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Distributed priority ranking of strategic preliminary requirements for management information systems in economic organizations ☆

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Abstract

The development and construction of a management information system (MIS) is a complex task. Selection of the correct requirements to be implemented in the MIS is a serious problem. The problem is made even more difficult by inadequate methods of requirements priority ranking. This paper describes instruments for distributed priority ranking of strategic preliminary requirements for MISs in organizations, profit-making or non-profit making, that are involved in the economy. The instrument consists of a metamethod that combines several methods, each accomplishing a different subtask of the priority ranking. A Web-based tool is provided to assist the requirements engineers in applying the instrument with a distributed group of stakeholders. The instrument and the tool are validated as effective by their use in an effort to create requirements for the management information system for city government. The paper reports lessons learned in this validation exercise.

Keywords: Analytical hierarchy process (AHP); Balanced Scorecard planes; Borda Scoring; Economic organization; FocalPoint; Management information system (MIS); Preliminary requirements; Priority ranking; Requirements engineering (RE); Stakeholder; Strategy; Technique for order preference by similarity to the ideal solution (TOPSIS); Web-based application; Weighted sum model (WSM)

1. Introduction

1.1. Organizational strategy and ranking MIS requirements

Adapting an organization's management systems, structure, and culture to rapidly changing requirements of the external environment is becoming more and more critical for organizations bound to the economy. This criticality is even more pronounced when the organization uses the Internet for interaction with its members and customers.

Strategic change, a particular kind of change taking place in a business organization, is defined as "a major modification of the organization's strategy, structure, or technique in order that it function better in the future" [3,51,61]. Strategy constitutes one of the fundamental instruments for managing an organization. The success of many an organization can be traced back to a properly developed and implemented strategy, while just as many a failure can be traced back to errors in strategy. Requirements for an organization should therefore be tuned to strategic goals.

Any modification of an organization's goals requires that its management information system (MIS) deliver information that it did not deliver before. Therefore, the selection of an MIS must be placed in the context of the organization's overall strategy. The MIS's requirements must be the consequence of this strategy and must serve the organization's purpose. However, the decision of which

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specific requirements to include into the constructed systems can be assessed completely only when the system has been deployed at the customer's site. Often, one cannot know a requirement is right or wrong until the requirement has been implemented. In other words, the client says, "IKIWISI! (I'll know it when I see it!)" and "IKINROWISI! (I'll know it's not right only when I see it!)" This apparent putting the cart before the horse is a fundamental difficulty in requirements engineering (RE).

On the other hand, requirements selection is often done too late. The resulting poorly selected requirements lead to, at best, an only marginally successful system deployment and, at worst, a complete failure. Part of the problem with these poorly selected requirements is that the requirements used are those that happened to be found, and they may not form a coherent MIS that is useful to its stakeholders. Therefore, it is necessary to take time to find as many requirements as possible, as difficult as that may be, and to select from them a set that both (1) forms a coherent, complete MIS and (2) includes the requirements that are most essential to the MIS's stakeholders [9].

No matter when requirements are found, the initial set of found requirements must be ranked according to their usefulness and significance to the organization. We call this initial set of found requirements the *preliminary* requirements, which have been called also *early* requirements [82]. Then, on the basis of this ranking, the MIS must be implemented to meet only the most important requirements plus those of the rest needed to ensure the coherence of the system containing the most important requirements [41,43,47]. The focus of this paper is, therefore, on techniques and technology to rank the preliminary requirements for an MIS on the basis of their priorities to the MIS's stakeholders.

The most important advantages of ranking MIS requirements by priority include:

- the possibility to focus on meeting the needs that provide the best support for the organization's strategic goals;
- earlier agreement on the required features of the MIS, thus reducing the time until its deployment;
- a better functioning MIS, by having focused on critical requirements, including usefulness, reliability, ease of operation, and efficiency; and
- the possibility to reduce the costs of MIS construction by minimizing outlays and by smarter allocation of the available resources.

1.2. Weaknesses of existing ranking technology

Section 5 discusses related work in detail. However, part of the conclusions from that related work justify and motivate the direction of the research reported herein. So, the conclusions are summarized here. At the time the research reported in this paper began, an analysis of existing technology for ranking requirements by priority showed that:

- the existing methods of requirements ranking, such as e.g., the Hill Model and Quality–Function Deployment, took into account the organization's strategy only to a limited extent [19] mainly because concern for strategy in requirements engineering is a relatively recent phenomenon;
- most existing methods of requirements ranking took into account only to a limited extent that decisions are made by a group of stakeholders rather than one [23,25,24,31,49,50,59];
- many existing methods of requirements ranking assumed that votes of all stakeholders are equally important [24,31,49,50]; and
- many existing computer-based tools for priority ranking did not allow the rankers to be distributed at many locations, as had become frequent in the development of new computer systems [31,49,50].

1.3. Goals, background, and assumptions of new method and tools

In order to address these weaknesses, the goals of the work reported in this paper were to develop for MISs:

1. instruments for analyzing preliminary requirements from the viewpoints of both the MIS's customers and the MIS's constructors, using technological, economic, and organizational criteria and ensuring that the organization's strategic goals are considered;
2. a method for ranking of preliminary requirements by a *group* of stakeholders, each making use of the organization's strategic goals; and
3. a prototype network-resident software tool facilitating ranking of preliminary requirements.

It was assumed that the organization has many stakeholders and that they are distributed. Hence, the tool should allow these many stakeholders to view, discuss, rank, and choose requirements from a distance. The simplest base for such a tool would be the Web. Also, the tool should be able to work in the local language, i.e., Polish in this case, rather than forcing everyone to use English.

To meet these goals, we have developed a metamethod, the Multi-Criteria Preliminary Requirements Ranking Technique (MCPRRT), for ranking of preliminary requirements for MISs. To facilitate the use of MCPRRT, we have developed the suggested Web-based software tool enabling distributed ranking of preliminary requirements. The tool enables also visualization of the ranking, thereby making it easier for stakeholders to make final decisions about requirements for their MIS.

1.4. Outline of the rest of this paper

Section 2 describes MCPRRT. Section 3 describes the prototype tool that assists in carrying out MCPRRT. Section 4 describes a case study of the application of MCPRRT and the use of the tool in ranking requirements for an MIS for city government. Section 5 reviews related work. Section 6 reports lessons learned from the case study, and Section 7 concludes the paper.

2. Methods and metamethods

MCPRRT is what can be called a metamethod. Suppose that an activity A consists of subactivities $a_1, \ldots,$ and a_n. A *metamethod* for doing an activity A composes a variety of methods $m_1, \ldots,$ and m_n for doing $a_1, \ldots,$ and a_n, respectively, into a method for doing A. One of the contributions in this paper is the metamethod MCPRRT. For all but one of the subactivities that need to be done, MCPRRT uses methods that are well known in the literature. These well known methods are only briefly described and cited. In principle, for any subactivity, any method for doing the subactivity may be used without changing the metamethod. Discussions about the relative merits of different methods for doing any subactivity are out of the scope of this paper.

The metamethod MCPRRT, described in Section 2.2, shows how to rank an organization's preliminary requirements according to criteria of different and distributed stakeholder groups, taking into account each group's ranking of criteria and the groups' importance weights within the organization.

There are a number of methods for producing a result ranking given some input rankings and weights. In some methods, the weights are applied to whole rankings, and in other cases, the weights are applied to the elements of a ranking. In the former cases, the result ranking tends to resemble the most important, and heavily weighted, ranking. In the latter cases, an element's position in the result ranking depends on its weighted positions in the individual input rankings.

One of MCPRRT's subactivities is done by a method that is new and is a contribution of this paper. The method, called MPRAC and described in Section 2.1, is for partitioning and ranking of the criteria of any group of stakeholders.

Another of MCPRRT's subactivities requires the use of Saaty's [60,78] Analytical Hierarchy Process (AHP) [11,21,39,77]. AHP is a method of calculating a total ranking from pairwise comparisons establishing for each pair which of its elements is higher in the ranking than the other. AHP is able to produce a total ranking provided that the input rankings are consistent, i.e., for no two elements, a and b, does the transitive closure of the pairwise rankings establish that both $rank(a) > rank(b)$ and $rank(b) \geq rank(a)$. The idea is that it is easier for a user to assign a ranking pair by pair than to assign an absolute rank to each element. In the variation of AHP used in MCPRRT, when a user is presented a pair of elements in order for him to indicate the elements' pair-wise ranking, he is shown, on the screen, the elements together with 17 selection buttons laid out between the elements, as is shown in Fig. 13 in Section 3. The numbers under the buttons are, from left to right, "9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9". The meaning of "1" is that the elements of the pair have equal rank. The meaning of the left-hand "9" is that the left-hand element's rank is as far above the right-hand element's rank as possible. The meaning of the right-hand "9" is that the right-hand element's rank is as far above the left-hand element's rank as possible. The numbers between 9 and 1 establish a graduated scale of the strength of the difference. The preference is to use an odd-numbered difference measure, with the even numbers reserved for compromising between two odd numbers. The standard meanings of these difference measure numbers established by Saaty [60,78] is given in Table 1. When a user of AHP has no ranking for a pair, i.e., he really does not care, he should regard them as ranked equally.

Several of MCPRRT's subactivities require the use of well-known calculations on vectors of rankings, which are described elsewhere in the literature:

1. The Weighted Sum Model (WSM) [21,53,78]: In a weighted sum, each element of a sum is multiplied by its weight.
2. The Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) [20,83]: Intuitively, from among a set of vectors, the solution vector is simultaneously as close as possible to the ideal solution and far as possible from the negative ideal solution.
3. Borda Scoring [39,73]: Borda Scoring takes a set of independent rankings of the same elements as input and produces a single aggregated ranking. Each element is ranked in the aggregate according to the sum of its ranks in all the input rankings.

2.1. Multi-plane requirements analysis card (MPRAC) for MISs

The Multi-Plane Requirements Analysis Card (MPRAC) for MISs is an instrument that gathers the criteria that will be used to evaluate each requirement from all sources and then partitions these criteria into four planes, each of which offers a different viewpoint of the system.

Table 1
Saaty's Pairwise Comparison Scale

Value	Definition
1	Equally important
3	Slightly more important
5	Considerably more important
7	Highly more important
9	Extremely more important

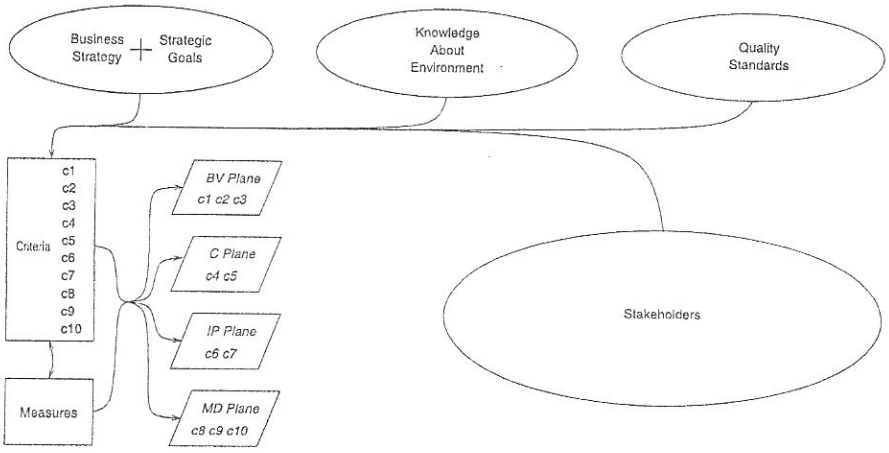

Fig. 1. MPRAC input, flow, and output.

MPRAC is part of a larger activity that uses the criteria to rank the preliminary requirements. Fig. 1 illustrates the input information, the information flows, and the output information of MPRAC, and it should be consulted while reading the following description.

MPRAC is based on the Balanced Scorecard [27,28,40,58,57,62,79,80]. Like the Balanced Scorecard, MPRAC uses four planes: (1) business values, (2) customers, (3) internal processes, and (4) MIS development. These four planes enable MPRAC to analyze the preliminary requirements for an MIS, taking into consideration the economic, organizational, and technological aspects of the organization. MPRAC may serve also as a tool to improve requirements communication between different groups of stakeholders, particularly between the managers and the computer experts, who are known to speak different professional languages even when they ostensibly speak the same natural language. As with the Balanced Scorecard, each of the four MPRAC planes is built as (1) a set of criteria and (2) measures for evaluating when these criteria are met:

- The business values plane comprises criteria that measure the how well the MIS does its management functions.
- The customers plane comprises criteria that measure the acceptance of the MIS by its customers,[1] both external and internal;
- The internal processes plane comprises criteria to determine the MIS's ability to support the organization's business processes.
- The MIS development plane comprises criteria to determine the MIS's ability to adapt to future changes.

Grouping the criteria into four planes enables classifying each preliminary requirement by both (1) its planes, containing all criteria the requirements satisfy, and (2) its overall significance.

Input for the criteria for any MPRAC plane comes from the organization's business strategy; the organization's strategic goals; general knowledge about the organization's environment; quality standards, such as the ISO 9126 [26] standards; and laws, including market and environmental regulations. A requirements engineer aided by major stakeholders develops a list of the criteria for each MPRAC plane. The stakeholders should be recruited from among (1) the top executives of the organization, (2) competent workers from selected function areas, and (3) external experts. Each group may contain also a person with minimum or no experience to take the role of the ignorant final customer of the MIS to help identify obvious problems overlooked by the experts [6].

