Research Journal of Applied Sciences 9 (12): 1185-1190, 2014
ISSN: 1815-932X

Supporting Tools for Decision Making in the Outdoor Lighting Control Systems

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Abstract: Study is devoted to the development of tools for decision support systems in the outdoor lighting control in the process of their life cycle. A model of the life cycle of automated control systems for outdoor lighting which implies the need for the development of decision support tools. Researchers consider the problem of ranking system functions at the stage of design and development. The solution to this problem is connected with the development of a hierarchy of selection criteria and the subsequent decision of the problem of increasing the consistency of expert judgments in the survey on the constructed structure. The tools developed have been an experimental study on the adequacy and performance. The proposed methods and algorithms used by the researchers in the developed software.

Key words: Decision making, paired comparisons, the consistency of paired comparison matrix, performance, expert data processing, life cycle support

INTRODUCTION

An automated system Life Cycle (LC) is the system development, starting from the conceptual stage of development and ending with the system application cessation.

From this definition, it follows that the identification and the LC Model selection primarily addresses such issues as the requirements determinacy and stability, the severity and attention to detail for the work plan as well as the frequency of new software versions release. The life cycle models are divided into three main types: cascade, iterative and spiral one. The Spiral Model of the LC is the preferred one for an Automated Control System of Outdoor Lighting (ACSOL) as the ACSOL development is associated with poor detailing of the works with their complexity and the need for the frequent release of new system prototypes (Wojnicki *et al*., 2014).

In a general way the ACSOL improvement sequence according to the Spiral Model may be represented as a diagram (Fig. 1). General ACSOL development diagram according to the Spiral Model may be represented in the form of a diagram (Fig. 1).

Figure 1 generalized scheme of development systems is made in a spiral pattern. An objective expert assessment shall be taken in accordance with a specific set of requirements at each design iteration and the function of system development. Therefore, it is necessary to solve the problem of the system functions ranking (Ulrich and Eppinger, 2008).

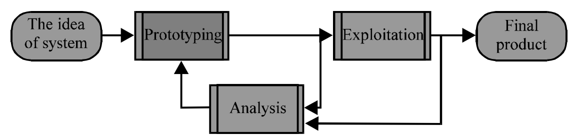

Fig. 1: General ACSOL development diagram according to the Spiral Model

In order to range the system functions it is necessary to define a system of criteria and choose an appropriate method of decision-making. Due to the fact that the task of functions ranking is related to weakly structured and multi-criteria tasks for decision-making the Method of Hierarchy Analysis was chosen (MHA) (Saaty, 1990a; Battistoni *et al*., 2013; Soota *et al*., 2008).

MAIN PART

Systematization of criteria for ranking the features of outdoor lighting control systems: Let us analyze the criteria that should be used by experts to assess the intensity of the properties concerning the manifestation of separate system functions. In the view, it is rational to distribute all criteria by clusters such as economic, technical and organizational ones. Let's choose and describe the criteria included in these clusters.

Mt subset (Fig. 2) consists of Kd: implementation complexity, Ks: impact on the system reliability, Ki: integrability with other technical solutions and systems, Ksc: functional scalability, Kexp: implementation experience for this kind of functionality, Keq: the quality

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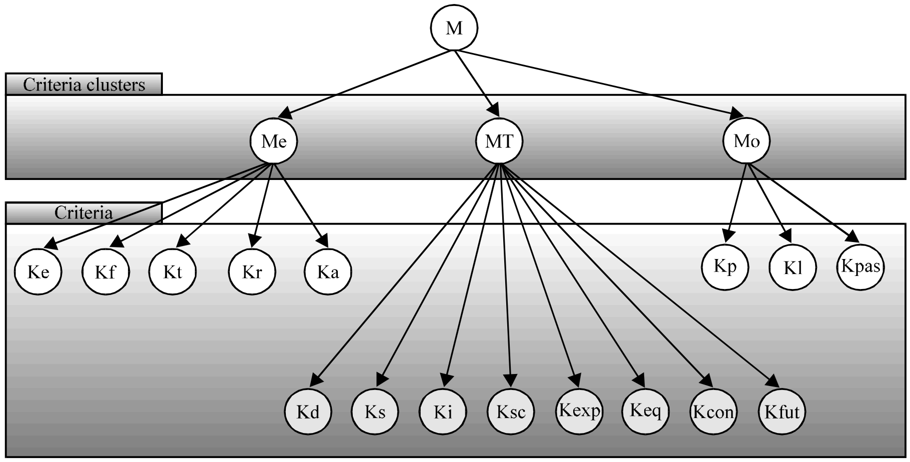

