects require high initial capital cost and long-term funding and operational management. This requires proper prioritization of needs and efficient infrastructure implementation strategy, which takes into consideration the multiple-criteria nature of the problem with its conflicting objectives (Ziara and Ayyub 1999). A strategy for prioritizing infrastructure projects should integrate the views of different parties involved in order to meet the goals of a national policy. Despite this goal, decisions related to the selection of infrastructure projects in some countries are often made in an ad-hoc fashion with little consideration of possible alternatives. Planning infrastructure projects in a nonsystematic, nonmethodical manner may result in selecting suboptimal alternatives. The level of difficulty increases to an intractable level when a large number of involved parties try to simultaneously consider all sector and subsector priorities, financing possibilities, implementation options and risks, operation and maintenance procedures, and other factors that can influence the decision. The number of decision variables becomes too large to handle, and errors or omissions may occur. To avoid such a situation, decision variables need to be considered in a systematic way that can allow for the assessment of the decision variables in accordance with their relative importance. Such a decision-making process helps governments to achieve social justice and equity under a set of financial, political, geographical, physical, economical, social, and other constraints.

The strategy described in this paper provides guidelines and a risk-based analytic hierarchy process (AHP) methodology for prioritizing infrastructure projects, which incorporates potential outcomes of projects through their respective life cycles. Underlying concepts that are needed for developing the methodology are described in subsequent sections.

Project Life Cycle

Successful selection of urban infrastructure projects must be based on full understanding of the project life cycle. The life cycle of a project may include four phases: (1) concept; (2) planning; (3) studies and documentation; and (4) performance. The concept phase begins with the initial notion of accomplishing something such as providing a school, clinic, road, water network or human development. It includes identification of relevant constraints and risks such as budget, time, use of specific tools, personnel or procedures (Walker 1996). The planning phase includes the detailed plan preparation of tasks, budget, and resource requirements to achieve the required task. The studies and documentation phase consists of literature searches, field reconnaissance, and other forms of data gathering to validate or rectify any assumptions made in the plan. If preliminary studies have indicated high risks, the previous phases must be reevaluated in relation to the project objectives (Tiong 1990; Kerf et al. 1998). The final phase in the project life cycle is the performance phase, which includes all of the efforts taken after the execution to achieve the objectives of the project.

Deliverables of Infrastructure Projects

Generally, infrastructure projects that are successfully implemented and operated provide social and economical benefits. Infrastructure projects must have a clear goal and objectives. Broadly, infrastructure projects have four deliverables (MUIM 1998): (1) achieving greater social justice; (2) developing the economy and sustainable employment; (3) developing more financially responsible programs; and (4) protecting the environment. Each is briefly discussed below.

Achieving Greater Social Justice

Social justice linked with priorities identified by the strategy result in a better quality of life to all communities. This benefit is achieved by fair distribution of available resources where population growth provides challenges for human services and needs, appropriate access to employment, facilities and services, and ensures citizen participation in the process of decision making. The development objectives should tackle problems in areas related to poor facilities and hygienic conditions, as well as areas needing economic development. Poor and marginal communities often directly benefit from good infrastructure services, because they usually live in areas subject to unsanitary conditions, hazardous emissions, and high accident risk.

Developing Economy and Sustainable Employment

Focus should be placed on investment, exports, legislation, efficient transport and communication systems, innovation, ongoing training and development of workforce, and business conditions conducive to success. In this regard, infrastructure facilities function as a catalyst for investment and enhance the sustainability of jobs.

Developing Financially Responsible Programs

Infrastructure programs should ensure sound allocation of available funds and reduce public debt and unfunded liabilities. They should foster competition, participation of the private sector, and effective management of all available resources at the microeconomic level.

Protecting the Environment

Protecting the environment should include minimizing air and noise pollution, conservation and improvement of water, minimizing waste and conserving natural resources, protecting biodiversity, and addressing climate change. Economic development should be integrated with protection of the environment by introducing regulations, public awareness programs, and incentives.

Risk-Based Analytic Hierarchy Process for Prioritization of Projects

Formal techniques are often required in situations that require documentation and justification of the decision process involving large number of conflicting objectives. A plethora of tools and techniques have been developed during the last three decades to aid decision makers in structuring their preferences and values when dealing with these problems (Mollaghasemi and Pet-Edwards 1997). These methods include prior articulation of preferences (e.g., scoring methods, utility-based methods, analytical hierarchy process, goal programming, etc.), progressive articulation of preferences to solve multiple-objective mathematical problems using iterative process, and posterior articulation of preferences. The multiple-criteria methods differ by the types of problems they are designed to solve (i.e., multiattribute versus mutiobjective), the timing of decision makers information (e.g., prior versus progressive), the type of information required from the decision maker (e.g., pairwise comparison of alternatives, lotteries, trade-offs, etc.), and the availability of supporting software. The AHP is one of the most widely used multiple-criteria