A numerical estimate of the achievement of an adopted criterion constitutes an element of an MPRAC plane. The following two-step procedure, based on that of Moszoro and Obłuski [45 p. 12], allows estimating the achievement of the criteria for any plane.

1. Determine the measures relevant to the criterion. For example, for the criterion of cost, possible measures are salaries, cost of equipment, cost of utilities, hours worked, number of developers, etc.
2. From among the relevant measures, select the most suitable measure for the criterion as determined by:
   - the measure's coverage, i.e., how completely the criterion's satisfaction is evaluated by the measure;
   - the measure's decisiveness, i.e., how well the differences in the measure's values reflects differences in the criterion's satisfaction;
   - the measure's sensitivity, i.e., how little overlap there are in different measure values.

For example, among the measures for cost, the number of developers and salaries are often very suitable, because many of the other costs, including those of equipment

[1] The MIS's customers are its users and are *not* the customers of the organization that owns the MIS.

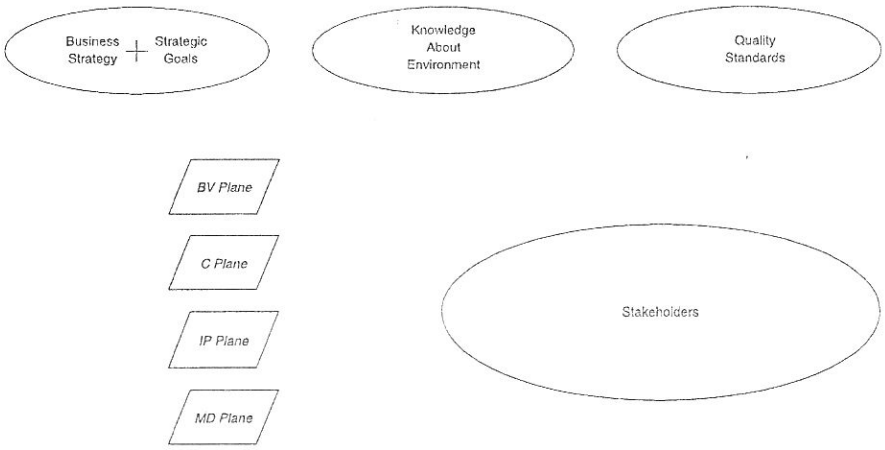

Fig. 2. Initial state of MCPRRT.

and utilities, can be accurately estimated as a function of the number of developers and their salaries. Of course, if OTS components are used instead of only new code, the measures will have to include the cost of the OTS components.

The four planes form a partition of the criteria. That is, each criterion is associated to one and only one plane.

2.2. Multi-criteria preliminary requirements ranking technique (MCPRRT) for MISs

This subsection describes the metamethod, the Multi-Criteria Preliminary Requirements Ranking Technique (MCPRRT), for ranking of preliminary requirements for MISs. Fig. 2 shows the information, concepts, and players that are involved in the entire MCPRRT, but at the beginning before any steps have been taken. There are the business strategy and strategic goals, the available knowledge about the environment, the mandated quality standards, the four MPRAC planes,[2] and the stakeholders. After the description of each step of MCPRRT comes a figure showing the effect of that step, given the preceding figure as input. These figures assume 10 criteria, c1, ..., c10, with 2 or 3 criteria associated with each of the 4 planes, BV, C, IP, and MD; 3 stakeholder groups, SG1, SG2, and SG3; and 4 preliminary requirements, R1, ..., R4.[3]

The MCPRRT procedure consists of three stages:

1. Stage I is gathering information about the organization and about the MIS being developed or modified.
2. Stage II is ranking of the preliminary requirements.
3. Stage III is visualizing the ranking and choosing requirements to implement based on the ranking.

2.2.1. Stage I

Stage I consists of the following three steps:

1. identification of the groups of stakeholders,
2. elicitation of preliminary requirements for the MIS, and
3. assignment of a weight to each group of stakeholders.

The identification of stakeholder groups affects the entire construction of an MIS. MCPRRT uses Sharp, Finkelstein, and Galal's stakeholder identification technique [70], which begins by determining the boundaries of the MIS being built or modified. The requirements engineer starts the process of stakeholder group identification by determining whether the usual set of basic stakeholder groups, users, developers, and decision makers is sufficient for the MIS to be constructed, whether the set should be reduced, and whether the set should be extended to include additional groups of stakeholders. Then, as suggested in Fig. 3, customer, supplier, and satellite stakeholders should be identified for each basic stakeholder group. For example, Table 2 in Section 4 shows the customer, supplier, and satellite stakeholders for each of the baseline stakeholder groups of the case study of Section 4.

Fig. 4 shows the results of Step 1. The stakeholders have been divided into 3 groups, SG1, SG2, and SG3, and one representative, illustrated as a black dot, has been appointed for each group. The diagram of Fig. 4 illustrates a case in which there is one representative for each stakeholder group, but in practice, there may be more than one representative for a group. When there are more than one representative in a group, the representatives of the group must reach a consensus, so that they speak with one voice. Of course, reaching a consensus may be difficult, but that difficulty is the subject of other negotiation methods, such as Win–Win [8,7].

Step 2's elicitation of preliminary requirements for the MIS is done by any of a variety of methods, such as *i**

[2] Only the four planes are shown, because the MPRAC steps described in Section 2.1 do not get done until Step 1 of Stage II.

[3] This fictitious running example should not be confused with the case study that is described in Section 4.

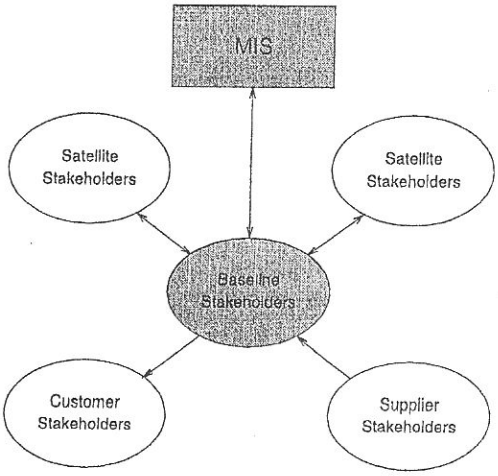

Fig. 3. Identification of stakeholder groups.

[82] or those described by Coughlan and Robert [13]. Fig. 5 shows the results of this step. The stakeholder representatives have used the available knowledge to generate a list of 4 preliminary requirements, R1, R2, R3, and R4.

Assigning weights to the groups of stakeholders is the last step of Stage I of MCPRRT. The primary aim of weighting stakeholder groups is to ensure that data received from any stakeholder group reflect the group's weight in the organization by any criterion upon which the stakeholders agree. The expert method is used for this weighting [74]. Note that a group's weighting need not match the group's official importance based on its position in the organizational hierarchy. The experts may decide that more informal factors count more in determining a group's weight.

If the requirements engineer decides not to weight stakeholder groups, then the input from each stakeholder group is considered of equal importance. Fig. 6 shows the results of this final step of Stage I. The weight of a stakeholder group is represented by what appears like a little weight for a balance scale, with the heaviness of a weight being proportional to its darkness. Thus SG2 is weighted the most and SG3 is weighted the least.

Table 2
Identification of stakeholder groups in case study

Baseline stakeholder group	Customer stakeholder	Supplier stakeholder	Satellite stakeholder
User	Media	Legislator (Sejm[a])	Citizens
			Non-profit organizations
			Entrepreneurs
			Investor
			Other public units
Designer	Citizens	Legislator (Sejm)	City Hall workers
			MIS administrators
Decision maker	Media	Legislator (Sejm)	Citizens
			Non-profit organizations
			Entrepreneurs
			Investor
			Other public units

[a] The Sejm and the Senate are the two houses of the Polish National Parliament.

2.2.2. Stage II

Stage II consists of the following six steps:

1. identifying the criteria shared by all stakeholder groups for each MPRAC plane,
2. for each stakeholder group, assigning a weight to each criterion,
3. for each stakeholder group, using the shared criteria with the group's weightings for the criteria, ranking the preliminary requirements four times, once for each plane,
4. for each stakeholder group, assigning a weight to each MPRAC plane,
5. for each stakeholder group, calculating an aggregated ranking of all preliminary requirements, based on the stakeholder group's weighting of the MPRAC planes, and
6. for all stakeholder groups, calculating a shared aggregated ranking of all preliminary requirements.

Step 1 of Stage II is the identification of the criteria shared by all stakeholder groups for each MPRAC plane. Since the planes constitute a partition of the criteria, each criterion is associated with precisely one plane. This criteria identification is one of the most important activities in MCPRRT, because the criteria form an evaluation scheme for the requirements. Fig. 7 shows the results of this step. This step does the MPRAC procedure, described in Section 2.1, in which the stakeholder representatives collectively decide on the criteria, select the measures, and assign each criterion to one plane.

Step 2 of Stage II has each stakeholder group assigning a weight to each criterion using AHP, as described in the initial part of Section 2. When a stakeholder group does not feel able to assign a weight to a criterion, MCPRRT uses instead the arithmetic mean of the weights assigned to the same criteria by the remaining stakeholder groups. Fig. 8 shows the result of Step 2. A set of 4 planes has been made for each stakeholder group. In each plane of each set, a weight has been given to each criterion in the plane.

Step 3 of Stage II has each stakeholder group ranking the preliminary requirements once for each plane, based on the weighted criteria in its own set of planes, using AHP and the WSM, as described in the initial part of Section 2. When a stakeholder group does not feel able to rank a particular preliminary requirement in a particular plane, MCPRRT

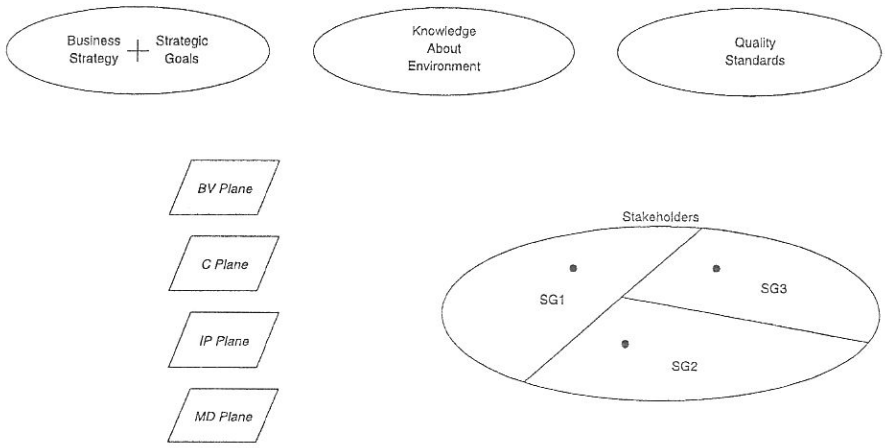

Fig. 4. After Step 1 of Stage I of MCPRRT.

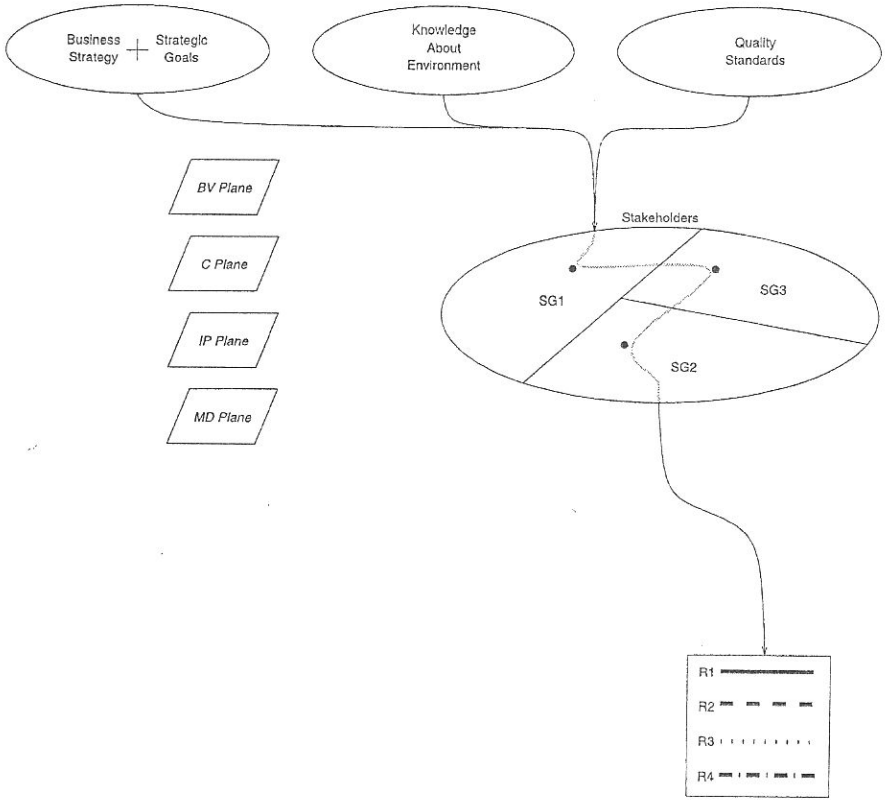

Fig. 5. After Step 2 of Stage I of MCPRRT.

uses instead the arithmetic mean of the ranks assigned to the same preliminary requirement in the same plane by the remaining stakeholder groups. Fig. 9 shows the results of this step. For each stakeholder group and for each plane, a ranking of the preliminary requirements has been generated based on the weights of the criteria in the plane.

Step 4 of Stage II has each stakeholder group assigning a weight to each MPRAC plane using the AHP method. No stakeholder group is allowed to not assign a weight to any plane. Fig. 10 shows the result of this step. Each stakeholder representative has put a weight next to each plane in its set of 4 planes.

In Step 5 of Stage II, for each stakeholder group, its preliminary requirements ranking for each plane is weighted by the group's assigned weighting for the plane, and these weighted per-plane rankings are aggregated into a single

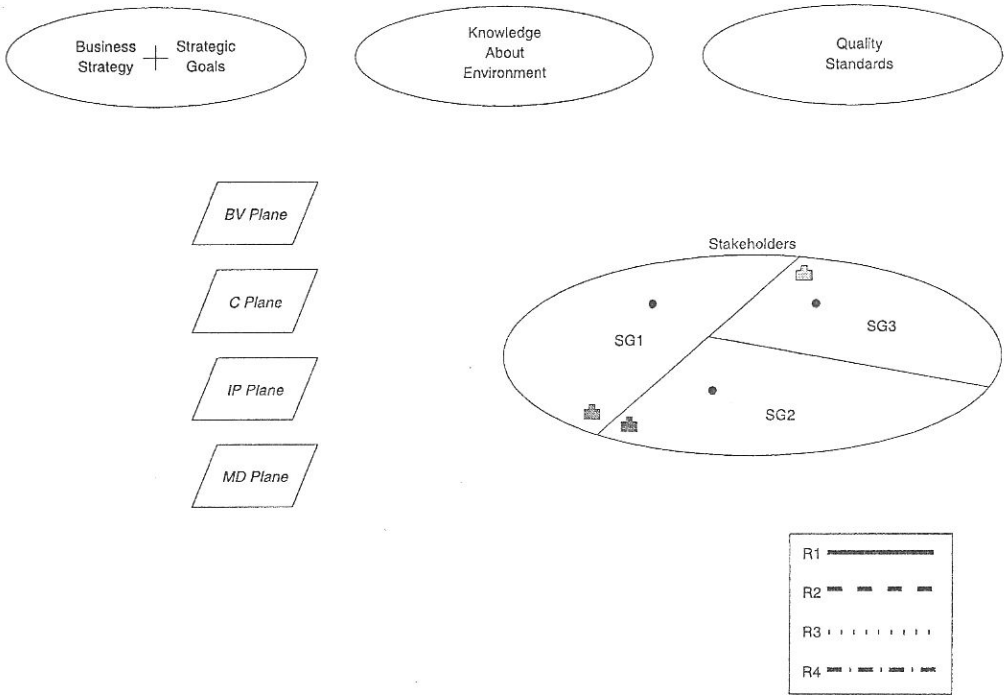

Fig. 6. After Step 3 of Stage I of MCPRRT.

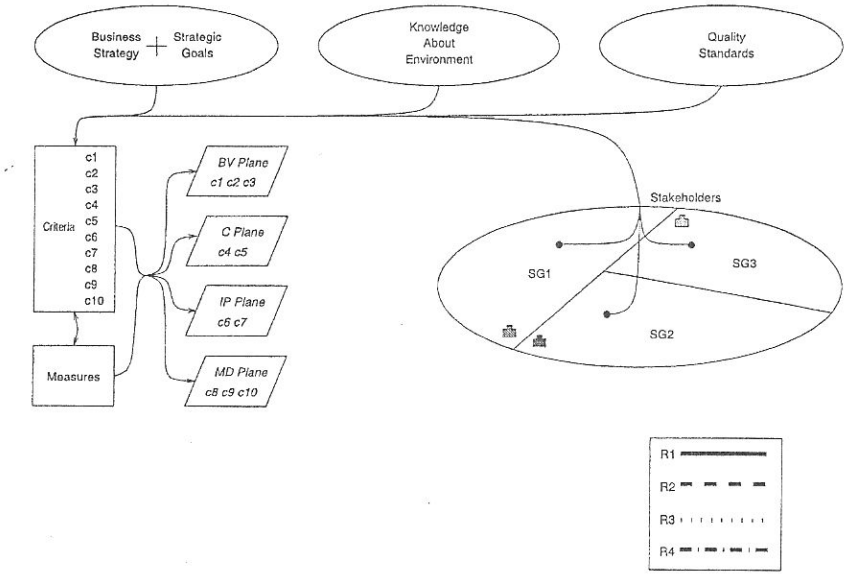

Fig. 7. After Step 1 of Stage II of MCPRRT.

ranking for all preliminary requirements using TOPSIS, as described in the initial part of Section 2. Fig. 11 shows the results of this step. The recently assigned plane weights have allowed each stakeholder group to produce a single ranking of the preliminary requirements from its four-per-plane rankings.

Step 6 of Stage II involves calculating a shared aggregated ranking based on the aggregated rankings produced for all stakeholder groups using Borda Scoring, as described in the initial part of Section 2. Fig. 12 shows the result of this step. The weights of the stakeholder groups have allowed generation of a single ranking of the preliminary require-

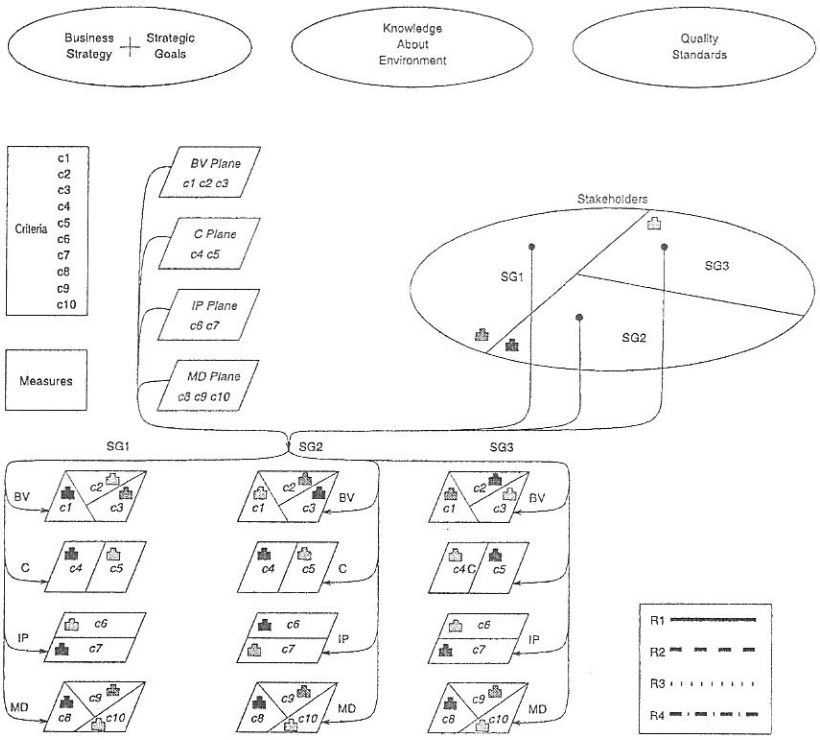

Fig. 8. After Step 2 of Stage II of MCPRRT.

ments from the single ranking previously generated for each stakeholder group.

2.2.3. Stage III

Stage III comes after the production in Step 6 of Stage II of the single aggregated ranking of the preliminary requirements and consists of the following two steps:

1. examination of the ranking of the preliminary requirements, and
2. choosing the requirements to implement in the MIS on the basis of the ranking.

To assist in Step 1, it helps to be able to visualize the ranking of the requirements in some graphic display of the ranking rather than to have to see only numbers. Therefore, any tool supporting MCPRRT should provide at least one graphical display of the ranking it produces.

In Step 2, the requirements engineer presents to the key decision makers the final list of preliminary requirements with aggregated priorities assigned to them, allowing the decision makers to choose which requirements to implement in their MIS. The way the decision makers choose is outside the scope of this paper. However, in making this choice, the decision makers may divide the ranked preliminary requirements into three groups:

- requirements that have been confirmed to be essential for the organization and its strategy,
- requirements that have been discovered to be essential for the organization and its strategy,
- requirements that have been abandoned as inessential for the organization [15].

3. Description of the tool developed to support MCPRRT

A MCPRRT support tool has been developed. Prior to developing this tool, we had a chance to study FocalPoint Version 2.01 [76], a professional tool for requirements ranking developed by FocalPoint A.B., Sweden. As an AHP tool, it is excellent, particularly for obtaining a single ranking from pairwise rankings. It detects inconsistencies in rankings, e.g. that $A > B$, $B > C$, and $C > A$. It displays results in several useful graphs that help the user to make the tradeoffs to choose a coherent set of highly desired features. However, our experience has shown that FocalPoint Version 2.01

- is not able to handle the Polish character set, and it has only limited capability to be internationalized, i.e. some of the messages intended for users insist on being displayed in English; and

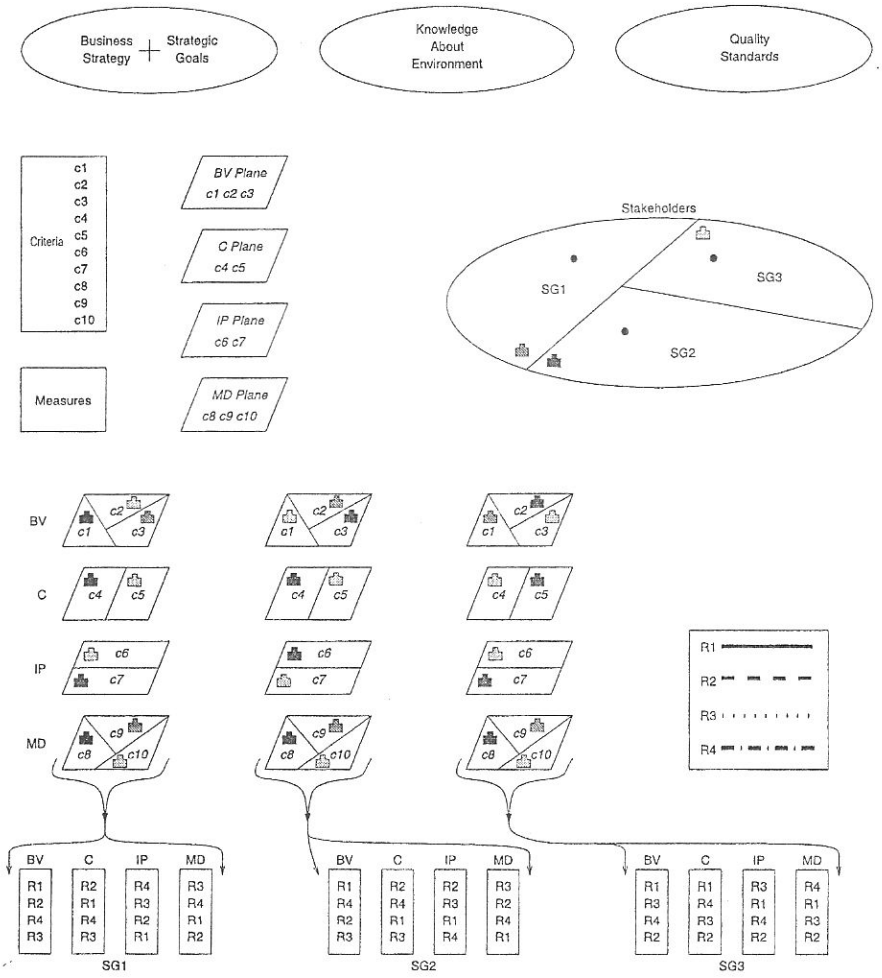

Fig. 9. After Step 3 of Stage II of MCPRRT.

- is not able to do some functionality required by MCPRRT, i.e.:
  - FocalPoint is not able to partition the criteria into the planes, and
  - FocalPoint is not able to perform aggregated ranking, based on collections of input rankings.

Soon after starting the research, we were kindly given an early copy of FocalPoint Version 4.0 [76]. It was a considerable improvement over FocalPoint 2.01, going beyond just ranking of requirements to various displays of the rankings. It supports group work through the Internet, but it did not work through the firewall we had installed. It adapts more to the user and permits limited internationalization to Polish, but it insists on English for many of the messages to users. We expect that these problems were fixed for later releases of the version. However, FocalPoint 4.0 lacks some functionality needed for MCPRRT.

As a result, we decided to develop a tool specially for MCPRRT that is able to:

- handle any number of participating stakeholders in requirements;
- assign criteria to MPRAC planes;
- aggregate a collection of rankings into a single ranking;
- operate in a network; and
- be configured by parameter settings for an arbitrary number of planes, stakeholders, stakeholder groups, requirements, and criteria.

We decided to use open-source software whenever possible. Java Server Pages (JSP) [75] were used extensively in the development to provide the user interface. MySQL V.3.2 [46] was used to provide database management functions, Tomcat V.4.1 [1] was used as the application server, and Eclipse V.2.1 [16] served as the developer's environment.