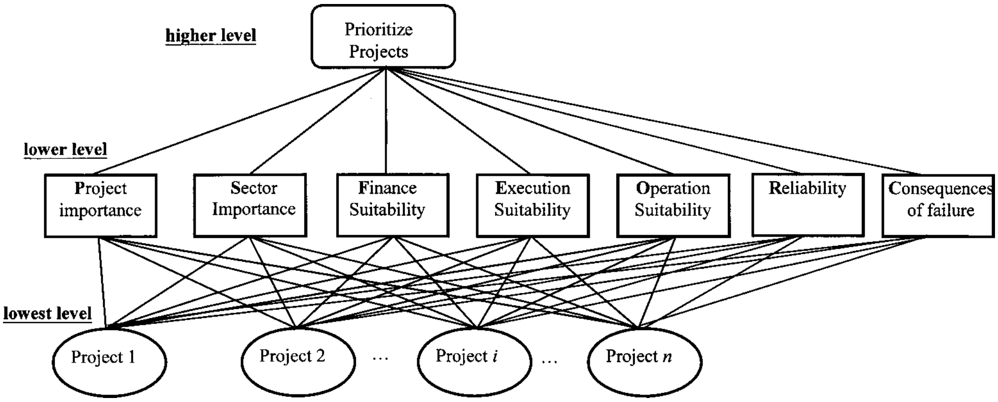

Fig. 1. Analytical hierarchy process for project prioritization

decision-making approaches. The analytic hierarchy process (AHP) model can adequately handle multicriteria decision ranking problems than other decision-tree like solutions (Ayyub and McCuen 1997). This technique allows consideration of both objective and subjective attributes, and it is the only approach for solving multiattribute decision problems that has the capability to provide a means for measuring the consistency of a decision maker's judgments (Mollaghasemi and Pet-Edwards 1997). The availability of several software packages for AHP has made it a popular technique. AHP has been used in civil engineering, including infrastructure projects (Goicoechea et al. 1982; Muralidhar et al. 1990; Mustafa and Al-Bahar 1991; Eder et al. 1997; Shen et al. 1998; Alhazmi and McCaffer 2000; Rotmans and Vanasselt 2000; Carlos and Costa 2001). However, most of these applications have been confined to one sector or one project type, e.g., projects selection (Muralidhar et al. 1990; Eder et al. 1997), prioritization of maintenance schedules (Shen et al. 1998), and assessment of projects (Mustafa and Al-Bahar 1991; Alhazmi and McCaffer 2000). Ayyub and Popescu (2000) recently suggested and applied the AHP method to prioritizing urban infrastructure projects.

A risk-based methodology based on the AHP is proposed in this paper for prioritizing infrastructure projects. The methodology deals with different fields of infrastructure and has been applied to real-life applications. Moreover, the methodology can incorporate uncertainty in the process. The methodology was developed for a group of players (methodology implementers) involved in decision situation related to implementation and management of urban infrastructure projects. Potential users include managers who have the authority to make a decision, the stakeholders in a decision problem who can influence the decision and/or be affected by it, and the analysts who synthesize the subjective and objective inputs of the decision makers and stakeholders into a meaningful outputs that aid in prioritizing urban infrastructure projects.

An AHP-based model for project prioritization requires a hierarchy structure to represent the decision situation, as well as pairwise comparisons to establish preference relations within this structure. These comparisons lead to dominance matrices. The AHP has four major steps as described in the subsequent sections. The discussions of these four steps are based on the aforementioned case study as an example.

Step 1. Decomposition of Problem Into Hierarchy

The project prioritization problem is decomposed into a three-level (higher, lower, and lowest) hierarchy structure that captures important elements as shown in Fig. 1. The elements of the higher level are more general goals and objectives. In the case study, the main objective is to identify urban infrastructure projects for prioritization.

The elements of the lower level are the multiple objectives or criteria. Seven multiple criteria or objectives, as described after the four steps, have been used in the case study.

The elements of the lowest level are the alternatives, i.e., the candidate projects from mixed infrastructure sectors. A preliminary estimate of the costs can be determined for each identified project. Unfortunately, countries of limited resources such as Palestine cannot respond to all of the identified sector development infrastructure projects in spite of their importance. In this case, the developed methodology allows a cardinal ranking of the projects under the multiple objectives.

Step 2. Pair-Wise Comparison of Criteria

The pair-wise comparisons of the criteria at the lower level in the hierarchy are arranged into a reciprocal matrix in this step (Saaty 1980, 1996). The pair-wise comparison of the criteria in the AHP method generates a set of matrices of the following form:

$$\tilde{\mathbf{A}}=(a_{ij}) \qquad (1)$$

where $\tilde{\mathbf{A}}$=reciprocal matrix $(a_{ij}=1/a_{ji})$. The priority vector $\mathbf{w}$ can be calculated by solving the following eigenvalue problem (Ayyub and McCuen 1996):

$$\tilde{\mathbf{A}}\mathbf{w}=\lambda_{\max}\mathbf{w} \qquad (2)$$

where $\lambda_{\max}$=eigenvalue. One important parameter that needs to be considered is the inconsistency index given by

$$\mathrm{ICI}=\frac{\lambda_{\max}-n}{(n-1)(\mathrm{R.I.})} \qquad (3)$$

where n=number of criteria considered; and R.I.=random index that depends on matrix size. The random index is equal to 1.32 and 1.49 for 7×7 and 10×10 matrices, respectively (Saaty 1980). If the inconsistency index is less than 0.1, then the judgements are considered satisfactory (Saaty 1996).