Prototyping [10] was used during the development of the tool. A prototyped tool was presented to a group of potential

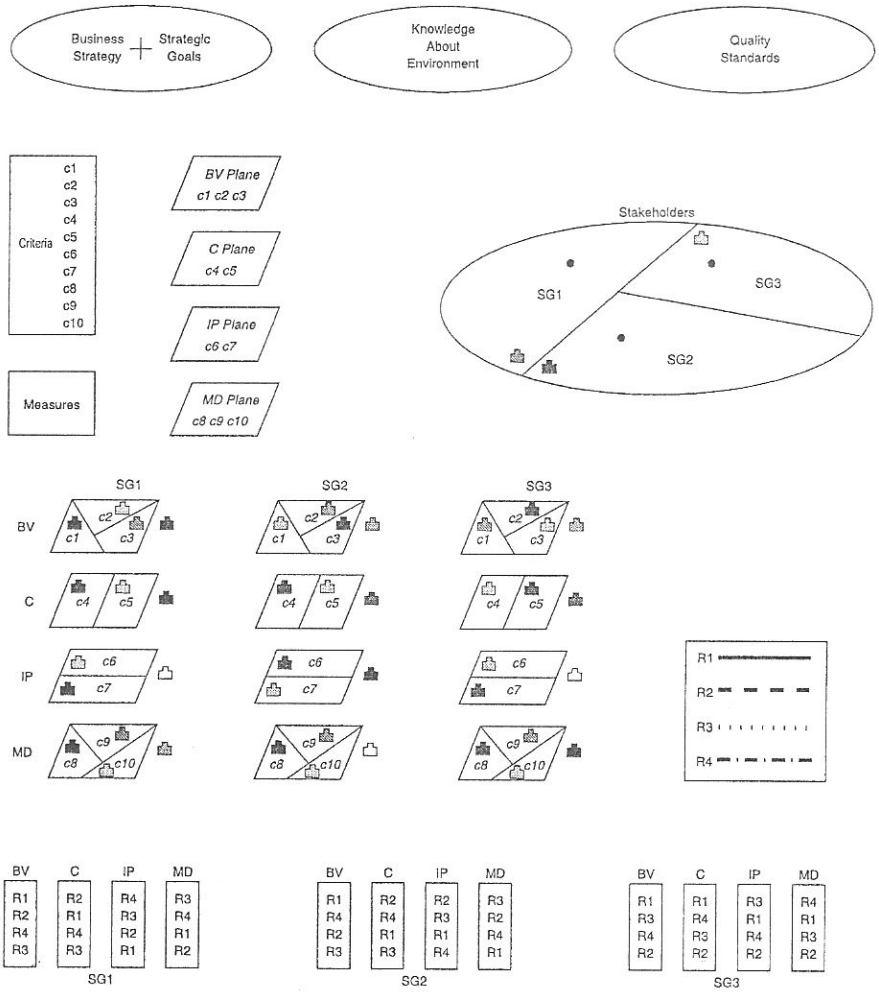

Fig. 10. After Step 4 of Stage II of MCPRRT.

users. During the presentation, they had the following remarks:

1. The criteria assigned to the planes should be made visible during ranking of the planes. Doing so would enable more reliable ranking.
2. During the ranking, the names of the groups of stakeholders currently logged in should be displayed.
3. It would be very desirable to provide transient hints containing extended descriptions of preliminary requirements, so that at any moment, a user can see the meaning of the phrase representing any preliminary requirement.
4. It would be very desirable to provide for the AHP part of the tool, an icon in the form of a moving balance, as shown in Fig. 6, whose arm swings to match the chosen value in the relative ranking of a pair.

After running a test ranking using the MCPRRT tool and then the FocalPoint software, these same users had the following comments:

- FocalPoint does not have the ability to aggregate rankings from users who used different criteria. The MCPRRT tool supports building aggregated rankings to be presented to the organization's decision makers, enabling them to make decisions in a relatively simple way. Recall that when a stakeholder group does not provide a weighting for a criterion, the MCPRRT tool calculates a replacement weight for the missing criterion as the average of the other stakeholders' weights of the same criterion. Therefore, the MCPRRT tool can work with differing sets of criteria among the stakeholders.
- The users concluded that the ability to partition the criteria by MPRAC planes made the process of assigning weights to the criteria much easier.

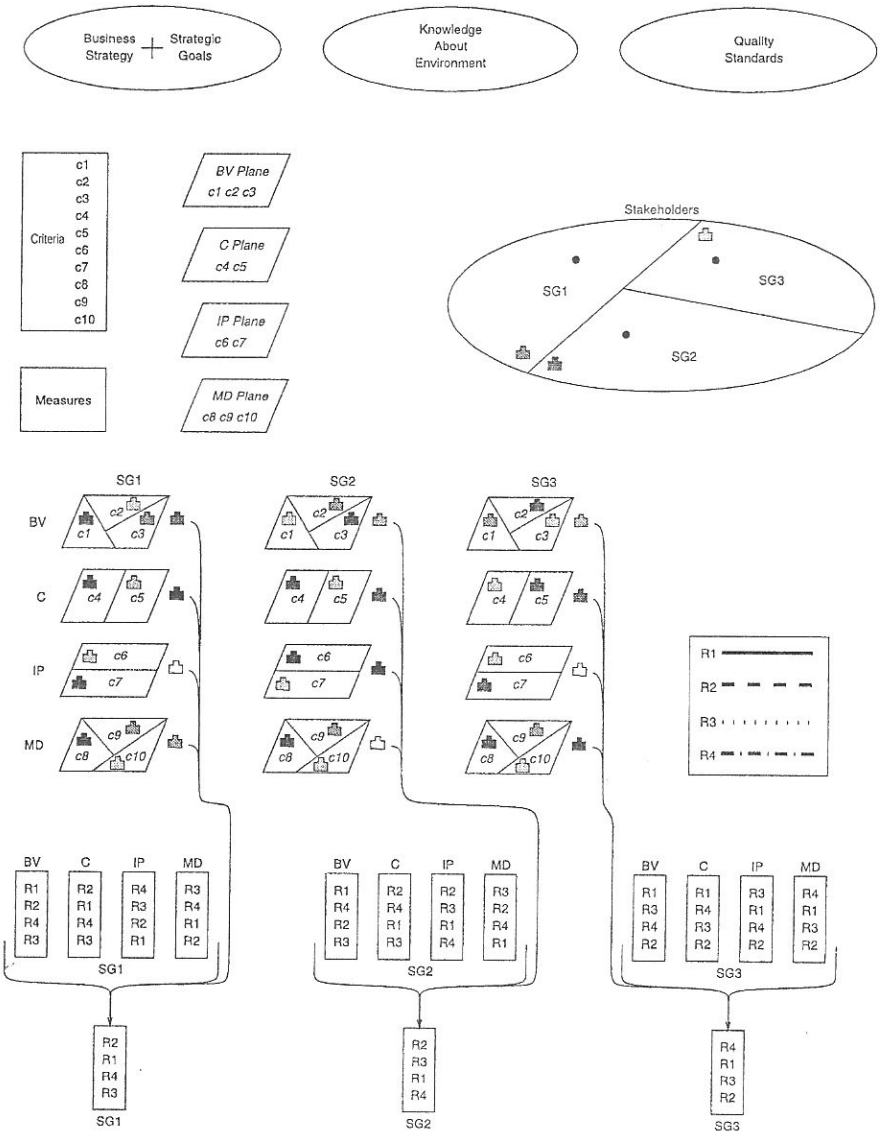

Fig. 11. After Step 5 of Stage II of MCPRRT.

- FocalPoint uses a 9-point scale, with maximum value 5, for pairwise comparison, while the MCPRRT tool uses a 17-point scale, with maximum value 9. According to 4 of the 5 users, a larger number of values allows finer, more accurate distinctions.
- The users pointed out that the different colors associated with the different scale values in the MCPRRT tool is of great assistance in comparing preliminary requirements according to any criterion. One participant of the pilot run suggested that the same colors be used on both sides of the scale, as shown in Fig. 13 (When a screen from the tool that was built is shown in a figure, the figure's legend gives an English translation of the Polish language text in the screen.).[4] However, the remaining participants were convinced that the current solution, shown in Fig. 14, is clearer.[4]

[4] For those readers who are seeing this paper in a black-and-white medium, the color scheme of Fig. 13 has both "9"s showing blue, both of each successive number less than "9" showing more and more purple blue, and the one "1" showing purple. The color scheme of Fig. 14 has the left instance of "9" showing blue, the left instance of each successive number less than "9" showing more and more purple blue, the right instance of "9" showing red, the right instance of each successive number less than "9" showing more and more purple red, and the only instance of "1" showing purple. To see this paper in color, the reader should visit the Web version of this paper.

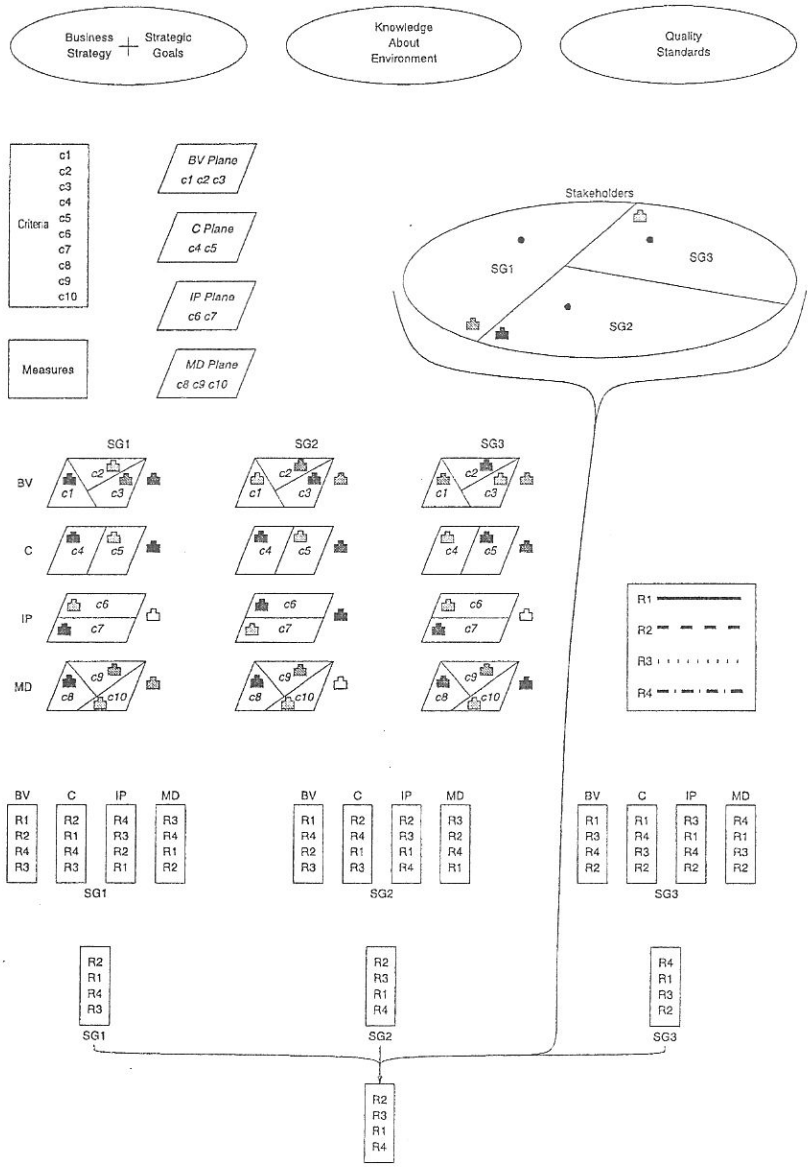

Fig. 12. After Step 6 of Stage II of MCPRRT.

- The users thought that the MCPRRT tool's word descriptors, e.g., "extremely more" and "slightly more", and their numeric equivalents, e.g., "9", "3", for the values on the pairwise comparison scale was a better idea than Focal-Point's use of only graphic signs, e.g., "$\ll$" and "<".

As the reader can see, the users' comments strongly influenced the behavior of the final version of the MCPRRT tool.

The tool built to support MCPRRT offers two types of graphs for visualizing the ranking of preliminary requirements [56,55]:

- A distribution chart is a block diagram showing the differences in the ranking of individual preliminary requirements. Fig. 18 shows an example of a distribution chart. The x-axis values are the numerals naming the preliminary requirements and the y-axis value for a requirement is the preliminary requirement's aggregated priority. Each block shows the total priority of a preliminary requirement. All priorities assigned by one stakeholder group are marked with a unique color assigned to the group. For any stakeholder, the size of the stakeholder's portion of a block is proportional to the stakeholder's ranking of the block's requirement.

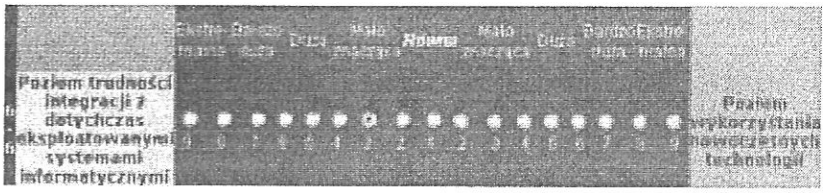

Fig. 13. Differences in color for the values on the pairwise comparison scale, a variant proposed by a participant of the pilot run. (Left side: Poziom trudności ... → Level of difficulty of integrating the preliminary requirement [at hand] with the computing systems already operated by the city's offices. Right side: Poziom wykorzystania ... → Level of utilization of advanced technologies. Scales: Ekstremalna → Extremely more; Bardzo duża → Highly more; Duża → Considerably more; Mało znacząca → Slightly more; Równa → Equally.)

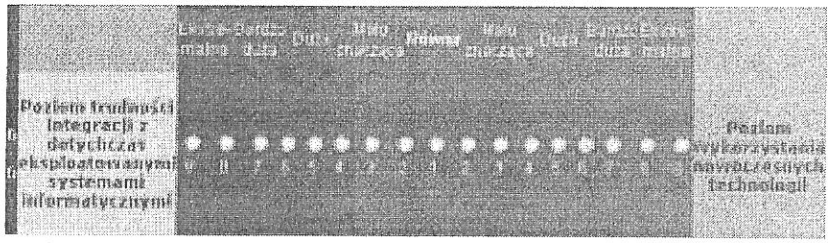

Fig. 14. Differences in color for the values on the pairwise comparison scale, as implemented in the final version. (Left side: Poziom trudności ... → Level of difficulty of integrating the preliminary requirement [at hand] with the computing systems already operated by the city's offices. Right side: Poziom wykorzystania ... → Level of utilization of advanced technologies. Scales: Ekstremalna → Extremely more; Bardzo duża → Highly more; Duża → Considerably more; Mało znacząca → Slightly more; Równa → Equally.)

- A weighed distribution chart is a block diagram showing the weighted priorities assigned to a single requirement by all stakeholder groups. Fig. 19 shows an example of a weighted distribution chart. The x-axis values are the numerals naming the requirements and the y-axis value for a requirement is the requirement's weighted aggregated priority. The height of a particular requirement's block is proportional to the total of the weighted priorities of that requirement by all stakeholder groups. All priorities assigned by one stakeholder group are marked with the unique color assigned to the group. For any stakeholder, the size of the stakeholder's portion of a block is proportional to the stakeholder's weighted ranking of the block's requirement.

4. Validating case study of the use of MCPRRT and its tool

The validation of MCPRRT and of its supporting tool was carried out during the requirements engineering for the MIS for a Polish self-governmental, eGovernmental unit making extensive use of Internet to allow its customers, its citizens, to interact with it [72,71].

4.1. Context of case study

A medium-large, 60-thousand-inhabitant city located in Central Poland was selected as the site of the first production use of the full MCPRRT and its final tool. The city's leaders had decided to improve the city's development strategy and were about to submit a proposal to the European Union to build a new MIS for the city and its adjacent parish. Sobczak presented a talk on the tool to the city ministry that would own the MIS being developed. There was sufficient interest that the key people gave permission for Sobczak to use the tool to help in the requirements engineering for this MIS.

The description below follows the sequence of stages of MCPRRT described in Section 3.

4.2. Stage I

Identification of stakeholder groups must be preceded by the definition of the boundaries of the MIS to be built. It was decided that the MIS should continue to use the existing hardware facilities and the existing collected information resources in the local area and the global area networks. (In retrospect, it might have been better to make this decision one of the preliminary requirements, perhaps highly ranked, but nevertheless subject to debate.) This MIS should provide new functionality to implement requirements resulting from the new development strategy adopted by the city. The five selected stakeholder groups and their representatives were:

1. about 120 users, represented by an independent 5-year city worker with a university-level education whose duties involve continuing contacts with the citizens, who are in essence, the city's customers;

2. twenty legislators, represented by a city council member with a university-level education, who is also the president of one of the council's committee;
3. four decision makers, represented by the city's vice-president.
4. five designers, represented by an external-company worker with a university-level education in computer sciences with several years of experience implementing systems for public administration;
5. three administrators, represented by a 3-year city worker, with a university-level education, in the city office that is responsible for the maintenance and development of the existing computer systems of the city.

Table 2 shows the customer, supplier, and satellite stakeholders for each of the baseline stakeholder groups of the case study.

To elicit the best possible set of preliminary requirements for the MIS to be developed, the following activities were carried out:

- analysis of the existing documents from the city office about the new development strategy for the city, about circumstances and plans for expansion of the city, and about the city's operational statutes;
- interviews with the representatives of the users and legislators stakeholder groups;
- analysis of the city's currently operating computer systems;
- analysis of regulations which affect, or may affect in the future, the form of the city's computer systems [69,63,65, 64,67,66,68];
- analysis of documents prepared by ministries and other governmental bodies about the problems of implementing computer systems in public administration [34,42, 35].

In this way, the 11 preliminary requirements listed in Appendix A were identified. These were then subjected to the rest of the MCPRRT procedure.

The last step of Stage I is assigning a weight to each stakeholder group that will participate in preliminary requirements ranking. The weights shown in Table 3 were assigned to each stakeholder group by 5 experts using the Expert Method [74].

Table 3
Mean weights assigned to stakeholder groups by the experts, with individual weights ranging from 0.0 through 10.0

Stakeholder	Group mean weights
Users	3.6
Legislators	2.0
Decision makers	2.0
Designers	1.3
Administrators	1.1

1. Expert A: D.Sc. in computer sciences with 12 years of experience building computer systems for public administration, at present responsible for adjusting to EU standards the computer systems operated by Polish public administration;
2. Expert B: M.A. with 5 years of experience as the editor-in-chief of the Web pages of major Polish self-governmental services;
3. Expert C: M.Sc. in computer sciences with 4 years of experience building computer systems for the Polish public sector;
4. Expert D: computer expert with 3 years of experience building Internet systems.
5. Expert E: master's degree with 5 years of experience applying modern management concepts, such as ISO standards and TQM, in self-governmental units.

To determine the criteria for the 4 MPRAC planes and adjust them to the needs of the city's MIS, the document "Strategy for the Development of the City 2002-2010" [53] was analyzed. As described in Section 2.1, the city's development strategy, the city's strategic goals and quality standards were considered to identify the full set of criteria. In all, the 16 criteria listed in Appendix B were identified. These amounted to

- three criteria in the business values, BV, plane,
- five criteria in the customers, C, plane,
- four criteria in the internal processes, IP, plane, and
- four criteria in the MIS development, MD, plane.

Table 4 shows the scope of each stakeholder's contribution to the assignment of weights to the criteria, each of which is in one plane. Each stakeholder took into account his knowledge and professional experience in doing his assignment. In the cell for a stakeholder and a plane, "Yes" means that the stakeholder had assigned a weight to the criteria in the plane, while "No" means that the stakeholder had not assigned any weight to any criteria in the plane. Fig. 15 shows the designer stakeholder's assignment of a weight to the customers plane. Table 5 shows the weights assigned to five criteria in the customers plane by all stakeholders. The text of each criterion is given in Appendix B. The criteria of the other planes were assigned weights in the same manner.

4.3. Stage II

The next step involved ranking the preliminary requirements by priority. Using the tool, each stakeholder first selected an MPRAC plane and then, a criterion by which to rank preliminary requirements. For that criterion, pairwise comparison was carried out as illustrated in Fig. 16. Table 6 shows the result of the ranking Requirement R1 by the criteria in the customers plane. The text of Requirement R1 is given in Appendix A. Each preliminary requirement was ranked according to each criterion in each plane

Table 4
Scope of contribution of each stakeholder in assigning weights to the criteria of a plane

Stakeholder	Business values plane	System customers plane	Internal process plane	System development plane
User	Yes	Yes	Yes	No
Legislator	Yes	Yes	No	Yes
Decision maker	Yes	Yes	Yes	No
Designer	Yes	Yes	Yes	Yes
Administrator	Yes	Yes	No	Yes

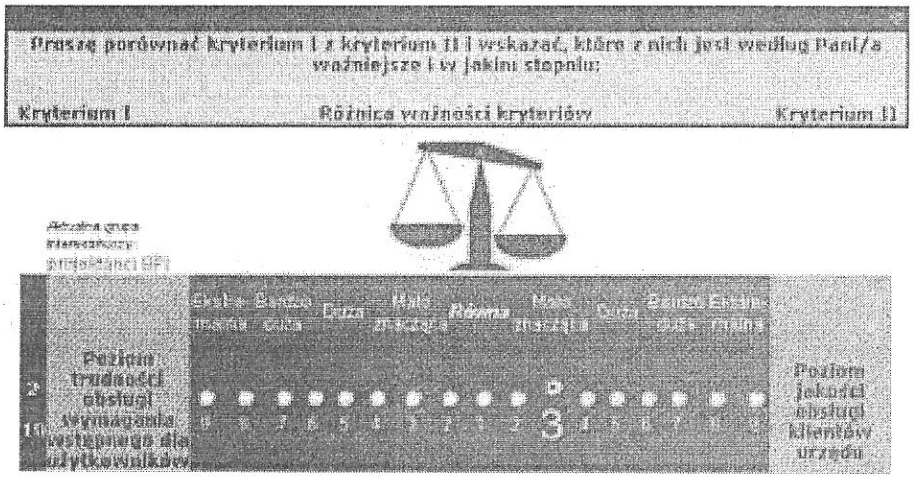

Fig. 15. The designer stakeholder's assignment of one weight to the customers plane. (Top of Top Box: Proszę ... → Please compare requirement I with requirement II and chose which is more important and by what degree. Bottom of Top Box: Różnica ... → Difference between the importances of the criteria; Kryterium → Criterion. Left of Balance: Actualna ... → Current interested group: SPI (Self-government Information Platform) Project. Left Side of Bottom: Poziom trudności ... → Level of difficulty of meeting the preliminary requirement by the users. Right Side of Bottom: Poziom jakości ... → Level of quality of services rendered to city's customers. Scales: Ekstremalna → Extremely more; Bardzo duża → Highly more; Duża → Considerably more; Mało znacząca → Slightly more; Równa → Equally.)

Table 5
Weights assigned by all stakeholders to the 5 criteria of the customers plane

Criteria	Stakeholders				
	User (%)	Legislator (%)	Decision maker (%)	Designer (%)	Administrator (%)
K1	16.2	10.0	9.6	5.8	11.6
K2	34.5	43.5	21.4	23.8	35.9
K3	10.2	26.9	26.2	11.7	23.3
K4	31.7	14.6	36.4	12.9	19.4
K5	7.4	5.0	6.4	45.8	9.8

in the same way. Step 4 of Stage II has each stakeholder assigning a weight to each plane. Fig. 17 shows a step in the designer stakeholder's assigning of weights to all planes. Table 7 shows the actual weights assigned to the planes by all the stakeholders. Step 5 of Stage II takes for each stakeholder, his preliminary requirements ranking for each plane as weighted by his assigned weighting for the plane, and aggregates these rankings into a single ranking for all preliminary requirements using TOPSIS. Table 8 shows the results. In Step 6 of Stage II, Borda Scoring is used to obtain an aggregated ranking of the preliminary requirements for each stakeholder. Table 9 shows for each preliminary requirement and each stakeholder, two numbers, the second one inside parentheses:

1. the priority calculated for the preliminary requirement and the stakeholder
2. the weighted priority calculated for the preliminary requirement and the stakeholder from this priority and the weight assigned to the stakeholder.

The table shows in the right hand column, for each preliminary requirement, the sum of the weighted priorities from all the stakeholders.

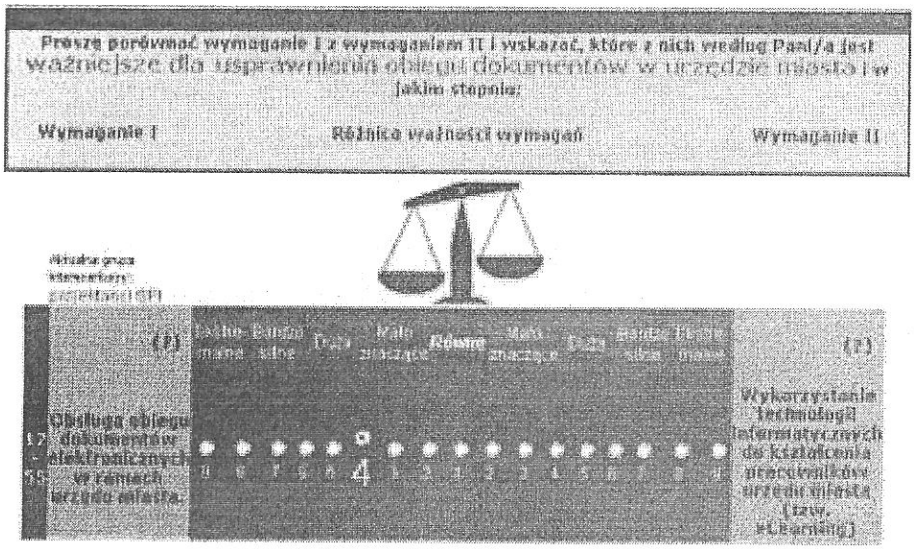

Fig. 16. Comparison of two preliminary requirements by one criterion. (Fig. 16: Top of Top Box: Proszę ... → Please compare requirement I with requirement II and chose which is more important *to the handling of the circulation of electronic documents within city offices* and by what degree. Bottom of Top Box: Różnica ... → Difference between the importances of the requirements; Wymanagie → Requirement. Left of Balance: Actualna ... → Current interested group: SPI (Self-government Information Platform) Project. Left Side of Bottom: Obsługa ... → Handling of the circulation of electronic documents within city offices. Right Side of Bottom: Wykorzystanie ... → Use of computer-aided information techniques to train city office's staff (e-learning). Scales: Ekstremalna → Extremely more; Bardzo silne → Highly more; Duża → Considerably more; Mało znaczaca → Slightly more; Równa → Equally.)