Step 3. Pair-wise Comparison of Candidate Projects

The pair-wise comparisons of the candidate projects on the lowest level of Fig. 1 are performed in this step. The corresponding priority vector and inconsistency indices are obtained using the same analytical procedures described in step 2.

If data are lacking, the aforementioned aspects of the project life cycle and project deliverables can be considered in an expert-opinion elicitation process. A methodology implementer should compare criteria pair-wise according to Step 2, and also pair-wise compare candidate projects based on each criterion according to Step 3 based on full understanding of the four phases of the project life cycle. The ''methodology implementer'' should also account for the socioeconomic and political objectives stated in the project deliverables.

Step 4. Synthesis of Priority Projects

The last step is to apply the principle of composition priorities to obtain a cardinal ranking of infrastructure projects (Saaty 1980; Saaty 1996).

Multiple Criteria or Objectives

It is recognized that different criteria have different levels of importance. For example, a project's importance to a sector may have more weight than its ease of operation. The higher weight in this case may be attributed to a decision maker's willingness to develop appropriate measures to facilitate project operation as a result of the project's importance to the sector.

Appropriate multiple criteria or objectives may vary from one country to another depending on the prevailing socioeconomic conditions and the required deliverable or benefits for that country. Nevertheless, the following seven criteria have been identified in the case study to allow for the inclusion of more specific subobjectives. Depending on the locale, some of these criteria may be ignored or other objectives may be added to meet the special needs of each country. The methodology can, therefore, be adopted for prioritizing urban infrastructure projects in different countries. The effectiveness and utility of the method become more evident in cases of limited resources such as in Palestine.

Criterion 1: Project Importance (P)

Candidate projects are normally identified not only because of their importance to the development of the country within the relevant sectors but also for their added values to the country's economy. In reality, the list of projects is influenced by the political or economic emergency situations. In the case of inadequate available resources, the methodology considers a relative importance of the project as one of the criteria influencing project prioritization.

Criterion 2: Sector Importance (S)

National development plans normally identify priority sectors to meet specified investment objectives. For example, education could be considered more important than tourism, if severely overcrowded classes, high illiteracy, and multishifts in schools exist.

Criterion 3: Finance Suitability (F)

Financing of projects may become difficult, even if budgets were initially envisaged to be available. The finance conditions and availability of funds differ from one project to another. This depends on the nature of project, e.g., low-cost, labor-intensive projects may face less financial difficulties in high unemployment locations. Ineffective cost and time management, political influence, sudden economic depression, collapse of financial markets all have severe financial implications that have to be considered in prioritizing the projects, as they add unaffordable risks.

Criterion 4: Execution Suitability (E)

Execution of selected projects may face difficulties in spite of the care that has been taken in their preparation. The degree of execution suitability varies among different projects as well. This variation depends on the nature of projects (e.g., execution of high-tech projects in developing countries could be more difficult than the construction of a road a school), availability of relevant technical and managerial experience, project cost and cash flow availability, political influence, public desirability, etc. In extreme cases, completion of projects could be endangered or severely delayed because of execution difficulties. Some of these difficulties may be beyond the control of the implementing agency. Therefore, the selection of priority projects cannot be based only on their level of importance. A project can be of great importance and still not be considered high priority if its execution may pose a great risk. Therefore, the suitability of execution conditions must also be considered when deciding on the priority of projects to ensure that selected projects are not only important but also feasible.

Criterion 5: Operation Suitability (O)

Experience has shown even important projects that have been properly executed can be inefficiently used or even remain unused. The operation suitability reflects the need of a continuous supply of raw materials, sophisticated technical experience and/or a large operational budget, lack of maintenance (due to technical or financial reasons), environmental impact (e.g., noise and pollution), etc. Similar to execution conditions, the degree of operation suitability varies among different projects. This criterion ensures that priority projects are not only important and practical for execution but also operable and maintainable efficiently during the life span of the project.

Criterion 6: Reliability (R)

The decision analysis includes the introduction and identification of involved uncertainties due to the ambiguity and vagueness in defining the involved decision parameters and their interrelationships (Ayyub 1994). The ambiguity component reflects noncognitive sources, which include physical randomness, statistical uncertainty due to the use of limited information to estimate the characteristics of these parameters, and uncertainties due to simplifying assumptions. The vagueness related uncertainty is due to cognitive sources, such as definition of certain parameters, quality, deterioration, experience of people, human factors, and defining interrelationship of parameters (Gruhn 1991). To account for the presence of uncertainties, the outcomes of the decision model need also to be defined. The decision outcomes are the events that can happen as a result of a decision. They are random in nature, and their occurrence cannot be fully controlled by the decision maker. Decision outcomes depend on project and sector importance and are affected by location, the influence of political and natural events, unplanned financing terms, execution conditions, which do not meet planned time schedule, or operational conditions, which do not meet adopted plans. In the case study, the methodology is demonstrated with the reliability factor consid-

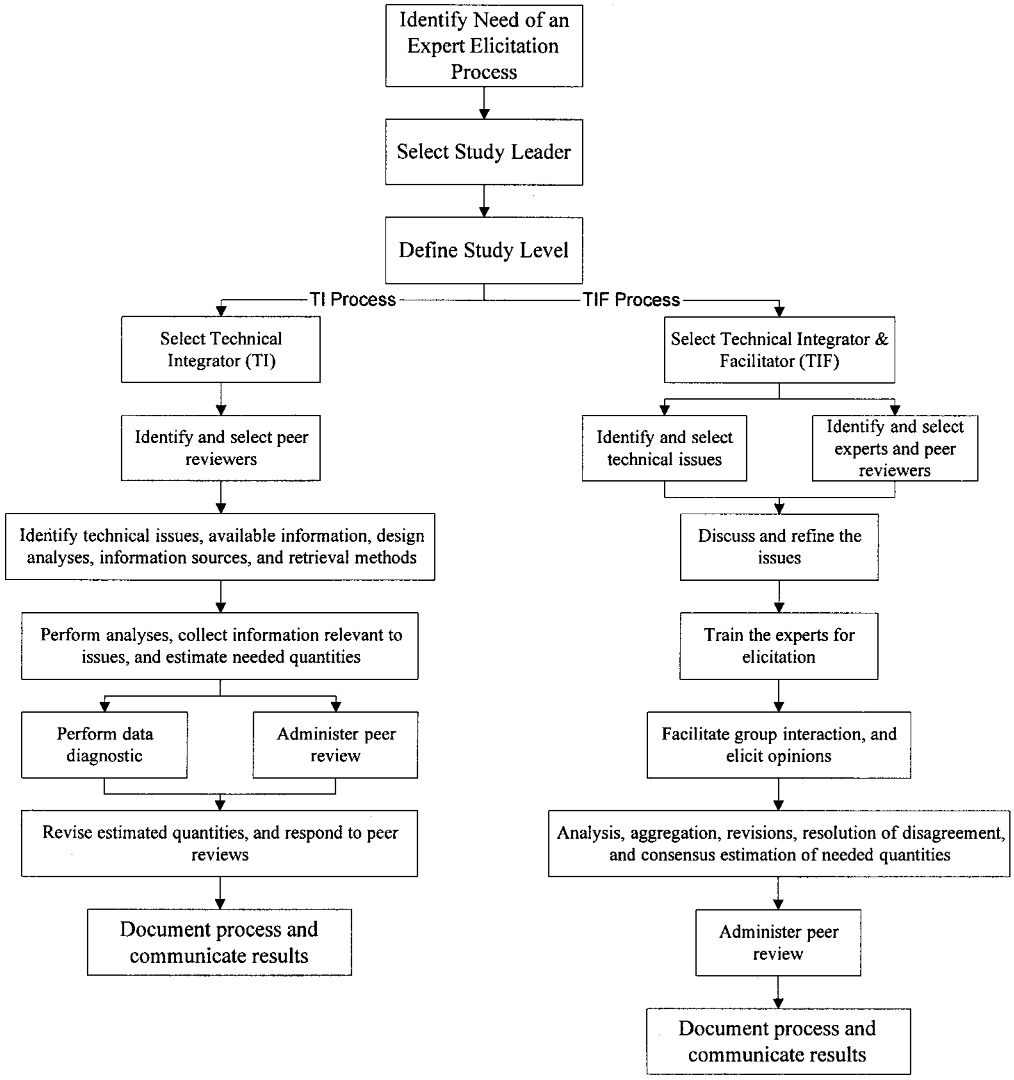

Fig. 2. Expert-opinion elicitation process

ered as a criterion influencing project prioritization based on its failure rates and associated maintenance and repair requirements.

Criterion 7: Consequence of Failure (C)

The consequence of failure varies from one project to another. The consequences in this context may include the adverse effects of failure, such as, the cost of deviating from planned targets. The methodology developed in this paper considers the expected consequence of failure factor as another criterion in the AHP, as shown in Fig. 1.

Expert-Opinion Elicitation

Expert-opinion elicitation (EE) is a heuristic process of gathering data or answers to the questions on issues or problems of concern, such as unsatisfactory performance rates, unsatisfactory performance consequences, and expected service life. EE should not be used in lieu of rigorous reliability and risk analysis but should be used to supplement them and to prepare for them. The EE process used for this study follows what Ayyub (2001) suggested, which consists of a variation of the Delphi technique (Helmer 1968a,b), scenario analysis (Kahn and Wiener 1967), and civil works and nuclear industry recommendations (NRC 1997).