Table 6
Priorities assigned to the preliminary requirements according to the criteria in the customers plane

Preliminary requirements	Stakeholder No.	Criteria				
		Speed of serving office's customers K1	Quality level of services rendered to office's customers K2	Level of support to companies operating in the city K3	Level of support in attracting external investors K4	Difficulty level of serving preliminary requirement for users K5
RI	1	0.078	0.146	0.042	0.257	0.021
	2	0.016	0.024	0.020	0.291	0.037
	3	0.025	0.063	0.034	0.139	0.048
	4	0.052	0.045	0.031	0.235	0.142
	5	0.044	0.033	0.036	0.134	0.081

To allow assessment of the significance of the individual preliminary requirements, the results were standardized and sorted into descending order. Table 10 shows the results.

4.4. Stage III

In Stage III, the priorities had to be visualized. Figs. 18 and 19 are graphs generated by the MCPRRT tool. Fig. 18 shows the priorities calculated for the preliminary requirements. The *x*-axis values are the numerals naming the requirements and the *y*-axis value for a requirement is the requirement's aggregated priority. Fig. 19 shows the weighted priorities calculated for the preliminary requirements. The *x*-axis values are the numerals naming the requirements, and the *y*-axis value for a requirement is the requirement's weighted aggregated priority. (See the end of Section 3 for descriptions of the two graphs.)

The ranking information was used to write a final requirements document. This document was incorporated into a funding proposal to the European Union (EU) to implement the specified MIS for use by the cities in a regional association of the cities of central Poland.

As of the date of this publication, the MIS has not been built for reasons beyond control of the stakeholders. The proposal to the EU failed to win funding. Moreover, recently the EU funded an infrastructure project proposed by the same regional association; hence the EU is unlikely to fund the MIS proposal. Hence, there is no way to determine the effect of MCPRRT and of the tool on a downstream development. Nevertheless, all on the project who had participated in requirements engineering efforts in other projects in the past and had experiences in the

Fig. 17. A step in the assigning of weights to planes by the designer stakeholder. (Top of Top Box: Proszę ... → Please compare plane I with plane II and chose which is more important and by what degree. Bottom of Top Box: Różnica ... → Difference between the importances of the planes; Płaszczyzna → Plane. Left of Balance: Actualna ... → Current interested group: SPI (Self-government Information Platform) Project. Left Side of Bottom: Płaszczyzna klientów (including bullets) ... → Customers' plane. Criteria at this plane: • Level of difficulty of meeting the preliminary requirement by the users. • Time to serve the city's customers. • Level of quality of services rendered to city's customers. • Level of support offered to businesses operating in the city. • Level of support for attracting external investors. Right Side of Bottom: Płaszczyzna rozwoju (including bullets) ... → System development plane. Criteria at this plane: • Scope of the possibilities to extend the functionality of the preliminary requirement. • Level of flexibility of the preliminary requirement. • Level of difficulty of integrating the preliminary requirement with the computer systems already operated by the city's offices. • Level of utilization of advanced technologies. Scales: Ekstremalna → Extremely more; Bardzo duża → Highly more; Duża → Considerably more; Mało znacząca → Slightly more; Równa → Equally.)

Table 7
Weights assigned by stakeholders to the planes

Planes	Stakeholders				
	User (%)	Legislator (%)	Decision maker (%)	Designer (%)	Administrator (%)
BV	9.4	25.4	51.3	44.6	8.2
C	45.6	57.1	21.5	17.4	36.7
IP	30.3	13.2	21.5	9.3	30.9
MD	14.7	4.3	5.7	28.7	24.2

Table 8
Aggregated results of preliminary requirements ranking for all MPRAC planes

Preliminary requirements	Stakeholders				
	User	Legislator	Decision maker	Designer	Administrator
R1	0.784	0.784	0.398	0.212	0.523
R2	0.623	0.289	0.113	0.397	0.502
R3	0.612	0.848	0.413	0.217	0.545
R4	0.444	0.509	0.613	0.883	0.418
R5	0.417	0.199	0.204	0.137	0.198
R6	0.164	0.02	0.053	0.0	0.004
R7	0.185	0.133	0.379	0.5	0.197
R8	0.745	0.495	0.221	0.208	0.582
R9	0.524	0.706	0.436	0.221	0.725
R10	0.41	0.315	0.536	0.366	0.387
R11	0.212	0.215	0.223	0.203	0.308

Table 9
Aggregated results of the ranking of preliminary requirements for a group of stakeholders (values in brackets represent their weighted values)

Preliminary requirements	Stakeholders					Sum
	User (weight: 3.6)	Legislator (weight: 2.0)	Decision maker (weight: 2.0)	Designer (weight: 1.3)	Administrator (weight: 1.1)	
R1	10 (36.0)	9 (18.0)	6 (12.0)	4 (5.2)	7 (7.7)	78.9
R2	8 (28.8)	4 (8.0)	1 (2.0)	8 (10.4)	6 (6.6)	55.8
R3	7 (25.2)	10 (20.0)	7 (14.0)	5 (6.5)	8 (8.8)	74.5
R4	5 (18.0)	7 (14.0)	10 (20.0)	10 (13.0)	5 (5.5)	70.5
R5	4 (14.4)	2 (4.0)	2 (4.0)	1 (1.3)	2 (2.2)	25.9
R6	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0.0
R7	1 (3.60)	1 (2.0)	5 (10.0)	9 (11.7)	1 (1.1)	28.4
R8	9 (32.4)	6 (12.0)	3 (6.0)	3 (3.9)	9 (9.9)	64.2
R9	6 (21.6)	8 (16.0)	8 (16.0)	6 (7.8)	10 (11.0)	72.4
R10	3 (10.8)	5 (10.0)	9 (18.0)	7 (9.1)	4 (4.4)	52.3
R11	2 (7.2)	3 (6.0)	4 (8.0)	2 (2.6)	3 (3.3)	27.1

Table 10
Normalized priorities for preliminary requirements, expressed as percentages

Preliminary requirements	Normalized priority of preliminary requirements (in %)
R1	14.35
R3	13.55
R9	13.16
R4	12.82
R8	11.67
R2	10.15
R10	9.51
R7	5.16
R11	4.93
R5	4.70
R6	0.00

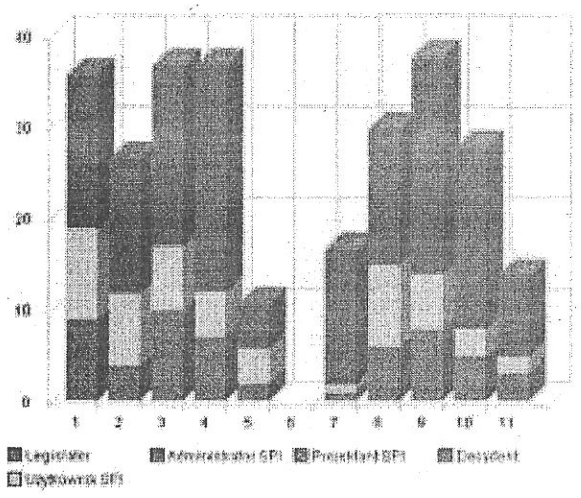

Fig. 18. Graph showing aggregated priorities of preliminary requirements. (Under x-axis: Legislator → Legislators; Administrator SPI → SPI (Self-government Information Platform) Administrators; Projektant SPI → SPI Designers; Decydent → Decision Makers; Użytkownik SPI → SPI Users.)

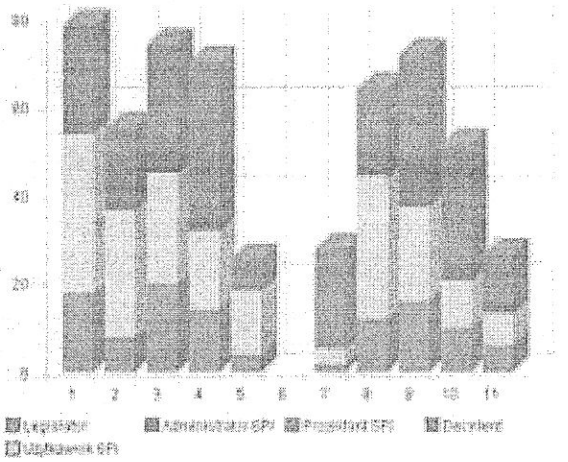

Fig. 19. Graph showing weighted aggregated priorities of preliminary requirements. (Under x-axis: Legislator → Legislators; Administrator SPI → SPI (Self-government Information Platform) Administrators; Projektant SPI → SPI Designers; Decydent → Decision Makers; Użytkownik SPI → SPI Users.)

past to which to compare the current experience reported being certain that they had done a better job writing requirements than they had ever done in the past. Section 6 discusses lessons learned from the participating stakeholders.

5. Related work

The distributed priority ranking work described in this paper differs from but builds on all the previously done work on distributed RE and priority ranking, a.k.a "prioritization" in the literature.

To discuss some of this work, a bit of vocabulary is needed: AHP calculates a ranker's total ranking of requirements from pair-wise rankings supplied by the ranker, provided that the supplied pair-wise rankings are consistent with each other. In opposition to pair-wise ranking is what

is called for the purpose of this discussion *monolithic ranking*, in which the ranker somehow produces the total ranking by working with the entire list of requirements, for example, by shuffling cards, each of which contains one requirement.

First, an examination of the technology for ranking requirements by priority that existed before beginning the work described in this paper shows that:

- Most existing methods of requirements ranking took into account only to a limited extent that decisions are made by a group of stakeholders rather than one [23,25,24,31,49,50,59];
- many existing methods of requirements ranking assumed that votes of all stakeholders are equally important [24,31,49,50]; and
- many existing computer-based tools for priority ranking, e.g., FocalPoint [76,29] did not allow the rankers to be distributed at many locations, as had become frequent in the development of new computer systems [31,49,50].

Below is a listing of other work addressing at least a part of the work of this paper. Among these, only issues considered in this work are discussed in detail:

- the use of i^* to model goals and early requirements [82],
- surveys (i.e., reviews) and bibliographies about theory and applications of AHP [54,17],
- empirical studies of the problems in practice of ranking requirements by priority, independent of method, for a variety of projects, bespoke and market-driven [48],

  Herzwurm, Schockert, and Mellis concluded in 1999 that existing methods of requirements ranking, such as, e.g., the Hill Model and Quality Function Deployment, take into account the organization's strategy only to a limited extent;

  Lehtola, Kauppinen, and Kujala found that (1) priority ranking is highly ambiguous and context-specific, (2) priority ranking must be performed repeatedly during development, (3) the difficulties of priority ranking include taking all relevant factors into account and aggregating multiple stakeholders' views, and (4) practitioners who do priority ranking manually hope for a more systematic way to do it [37].
- empirical studies of the apparently non-distributed use of AHP in RE, often in comparison with another method of ranking,

  J. Karlsson, Wohlin, and Regnell found in several medium-sized projects, that among six methods of ranking quality requirements for a telephony system: AHP, Hierarchy AHP, Minimal Spanning Tree, Bubble Sort, Binary Search Tree, and Priority Groups, AHP was the most effective but was not perceived as scalable, because the number of pairs to rank grows quadratically with the number of requirements. While AHP compares each requirement to all requirements, in Hierarchy AHP, the requirements are grouped by abstraction level and AHP is used to compare each requirement in any level with all requirements in only the same level. Hierarchy AHP is effective in reducing the number of pairs to consider, but is subject to inaccuracies as a result of judgment errors in the classification of requirements into levels. In a large project, the ranking practitioners found AHP to be more demanding of their time, but they felt that the reliability of AHP's conclusions made the time well spent [30].

  Lehtola and Kauppinen compared two methods of ranking requirements by priority: (1) AHP, as implemented by FocalPoint, and (2) Wiegers's method that monolithically ranks the costs, risks, and value of each requirement [81]. The value of a requirement includes both the value of the requirement to the customer and the penalty incurred from the customer if the requirement is not met. Each method was found to be suitable and effective. The lessons learned about FocalPoint's implementation of AHP include:
  1. Users found it difficult to estimate how much more valuable one requirement is than another.
  2. Pair-wise comparisons with over 20 requirements were difficult in practice.
  3. Requirements at different levels of abstraction caused trouble.
  4. Some users thought that pair-wise comparisons were pointless; they thought that it would have been easier to just select the most important requirements or to put the requirements in descending order without any pair-wise comparison.

  The lessons learned about both methods include:
  1. When the user of a ranking method has a strong experience-based intuition about the ranking of requirements, she typically mistrusts method-produced rankings that disagree with her own intuition.
  2. A lack of clarity concerning the method itself may effect the results. The ranking results are no better than the raw data inserted.
  3. A tool's ranking of requirements may lead to a wrong decision of what to do. If two requirements of different levels are compared, their comparison is really meaningless, and the total ranking is suspect [36,38].

  L. Karlsson, Berander, Regnell, and Wohlin compared manual AHP (called only "pair-wise comparison" in their paper) with extreme programming's (XP's) [4] planning game (PG) for effectiveness in ranking requirements by priority. The PG is the XP step of each development iteration that is used to select which requirements, each expressed in the form of a story, are to be implemented in the upcoming iteration. In the PG, each story is triaged [15] by value to the customer and triaged by cost to implement. The triage of a story for a criterion categorizes the story as low, medium, or high in the criterion. The group playing the PG balances the two triages of all stories to determine a good combination of desired stories that are implementable in the time allotted to the upcoming iter-

ation. The findings are that the PG is more effective than manual AHP in several specific ways:

1. The PG took less time on average than manual AHP to rank a set of stories.
2. The PG was regard as easier to use by the subjects than manual AHP.
3. The subjects perceived the PG as more accurately reflecting their views than manual AHP [32].

L. Karlsson, Thelin, Berander, Regnell, and Wohlin followed this experiment up with a second experiment to compare the PG with tool-supported AHP (called only "tool-supported pair-wise comparison" in their paper) as implemented by FocalPoint. This experiment found that

1. tool-supported AHP requires less time than manual AHP, and tool-supported AHP requires less time than the PG,
2. it could not be determined objectively which of tool-supported AHP and the PG is easier to use although a majority of the subjects regarded tool-supported AHP as easier to use than the PG
3. it could not be determined objectively which of tool-supported AHP and the PG is more accurate although a majority of the subjects preferred the PG to tool-supported AHP [33].

- suggestions for improvements [44] to AHP, usually for overcoming the scalability problem,

The main approach to allowing AHP to be scaled to larger sets of requirements is to reduce the number of pairs of requirements to be compared. Recall that J. Karlsson, Wohlin, and Regnell suggested Hierarchy AHP as a variation of AHP to reduce the number of pairs to consider by grouping requirements to be ranked by abstraction level and then comparing any requirement to only those of the same level [30].

Avesani, Bazzanella, Perini, and Susi attempted to mitigate the combinatorial explosion of pair-wise comparison suffered by AHP applied to a large set of requirements. They used a machine learning algorithm that tries to approximate the rankings of some pairs by using predefined ranking criteria combined with already assigned rankings to reduce the number of pairs of requirements that humans have to rank. In an industrial case study comparing the learning algorithm to complete manual AHP, the learning algorithm was able to achieve 96% accuracy compared to the manual ranking while ranking only 8% of the full number of pairs. Interestingly, the learning algorithm tool uses a Web interface to allow a user to do her rankings [2].

- discussion of general challenges to RE, including that of ranking requirements by priority, caused by a distributed location of stakeholders [14],
- suggestions of techniques for distributed ranking of requirements by priority [49],

Regnell, Höst, Nott och Dag, Beremark, and Hjelm conducted a case study of a distributed requirements ranking effort in an industrial market-driven RE effort. The study evaluated the effectiveness of a variety of visualizations in helping stakeholders collectively choose features to implement in the next release of the software product being built. In the effort, each stakeholder represented a market segment for the product. The 58 features were divided into 17 groups of features that should be implemented together. Each stakeholder monolithically ranked the 17 groups and the 58 individual requirements into one list of 75 items in which each item received its appropriate share of $100K. One of the visualizations is a bar graph that matches the bar graphs of Figs. 18 and 19 of this paper. While the project used monolithic ranking, the authors suggest that in the future AHP will be used to simplify the process of ranking prior to the displaying. The automatic generation of the visualization displays from stakeholders' rankings assists in continuous ranking as new requirements arrive on the scene and as the market changes [55,56].

Hagge and Lappe offer a requirements engineering pattern specifically applicable to distributed shareholder groups [18]. Their Pattern 1 suggests organizing the specification procedure along the project structure. MCPRRT follows the advice of this pattern. MCPRRT organizes the priority ranking according to the structure of the distributed stakeholder groups; each group contributes its input independently and the organizational chart for these groups dictates the groups' weights that are used to distill the different sets of requirement rankings into a single one for the whole organization. Moreover, by using the Internet, an established communication channel is used.

- proposal for a method of financially informed ranking of requirements by priority [12],
- empirical study of empirical studies to evaluate the validity of using students as subjects in empirical studies of ranking requirements by priority [5].

6. Lessons learned during case study

Sobczak collected comments from the five representative stakeholders during the use of the tool and during the writing of the requirements based on the tool's output

- The most common comment was that the use of the tool was time consuming. However, four agreed that the use of the tool was a good investment, in that they learned things about the system that they were going to be building before building it rather than during its construction or after its deployment.
- All five found the ranking information useful and used it to prepare a final requirements document, which, as mentioned was included in a funding proposal to the European Union for the specified MIS.

- The decision maker stakeholder representative regarded the exercise as a success, while the other four stakeholders, who were under orders to participate, were not so sure about the degree of success. However, because the decision maker is the one who makes the final decisions about the conduct of the project, that he considers the exercise a success was sufficient to ensure the tool's continued and future use.
- The administrator stakeholder thought he would use such a tool in the future, but he was concerned about security. He was reacting to the tool's use of the Internet and the http protocol. He suggested changing the protocol to the https protocol. This change will be enacted for future versions of the tool.
- Three stakeholders pointed out that the tool needed a way to import requirements from any of the standard requirements engineering environments such as RequisitePro [22] and DOORS [52].

We did not observe any of the problems with AHP that were reported in Section 5. The fact that the preliminary requirements were strategic in nature

1. kept the number of requirements down to 11, a manageable number for which pair-wise comparison was not overly burdenson.
2. caused all the requirements to be of the same level of abstraction; thus, comparison of all pairs of requirements was meaningful.

None of the stakeholders complained that he did not trust or that he did not believe the results computed by the tool. It appears that the tables and graphs produced by the tools made the results transparent enough that each stakeholder could trust and believe the results.

Each of the representative stakeholders was technically savvy to the point that use of the tool presented no real obstacle. On the contrary, the tool probably provided enough technical novelty to forestall major complaints. Also, it appears that each stakeholder had enough experience from past efforts to know that this effort was proceeding better.

7. Conclusions and future research

MCPRRT has the following advantages:

- It enables strategic goals of a commercial organization to be taken into account in the process of preliminary requirements ranking;
- It enables aggregate ranking of preliminary requirements based on economic, organizational, and technological aspects of the organization.
- It enables the requirements engineers to concentrate their initial attention on just *getting* the requirements from major stakeholders without worrying at the same time about ranking them by priority.

The main conclusions from the research are as follows:

1. MPRAC enables systematic analysis of criteria by which to evaluate requirements.
2. MPRAC enables considering strategic goals of an organization in determining the criteria by which to analyze preliminary requirements.
3. MCPRRT enables determination of the importance of each preliminary requirement based on the criteria determined from the strategic goals considered in MPRAC.
4. MCPRRT ensures that the ranking of preliminary requirements by priority takes into account the opinions of stakeholder groups and that it yields a single aggregated ranking.
5. MCPRRT makes it possible for MIS designers to concentrate on the needs of all essential stakeholder groups.

As noted by a majority of the stakeholders participating in the case study, the MCPRRT ranking process is laborious. Therefore, it is advisable to find ways to optimize MCPRRT. One referee suggests applying MCPRRT to its own requirements, with optimization as an important preliminary requirement, as one way to achieve this goal.

Finally, the reader is reminded that the case study of Section 4 is no more than one case study. Therefore, any conclusions drawn from the case study cannot be generalized to be applicable to all distributed rankings of requirements by priority. On the other hand, the case study is of the use of MCPRRT and its tool to rank the requirements of a genuine system with real customers.

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Appendix A. List of priority-ranked preliminary requirements

No.	Preliminary requirements
R1	Handling official matters by city office's customers (both individuals and corporate bodies) through the Internet.
R2	Publication of information (in various language versions) on the Internet by city office.
R3	Handling of the circulation of electronic documents within city office.
R4	Handling of electronic mail.
R5	Use of computer-aided information techniques to train city office's staff.
R6	Handling of electronic democracy-type developments.
R7	Publication of city office's daily paper on the Internet.
R8	Provision of maps and diagrams on the Internet.
R9	Collection of the official data in the electronic form in combination with the possibility of their advanced searching by electronic means.
R10	Personalization of the access to the collected information (data).
R11	Management of city office's human and technological resources.

Appendix B. List of the criteria in the individual MPRAC planes

I. Business values plane

1. Criterion: expenditures required to implement the preliminary requirement; these include the cost of acquiring necessary licenses and the costs of the implementation and necessary training. Measure: amount required to implement the preliminary requirement.
2. Criterion: scope of improving the management of city's assets, such as building sites, houses for residential and business purposes, etc. Measure: time necessary to access information on the actual condition of the city's assets.
3. Criterion: level of risk of disturbing the implementation of the preliminary requirement. Measure: number of days of the expected delay in the implementation of the preliminary requirement.

II. Customers plane

1. Criterion: time to serve the city's customers. Measure: time to serve the city's customers.
2. Criterion: quality level of services rendered to city's customers. Measure: number of errors made while serving city's customers.
3. Criterion: level of support offered to businesses operating in the city. Measure: time necessary for businesses to access official city information.
4. Criterion: level of support for attracting external investors. Measure: time necessary for investors to access information on the conditions of investment in the city.
5. Criterion: level of difficulty of meeting the preliminary requirement by the users. Measure: time necessary to acquire the ability to operate the preliminary requirement.

III. Internal process plane

1. Criterion: level of improving the circulation of documents within the city's offices. Measure: number of misaddressed or lost documents.
2. Criterion: level of improving the administrative procedures run in the city's offices. Measure: number of originally-misapplied administrative procedures.
3. Criterion: scope of support for planning the city's development. Measure: number of different types of report generated to facilitate planning the development of a self-governmental unit.
4. Criterion: level of improving information flow within the city's offices. Measure: number of ad meritum queries between individual departments of the city's offices.

IV. System development plane

1. Criterion: scope of the possibilities to extend the functionality of the preliminary requirement. Measure: number of accessible macros or instructions in the internal language.
2. Criterion: level of flexibility of the preliminary requirement Measure: number of accessible parameters that make it possible to customize the preliminary requirement according to city's needs.
3. Criterion: level of difficulty of integrating the preliminary requirement with the computer systems already operated by the city' offices Measure: degree of utilization of open standards in the implementation of the preliminary requirement.
4. Criterion: level of utilization of advanced technologies. Measure: level of use of Internet standards or object technologies by the preliminary requirement.

References

[1] Apache Software Foundation, "Apache Tomcat" (2006), http://tomcat.apache.org/.
[2] P. Avesani, C. Bazzanella, A. Perini, A. Susi, Supporting the Requirements Prioritization Process. A Machine Learning Approach, in: Proceedings of the Sixteenth International Conference on Software Engineering and Knowledge Engineering (SEKE 2004), KSI Press, Banff, AB, Canada, 2004, pp. 306–311.
[3] V.L. Barker, I.M. Duhaime, Strategic change in the turnaround process: theory and empirical evidence, Strategic Management Journal 18 (1997) 13–38.
[4] K. Beck, Extreme Programming Explained: Embrace Change, Addison-Wesley, Reading, MA, 1999.
[5] P. Berander, Using Students as Subjects in Requirements Prioritization, in: Proceedings of the International Symposium on Empirical Software Engineering (ISESE'04), IEEE Computer Society (19–20 August 2004), pp. 167–176.