EE can be formally performed following the steps provided in Fig. 2 (Ayyub 2001). Experts can be classified into five types: (1) proponents; (2) evaluators; (3) resource experts; (4) observers; and (5) peer reviewers. A proponent is an expert who advocates a particular hypothesis or technical position. In the sciences, a proponent evaluates experimental data and professionally offers a hypothesis that is challenged by the proponent's peers until proven correct or wrong. An evaluator is an expert who has the role of evaluating the relative credibility and plausibility of multiple hypotheses to explain observations. An evaluator considers available data, becomes familiar with the views of proponents and other evaluators, questions the technical bases of data, and challenges the views of proponents. A resource expert is a technical expert with detailed and deep knowledge of particular data, issue aspects, particular methodologies, or use of evaluators. An observer can contribute to the discussion but cannot provide expert opinion that enters in the aggregated opinion of the experts. A peer reviewer is an expert that can provide an unbiased assessment and critical review of an EE process, its technical issues, and results. EE involves a technical integrator (TI) or a technical

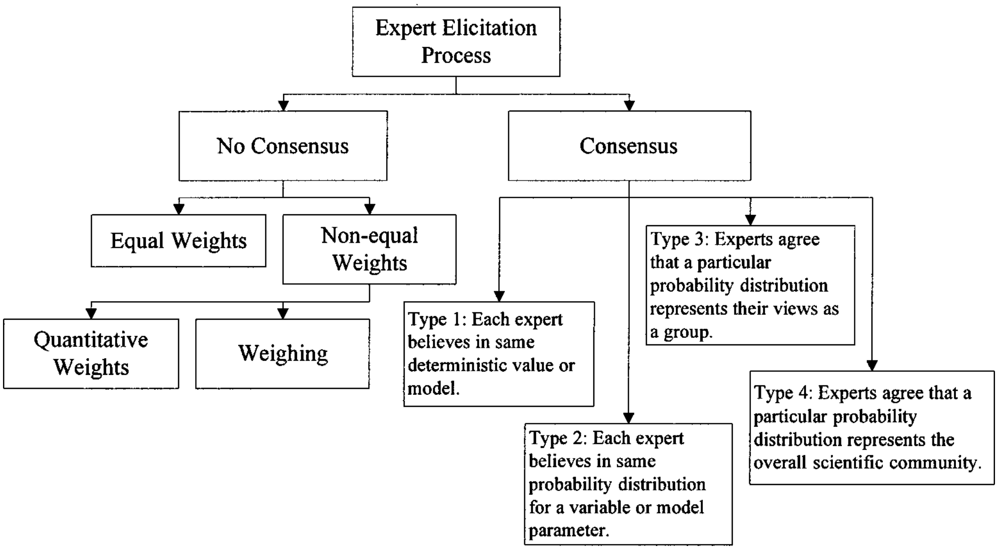

Fig. 3. Outcomes of expert-opinion elicitation process

integrator and facilitator (TIF). A TI can be a person or a team (an entity) who is responsible for developing a composite representation of issues based on the opinions of informed members and/or sources of related technical communities and experts, explains and defends composite results to experts and outside experts, peer reviewers, regulators, and policy makers, and obtains feedback and revises composite results. A TIF can be a person or a team (an entity) who is responsible for the functions of a TI as described above, structures and facilitates the discussions and interactions of experts in the EE process, stages effective interactions among experts, ensures equity in presented views, elicits formal evaluations from each expert, and creates conditions for direct, noncontroversial integration of expert opinions. The primary difference between the TI and the TIF is in the intellectual responsibility. The TIF has the added responsibility of maintaining the professional integrity of the process and its implementation.

The EE process should preferably be conducted to include a face-to-face meeting of experts. In advance of this meeting, background information, objectives, list of issues, and anticipated outcome from the meeting should be sent to the experts. The meeting of the experts should be conducted after communicating this information to them. The EE that is based on using a TIF results in consensus or no consensus, as shown in Fig. 3 (Ayyub 2001). The case study discussed in this paper used this TIF process.

Case Study in Palestine

Background

To examine the effectiveness of the proposed methodology, a case study was conducted in which a selection of projects in Palestine was made. Previous infrastructure projects in Palestine have been implemented and financed by the International Development Agency (IDA) of the World Bank. The list of projects under investigation is to be proposed for financing and/or appropriation. It is expected that limited funds will become available, sufficient to cover only 50% of the requested amount. The potential financiers for the projects are a group of donor countries and the World Bank. The information relating to the properties of the individual projects were gathered from relevant appraisal and needs assessment reports. The data used in this case study are for demonstration purposes. The results of the case study are presented in the subsequent sections, after a brief account of the country and the environment.

Fig. 4 shows the current Gaza and West Bank populated areas. The entire area of Palestine is approximately 27,000 km^2. In addition to political uncertainty, businesses suffer from confusing commercial legislation and a lack of public sector regulatory in-