[6] D.M. Berry, The importance of ignorance in requirements engineering, Journal of Systems and Software 28 (2) (1995) 179–184.
[7] B. Boehm, P. Bose, E. Horowitz, M.J. Lee. Software requirements as negotiated win conditions, in: Proceedings of the First International Conference on Requirements Engineering (ICRE94), IEEE Computer Society, Colorado Springs, CO, 1994, pp. 74–83.
[8] B.W. Boehm, R. Ross, Theory W software project management: principles and examples, IEEE Transactions on Software Engineering SE-15 (7) (1989) 902–916.
[9] F.P. Brooks Jr., No silver bullet, Computer 20 (4) (1987) 10–19.
[10] R. Budde, K. Kuhlenkamp, L. Mathiassen, H. Züllighoven, Approaches to Prototyping, Springer-Verlag, Berlin, 1984.
[11] R.J. Calantone, A. Di Benedetto, J. Schmidt, Using the analytic hierarchy process in new product screening, Journal of Product Innovation Management 16 (1) (1999) 65–76.
[12] J. Cleland-Huang, M. Denne, Financially informed requirements prioritization, in: Proceedings of the Twenty-Seventh International Conference on Software Engineering (ICSE'05), ACM Inc., St. Louis, MO, USA, 2005, pp. 710–711.
[13] J. Coughlan, D.M. Robert, Effective communication in requirements elicitation: a comparison of methodologies, Requirements Engineering 7 (2) (2002) 47–60.
[14] D. Damian, D. Zowghi, RE challenges in multi-site software development organisations, Requirements Engineering Journal 8 (3) (2003) 149–160.
[15] A. Davis, The art of requirements triage, IEEE Computer 36 (3) (2003) 42–49.
[16] Eclipse Fouccation, Eclipse—An Open Development Platform, 2006, http://www.eclipse.org/.
[17] Expert Choice, AHP References Partial Listing, 2006, http://www.expertchoice.com/alip/default.ritm/.
[18] L. Hagge, K. Lappe, Sharing requirements engineering experience using patterns, IEEE Software 22 (1) (2005) 24–31.
[19] G. Herzwurm, S. Schockert, W. Mellis, Higher customer satisfaction with prioritizing and focused software quality function deployment, in: Proceedings of the Sixth European Conference on Software Quality in Vienna, Wien, 12–16 April 1999.
[20] S. Hsu-Shih, L. Wen-Yuan, E.S. Lee, Group decision making for TOPSIS, in: Proceedings of the Joint Ninth IFSA World Congress and Twentieth NAFIPS International Conference, July 2001, pp. 2712–2717.
[21] E. Huizingh, H. Vrolijk, Decision Support for Information Systems Management: Applying Analytic Hierarchy Process, Research Report 95B26, Universiteitsbibliotheek Groningen, 1995.
[22] IBM, Rational RequisitePro, Read 21 July 2004, IBM Corporation, 2004, http://www-306.ibm.com/software/awdtools/reqpro/.
[23] H. In, B. Boehm, T. Rodgers, M. Deutsch, Applying WinWin to quality requirements: a case study, in: Proceedings of the International Conference on Software Engineering (ICSE 2001), IEEE Computer Society Press, Toronto, Canada, 2001, pp. 555–564.
[24] H. In, D. Olson, T. Rodgers, A requirements negotiation model based on multi-criteria analysis", in: Proceedings of the International Symposium on Requirements Engineering (RE'01), Toronto, Canada, 2001, pp. 312–313.
[25] H. In, B. Boehm, Using WinWin quality requirements management tools: a case study, Annals of Software Engineering 11 (2001) 141–174.
[26] International Standards Organization, Software Engineering – Product quality – Part 4: Quality in Use Metrics", SO/IECTR 9126-4:2004, International Standards Organization, 2004, http://www.iso.org/iso/en/CatalogueDetailPage.CatalogueDetail?CSNUMBER=39752.
[27] R. Kaplan, D. Norton, The balanced scorecard: measures that drive performance, Harvard Business Review (1992) 71–79.
[28] R. Kaplan, D. Norton, Using the balanced scorecard as a strategic management system, Harvard Business Review (1996) 75–85.
[29] J. Karlsson, S. Olsson, K. Ryan, Improved practical support for large-scale requirements prioritizing, Requirements Engineering 2 (1) (1997) 51–60.
[30] J. Karlsson, C. Wohlin, B. Regnell, An evaluation of methods for prioritizing software requirements, Information and Software Technology 39 (1998) 939–947.
[31] J. Karlsson, J. Brunnberg, Requirements Collaboration: prioritization and planning over the internet, in: Proceedings of Product Models, 2000, pp. 139–154.
[32] L. Karlsson, P. Berander, B. Regnell, C. Wohlin, Requirements prioritisation: an experiment on exhaustive pair-wise comparison versus planning game partitioning, in: Proceedings International Conference on Empirical Assessment in Software Engineering, Edinburgh, UK, 2004, pp. 145–154.
[33] L. Karlsson, T. Thelin, B. Regnell, P. Berander, C. Wohlin, Pair-wise comparisons versus planning game partitioning – experiments on requirements prioritisation techniques, Empirical Software Engineering, 2006 (to appear).
[34] Komisji Europejskiej, eEuropa+—wspólne działania na rzecz wdrożenia Społeczeństwa Informacyjnego w Europie, Plan działań sporządzony przez kraje kandydujące przy wsparciu Komisji Europejskiej—wersja polska, Komitet Badan Naukowych, Warszawa, Polska, 2001.
[35] Komitet Badan Naukowych, Wrota Polski, Wydanie Pierwsze, Komitet Badań Naukowych (Grudzien 2002).
[36] L. Lehtola, M. Kauppinen, Empirical evaluation of two requirements prioritization methods in product development projects, in: Proceedings of the European Software Process Improvement Conference (EuroSPINo. 11), Springer, Trondheim, Norway, 2004, pp. 161–170.
[37] L. Lehtola, M. Kauppinen, S. Kujala, Requirements prioritization challenges in practice, in: Proceedings of Fifth International Conference on Product Focused Software Process Improvement, Kansai Science City, Japan, 5–8 April 2004, pp. 497–508 .
[38] L. Lehtola, M. Kauppinen, Suitability of requirements prioritization methods for market-driven software product development, Software Process Improvement and Practice (SPIP) 11 (2006) 7–19.
[39] M. Limayem, G. DeSanctis, Providing decisional guidance for multicriteria decision making in groups, Information Systems Research 11 (4) (2000) 386–401.
[40] M. Martinsons, R. Davison, D. Tse, The balanced scorecard: a foundation for the strategic management of information systems, Decision Support Systems (25) (1999) 71–88.
[41] C. McPhee, A. Eberlein, Requirements engineering for time-to-market projects, in: Proceedings of the Ninth Annual IEEE International Conference and Workshop on the Engineering of Computer-Based Systems (ECBS 2002), Lund, Sweden, 8–11 April 2002.
[42] Ministerstwo Gospodarki, ePolska – plan działań na rzecz rozwoju Społeczeństwa Informacyjnego w Polsce na lata 2001–2006, Wydanie Pierwsze, Warszawa, Polska , 2001.
[43] F. Moisiadis, A framework for prioritizing use cases, in: Proceedings of the Conference on Advanced Information Systems Engineering, CAiSE*98, Pisa, Italy, 8–9 June 1998.
[44] F. Moisiadis, The fundamentals of prioritising requirements, in: Proceedings of the Systems Engineering, Test and Evaluation Conference, Sydney, NSW, Australia, October 2002.
[45] M. Moszoro, A. Obłuski, M. Posern-Zielińska, B. Turowski, M. Wójcik, S. Wysocki, Standard usiug publicznych-miara oczekiwah obywateli i narzędzie pomiaru efektywności działań administracji, Wydanie Pierwsze, Umbrella, Warszawa, Polska, 2002.
[46] MySQL AB, MySQL: The World's Most Popular Open Source Database, 2006, http://www.mysql.com/.
[47] B. Nuseibeh, S. Easterbrook, Requirements Engineering: A Roadmap, in: A. Finkelstein (Ed.), The Future of Software Engineering 2000, ACM, Limerick, Ireland, 2000.
[48] B. Paech, B. Reuschenbach, Open source requirements engineering, in: IEEE International Conference on Requirements Engineering (RE'06), IEEE Computer Society, Minneapolis-St. Paul, MN, USA, 2006.

[49] J. Park, D. Port, B. Boehm, H. In, Supporting distributed collaborative prioritization for WinWin requirements capture and negotiations, in: Proceedings of the Third International World Multiconference on Systemics Cybernetics and Informatics (SCI'99), 1999, pp. 578–584.
[50] J. Park, D. Port, B. Boehm, Supporting distributed collaborative prioritization, in: Proceedings of the Asia-Pacific Software Engineering Conference APSEC '99, Takamatsu, Japan, 7–10 December 1999.
[51] B.E. Perrott, Managing strategic issues in the public service, The Journal of Strategic Management: Long Range Planning 29 (3) (1996) 337–345.
[52] QSS, DOORS V3.0 Reference Manual, Quality Systems and Software, Mt. Arlington, NJ, 1996.
[53] Rada Miasta, Strategia rozwoju miasta 2002-2010, Załącznik do Uchwaly Rady Miasta, Krakow, Polska, 2002.
[54] V.M. Rao Tummala, Y.W. Wan, Analytic Hierarchy Process (AHP) in Practice: A Survey of Applications and Recent Developments, Technical Report, Department of Manufacturing Engineering, City Polytechnic of Hong Kong, Kowloon, Hong Kong, 27 November 1993.
[55] B. Regnell, M. Höst, J. Natt och Dag, P. Beremark, T. Hjelm, Visualization of agreement and satisfaction in distributed prioritization of market requirements, in: Proceedings of the Sixth International Workshop on Requirements Engineering: Foundation for Software Quality (REFSQ), Stockholm, Sweden, 5–6 June 2000.
[56] B. Regnell, M. Höst, J. Natt och Dag, P. Beremark, T. Hjelm, An industrial case study on distributed prioritisation in market-driven requirements engineering for packaged software, Requirements Engineering 6 (1) (2001) 51–62.
[57] M. Rosemann, J. Wiese, Measuring the performance of ERP software — a balanced scorecard approach, in: Proceedings of the Australasian Conference on Information Systems, Wellington, New Zealand, 1999.
[58] M. Rosemann, Evaluating the Management of Enterprise Systems with the Balanced Scorecard, in: Evaluating the Management of Enterprise Systems, Idea Group Publishing, 2001.
[59] G. Ruhe, A. Eberlein, D. Pfahl, Quantitative WinWin—A New Method for Decision Support in Requirements Negotiation, in: Proceedings of the Fourteenth International Conference on Software Engineering and Knowledge Engineering (SEKE'2002), Ischia, Italy, July 2002.
[60] T.L. Saaty, The Analytic Hierarchy Process, McGraw Hill, New York, NY, USA, 1980.
[61] H. Salmela, Designing information systems for changing organizations, in: M. Tanniru (Ed.), Proceedings of the ACM SIGCPR Conference, St. Louis, MO, USA, 1–3 April 1993, pp. 243–254.
[62] D. Sedera, G. Gable, M. Rosemann, A balanced scorecard approach to enterprise systems performance measurement, in: Proceedings of the Twelfth Australasian Conference on Information Systems, Coffs Harbour, Australia, 4–7 December 2001.
[63] R.P. Sejm, Ustawa o samorządzie terytorialnym, Dz.U. 1990, Nr 16, poz. 95 z późniejszymi zmianami, 1990.
[64] R.P. Sejm, Ustawa z dnia 10 czerwca 1994 r. o zamówieniach publicznych znowelizowana 21 grudnia 2001 r, Dz. U. Nr 154, poz. 1802, Warszawa, Polska, 1994.
[65] R.P. Sejm, Ustawa z 26 listopada 1998 r. o finansach publicznych, Tekst ujednolicony po zmianie z 30 sierpnia 2002 roku, Dz. U. Nr 156, Warszawa, Polska, 1998.
[66] R.P. Sejm, Ustawa z dnia 24 lipca 1998 roku o wprowadzeniu zasadniczego trojstopniowego podzialu terytori-alnego państwa", Dz. U. nr 96, poz. 603, Warszawa, Polska, 1998.
[67] R.P. Sejm, Ustawa z dnia 18 września 2001 r. o podpisie elektronicznym, Dz. U. Nr 130 z 15 listopada 2001 r, poz. 1450, Warszawa, Polska, 2001.
[68] R.P. Sejm, Ustawa z dnia 6 września 2001 r. o dostejrie do informacji publicznej, Dz. U. Nr 112 z 8 pazdziernika 2001 r, poz. 1198, Warszawa, Polska, 2001.
[69] R.P. Sejm, Ustawa o informatyzacji w działalności organów władzy publicznej (projekt), Projekt z 30 września 2002 r, Komitet Badan Naukowych, Warszawa, Polska, 2002.
[70] H. Sharp, A. Finkelstein, G. Galal, Stakeholder identification in the requirements engineering process, in: Proceedings of the 1999 Workshop on Requirements Engineering Process (REP'99), Florence, Italy, September 1999.
[71] A. Sobczak, Zarządzanie procesem zmian w systemach informatycznych, in: VIII Konferencja Sieci i Systemy Informatyczne, Łódź 2000, Antoni M. Zajączkowski, Politechnika Łódźka, Łódź, Polska (Październik 2000), pp. 119–133.
[72] A. Sobczak, Defining Requirements for Information Systems in the Context of the Strategic Management of the Public Sector Units, in: Konferencja Business Information System, Poznari, Polska, 2002.
[73] H. Sosnowska, Grupowe podejmowanie decyzji – elementy teorii, przykiady zastosowah, Wydanie Pierwsze, Wydawnictwo Naukowe, Scholar, Warszawa, Polska, 1998.
[74] A. Stabryla, Zarządzanie strategiczne w teorii i praktyce firmy, Wydanie Pierwsze, Wydawnictwo Naukowe PWN, Warszawa-Krakow, Polska, 2000.
[75] Sun Micro Systems, JavaServer Pages Technology, 2006, http://java.sun.com/products/jsp/.
[76] Telologic, FocalPoint, 2006, http://www.telelogic.com/campaigns/focalpoint/index.cfm redirected from http://www.focalpoint.se.
[77] E. Triantaphyllou, S.H. Mann, Using the analytic hierarchy process for decision making in engineering applications: some challenges, International Journal of Industrial Engineering: Applications and Practice 2 (1) (1995) 35–44.
[78] E. Triantaphyllou, B. Shu, S. Nieto Sanchez, T. Ray, Multi-Criteria Decision Making: An Operations Research Approach, in: J.G. Webster (Ed.), Encyclopedia of Electrical and Electronics Engineering, John Wiley & Sons, New York, NY, USA, 1998, pp. 175–186.
[79] J.T. Van der Zee, B. de Jong, Alignment is not Enough: Integrating Business and Information Technology Management with the Balanced Business Scorecard, Journal of Management Information System 16 (2) (1999) 137–158.
[80] W. Van Grembergen, R. Saull, Aligning business and information technology through the balanced scorecard at a major canadian financial group: its status measured with an IT BSC maturity model, in: Proceedings of the Thirty-fourth Annual Hawaii International Conference on System Sciences (HICSS-34), Maui, HI, USA, 03–06 January 2001.
[81] K.E. Wiegers, Software Requirements, Microsoft Press, Redmond, WA, USA, 1999.
[82] E.S.K. Yu, Towards modelling and reasoning support for early-phase requirements engineering, in: Proceedings of the Third IEEE International Symposium on Requirements Engineering, Annapolis, MD, USA, 1997.
[83] Y. Zhu, A. Buchmann, Evaluating and selecting web sources as external information resources of a data warehouse, in: Proceedings of the Third International Conference on Web Information Systems Engineering (WISE2002), Singapore, 2002.