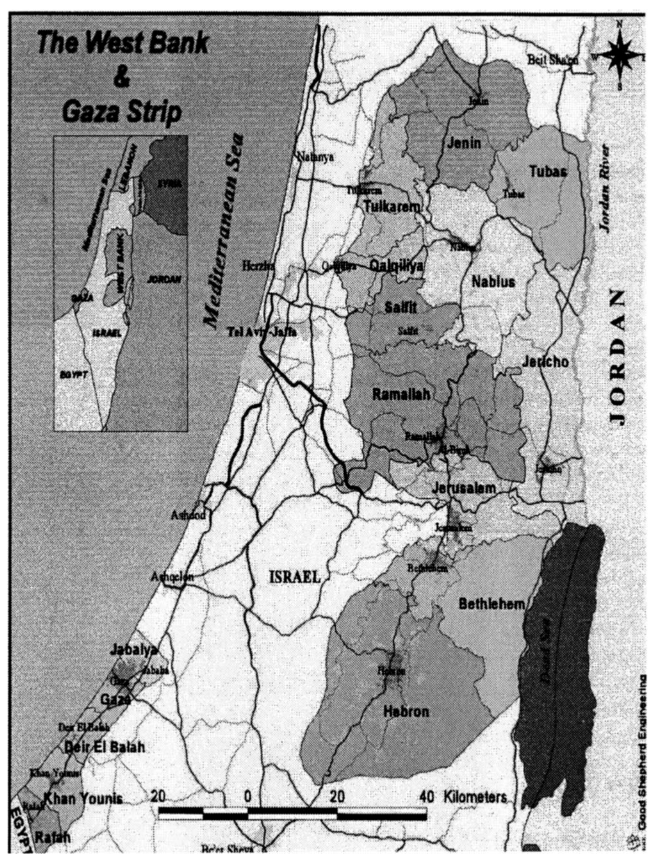

Fig. 4. Map of historic Palestine

Table 1. Criteria Pair-wise Comparison Reciprocal Matrix

Criteria	Project importance	Sector importance	Finance suitability	Execution suitability	Operation suitability	Reliability	Consequence of failure	Priority
Project importance	1.00	0.20	1.00	3.00	3.00	1.00	1.00	0.18
Sector importance	5.00	1.00	3.00	1.00	3.00	1.00	1.00	0.16
Finance suitability	1.00	0.33	1.00	5.00	1.00	0.20	5.00	0.16
Execution suitability	0.33	1.00	0.20	1.00	0.33	0.33	1.00	0.14
Operation suitability	0.33	0.33	1.00	3.00	1.00	1.00	1.00	0.14
Reliability	1.00	1.00	5.00	3.00	1.00	1.00	1.00	0.12
Consequence of failure	1.00	1.00	0.20	1.00	1.00	1.00	1.00	0.10

stitutions. Access to essential services is relatively good, compared with other developing countries; 84.1% of households have piped water supply. However, only 57% of rural communities have a 24-h electricity supply and only 35% of households are connected to sewage networks. Movement of people and goods is critical for a small economic block to tap international trade and investment; hence, physical infrastructure is essential to expedite economic development.

In October 1993, after the Oslo agreement, the World Bank and many donor countries committed financial and technical support to the Palestinian National Authority. The bulk of the donated funds were to be administrated by the Palestinian Economic Council for Reconstruction and Development (PECDAR). PECDAR local experts, along with assistance from several international consultants, started to draw emergency rehabilitation plans to revive the deteriorated condition of its infrastructure.

Study Method

Projects are identified within each sector based on data, obtained from sector needs diagnoses studies. In the education sector, for example, technical and planning department of the Ministry of Education identifies the number, size, type, and geographical distribution of new schools (set of projects needed in a specified period of time). The planning department identifies, also, the needs of human development and curriculum upgrading (a second set of projects) to match the physical development needs related to schools. Other sectors (e.g., health, transportation, communication, and water departments) also identify their physical and human development needs (or projects). Departments might also identify several other projects for emergency rehabilitation. The risk-based AHP methodology permits the systematic consideration of projects leading to a better use of funds, resulting in confidence building with donor countries that could lead to attracting additional funds.

Table 1 presents the criteria established for the study case with their pairwise comparisons and resulting priority. Table 2 shows the 10 candidate projects considered in the case study. The first letter of the project code indicates the area in which the projects will be implemented (e.g., the letter G stands for Gaza strip areas and W for West bank areas). The second and or third letter refers to the sector identification (e.g., E for the construction of classrooms, C for general construction works, H for the construction

Table 2. Case Study Projects

Number	Project code	Project description	Duration time (weeks)	Number of beneficiaries (direct & indirect)	Cost (U.S. dollars)
1	GC09	Upgrading a municipal center	12	82,000	180,000
2	GRH350	Roads improvement for historical places	24	230,000	400,000
3	GRR05	Municipal roads rehabilitation	24	450,000	750,000
4	GRS07	Roads rehabilitation and sewage network	48	260,000	600,000
5	GRW13	Roads improvement and water networks	24	340,000	380,000
6	WE15	Education, construction of classrooms	36	17,000	600,000
7	WE55	Education, construction of classrooms	36	27,000	420,000
8	WH03	Health, construction of primary care clinics	36	28,000	230,000
9	WH08	Health, construction of primary care clinics	36	38,000	430,000
10	WRD22	Roads development	12	32,000	340,000

Note: Project code: First letter=location: G=Gaza; W=West Bank. Second letter or second and third letters=sector ID: C=city center; E=education; H=Health; RD=roads development; RH=roads for historical places; RR=road rehabilitation; RS=road and sewer networks; and RW=roads and water networks. Number=project serial number.

Table 3. Pair-wise Comparison for Projects with Respect to Project Importance, Criterion 1

Project	GC09	GRH350	GRR05	GRS07	GRW13	WE15	WE55	WH03	WH08	WRD22	Priority vector
GC09	1.00	0.80	0.80	2.00	0.57	0.44	0.44	0.50	2.00	1.00	0.090
GRH350	1.25	1.00	1.00	0.63	0.71	0.56	0.56	0.63	0.63	1.00	0.073
GRR05	1.25	1.00	1.00	0.63	0.71	0.56	0.56	0.63	0.63	1.00	0.073
GRS07	0.50	1.60	1.60	1.00	1.14	0.89	0.89	1.00	1.00	1.60	0.106
GRW13	1.75	1.40	1.40	0.88	1.00	0.78	0.78	0.88	0.88	1.40	0.102
WE15	2.25	1.80	1.80	1.13	1.29	1.00	1.00	1.13	1.13	1.80	0.131
WE55	2.25	1.80	1.80	1.13	1.29	1.00	1.00	1.13	1.13	1.80	0.131
WH03	2.00	1.60	1.60	1.00	1.14	0.89	0.89	1.00	1.00	1.60	0.117
WH08	0.50	1.60	1.60	1.00	1.14	0.89	0.89	1.00	1.00	1.60	0.106
WRD22	1.00	1.00	1.00	0.63	0.71	0.56	0.56	0.63	0.63	1.00	0.071

Note: Project code: First letter=location: G=Gaza; W=West Bank. Second letter or second and third letters=sector ID: C=city center; E=education; H=Health; RD=roads development; RH=roads for historical places; RR=road rehabilitation; RS=road and sewer networks; and RW=roads and water networks. Number=project serial number.

of clinics, R for roads including pavements works, W for water networks, etc.). The numerical figures in the project-code column are the serial numbers for the projects.

The following procedure illustrates the use of the risk-based AHP by PECDAR to manage and select projects:

1. The projects are identified and submitted to PECDAR by various agencies, including Ministries of Education, Health, and Public Works. Municipalities and other local governments submit some of the projects directly to PECDAR.
2. The projects are then screened by PECDAR for conformity to the National Development Plan (Infrastructure Sector Policy for unfunded projects), which has been approved by the Ministry Council. Successful projects at this stage are called "candidate projects."
3. Candidate projects are submitted to the World Bank for possible funding. In the case study, the proposed methodology was applied to prioritize candidate projects.
4. The director of projects at PECDAR, two senior PECDAR staff and a university academician (the methodology implementer) have jointly performed the pair-wise comparisons for the candidate projects of the case study and documented the results in spreadsheets. Also, they acted as the experts in the expert-opinion elicitation process in cases where data were lacking. Senior staff members from PECDAR and the World Bank were regularly consulted on the details of each project. In addition, project appraisal sheets, including all the details of each project, were submitted by various agencies in accordance with PECDAR regulations. These sheets included necessary information of each project, such as objective, justification, cost, beneficiaries, bottlenecks, risk evaluation, time for execution, etc. Table 2 includes some necessary information related to each project. Criteria matrices could be used for each of the seven criteria to determine the values of the pair-wise comparison given by each of the experts. An average value could then be computed. For the purposes of the case study, a simpler procedure was adopted for the pair-wise comparisons for the criteria by using the national development plans in which the relative importance of each sector was identified. The pair-wise comparison of the projects with respect to each criterion was made after all the relevant information for each project was thoroughly discussed jointly by the experts.
5. The pair-wise comparisons were revised each time the inconsistency index (ICI) number was not satisfactory, and the outcomes were reevaluated.

Results

The four steps of the methodology were performed in the case study as shown below:

1. The project prioritization problem was decomposed into the three-level hierarchy shown in Fig. 1. The higher level is the main objective that is to identify urban infrastructure priority projects. The elements of the lower level are the 7 multiple criteria identified for the case study. The elements of the lowest level are the 10 candidate projects selected from mixed infrastructure sectors in accordance with the procedure explained in the "Study Method" Section.
2. Table 1 includes the reciprocal matrix of the pair-wise comparison of the 7 criteria included at the lower level in the hierarchy in Fig. 1 as determined by the "methodology implementer". The last column in the table represents the relative priority of the criteria. In this case, the sector importance criterion has the highest priority, and the execution suitability criterion has the lowest priority. The resulting ICI calculated using Eq. (3) for the seven criteria is 0.0038, which is much less than 0.1, indicating satisfactory assessments of pair-wise comparisons.
3. Step 3 results in seven 10×10 matrices of judgments, because there are 7 criteria on the lower level in the hierarchy, and 10 projects on the lowest level to be compared with respect to each criteria. However, for convenience only one pair-wise comparison matrix has been shown in Table 3 for the 10 candidate projects with respect to one of the 7 criteria considered, i.e., project importance Criterion 1. The last column in the table represents the priority vector for the projects with respect to this criterion. The priority vectors resulted from pair-wise comparison for the projects with respect to each of the 7 criteria shown in Table 4. The eigenvalues for the P, S, F, E, O, R, and C criteria were calculated using Eq. (3) which resulted in ICIs of 0.021, 0.000258, 0.082, 0.062, 0.005206, 0.003488, and 0.095, respectively. The ICIs are satisfactory, because each one is less than 0.1, indicating that the considered elicitation process was very effective.
4. Table 5 includes the composite global priorities of the projects. The global priorities were obtained by multiplying each column in the project local priority matrix by the priority of the corresponding criterion and adding across the

Table 4. Priority Vectors of Pair-wise Comparison for Projects with Respect to Each Criterion

Project	Project importance	Sector importance	Finance suitability	Execution suitability	Operation suitability	Reliability	Consequence of failure
GC09	0.090	0.044	0.013	0.167	0.124	0.121	0.054
GRH350	0.073	0.060	0.018	0.050	0.105	0.107	0.077
GRR05	0.073	0.076	0.029	0.072	0.096	0.097	0.101
GRS07	0.106	0.119	0.095	0.034	0.082	0.080	0.240
GRW13	0.102	0.095	0.164	0.038	0.082	0.079	0.181
WE15	0.131	0.134	0.148	0.147	0.111	0.111	0.036
WE55	0.131	0.134	0.148	0.147	0.111	0.109	0.036
WH03	0.117	0.134	0.177	0.147	0.097	0.099	0.036
WH08	0.106	0.134	0.177	0.147	0.097	0.100	0.034
WRD22	0.071	0.075	0.031	0.053	0.097	0.097	0.206

Note: Project code: First letter=location: G=Gaza; W=West Bank. Second letter or second and third letters=sector ID: C=city center; E=education; H=Health; RD=roads development; RH=roads for historical places; RR=road rehabilitation; RS=road and sewer networks; and RW=roads and water networks. Number=project serial number.

rows. In this case, the cardinal ranking of the projects were WE15, WE55, WH03, WH08, GRW13, GRS07, GC09, WRD22, GRR05, and GRH350.

The selected projects from mixed infrastructure were prioritized in a transparent way and, therefore, were accepted by the involved agencies despite the complexity of the decision situation. This demonstrates the effectiveness of the risk-based AHP methodology proposed in this paper.

The application of the risk-based AHP methodology to a large number of infrastructure projects from different sectors may prove to have some limitations. The pair-wise comparison could become tedious when a many projects are involved. However, for the type of decisions involved and for the purposes of the case study, it was appropriate. By automating the calculations, the process could easily handle 10 projects with 7 criteria, as was demonstrated in the case study. The methodology can be used for a larger number of projects and criteria by performing an initial filtering to develop a short list of project that can then be fed to the riskbased AHP process.

Conclusions

This paper builds a strategy that includes an effective risk-based AHP methodology for implementation of priority urban infrastructure projects. The proposed methodology uses expert-opinion elicitation for obtaining pair-wise comparison and accounts for uncertainties that may exist in the decision-making process, including socioeconomic factors. The methodology incorporates project life cycles, reliability, and failure consequences in the multiple-criteria decision-ranking analysis, which was used to identify projects that would optimally meet the economic needs of residents and human welfare.

The developed strategy was applied to a real world example in Palestine to demonstrate the effectiveness of the AHP methodology and EE process in a complex prioritization process. The projects considered in the case study were from different areas of infrastructure, such as roads, schools, community centers, etc. General objectives for prioritizing infrastructure projects were presented for use in the case study, but the methodology can

Table 5. Composite Global Priorities

Criteria or Project	Project importance	Sector importance	Finance suitability	Execution suitability	Operation suitability	Reliability	Consequence of failure	Composite priority vector
				Criteria Priorities				
	0.18	0.16	0.16	0.14	0.14	0.12	0.10	
				Project Local Priorities				
GC09	0.090	0.044	0.013	0.167	0.124	0.121	0.054	0.086
GRH350	0.073	0.060	0.018	0.050	0.105	0.107	0.077	0.068
GRR05	0.073	0.076	0.029	0.072	0.096	0.097	0.101	0.075
GRS07	0.106	0.119	0.095	0.034	0.082	0.080	0.240	0.103
GRW13	0.102	0.095	0.164	0.038	0.082	0.079	0.181	0.103
WE15	0.131	0.134	0.148	0.147	0.111	0.111	0.036	0.122
WE55	0.131	0.134	0.148	0.147	0.111	0.109	0.036	0.122
WH03	0.117	0.134	0.177	0.147	0.097	0.099	0.036	0.1203
WH08	0.106	0.134	0.177	0.147	0.097	0.100	0.034	0.118
WRD22	0.071	0.075	0.031	0.053	0.097	0.097	0.206	0.083

Note: Project code: First letter=location: G=Gaza; W=West Bank. Second letter or second and third letters=sector ID: C=city center; E=education; H=Health; RD=roads development; RH=roads for historical places; RR=road rehabilitation; RS=road and sewer networks; and RW=roads and water networks. Number=project serial number.

accommodate other objectives to suit specific conditions. The methodology can, therefore, be used for prioritizing urban infrastructure projects in other countries, where its effectiveness and utility could become more evident in cases of limited resources.

The case study showed that it was possible to obtain cardinal priority ranking of projects from mixed infrastructure sectors in a transparent way, despite the complexity of the decision situation. The main institutions involved accepted the prioritized projects, despite the disparity of the sectors. Therefore, it is concluded that the implementation of the AHP methodology was able to effectively assist the decision makers to prioritize projects objectively in a multicriteria decision-making environment.

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