Fig. 2: Criteria structure in a formalized manner; ME subset consists of Ke: the economic effect of the function introduction into the system; Kf: the financial costs for the function implementation; Kt: time costs; Kr: the risk of future irrelevance of this function; Ka: the relevance of this function

of the laboratory equipment, Kcon: he degree of the proposed technical and technological solution elaboration, Kfut; the impact on future developments.

Mo subset consists of 4 criteria: Kp: the availability of staff to implement the function, KI: the level of team preparation, Kpas: the team enthusiasm to implement the function.

Getting the matrix coherence assessment: The practical use of the proposed approach to rank the functions provided some difficulties associated with the obtaining of the expert consistent judgments. On the one hand MAI is focused on the formation of a pair comparison matrix by a man on the other hand, there are recommendations on the numerical limits of consistency parameters (Saaty, 1990b). During the practical use of decision-making methods the issues of enhancing the coherence of judgments are complex enough for Decision Makers (DM) and experts. Therefore, there is need to address the problem of improving the pair comparison matrix coherence used in MAI. During the study of coherence improvement methods (Cao *et al.*, 2008; Ishizaka and Lusti, 2004; Harker, 1987) their disadvantages were identified associated with the complexity of the process and the inability to determine the specific judgments of experts who have the least consistency with other judgments.

We propose a new method for the detection and automatic correction of specific judgments (Lomakin and Lifirenko, 2013), influencing the low coherence of paired comparisons which we will tentatively call as the wrong ones. Let's describe a series of steps to obtain more coherent judgments on the basis of the proposed method application. Let's consider the pair comparison matrix A:

$$A = \begin{pmatrix} a_{11} & \dots & a_{1j} & \dots & a_{1n} \\ \dots & \dots & \dots & \dots & \dots \\ a_{i1} & \dots & a_{ij} & \dots & a_{in} \\ \dots & \dots & \dots & \dots & \dots \\ a_{n1} & \dots & a_{nj} & \dots & a_{nn} \end{pmatrix} \quad (1)$$

In order to determine the matrix consistency let's use the property of completely coherent matrix. This is the property of strict connection of n elements in a completely coherent matrix and they satisfy the following property a_{ij}/a_{kj} = const, j = 1, ..., n.

Then, the lines of the matrix A may be regarded as the vectors $\vec{a_i} = (a_{i1} \quad a_{i2} \quad \dots \quad a_{in})$ and in the case of totally coherent matrix they shall be parallel to each other $\vec{a_i} \,||\, \vec{a_j}, (\cos(\angle \vec{a_i}\vec{a_j}) = 1)$. As can be seen, the dependence reduction of the matrix elements and thus the angle increase between the vectors from the matrix line elements indicates that the matrix consistency is also reduced and vice versa. Thus, calculating the cosine of the angle between the vectors, we define the degree of pair comparison matrix coherence.

Let's use the well known calculation formula to determine the cosine of the angle between the vectors (Eq. 2):

$$\Psi_{xy} = \frac{\langle \vec{x}, \vec{y} \rangle}{\sqrt{\langle \vec{x}, \vec{x} \rangle \cdot \langle \vec{y}, \vec{y} \rangle}} \quad (2)$$

where, $\langle \vec{x}, \vec{y} \rangle$ the scalar product of x and y vectors. Then, the equation for the cosine angle determination between the vectors (Eq. 2) in relation to the pair comparison matrix (Eq. 1) may be put down as follows:

$$\psi_{ij} = \frac{\sum_{k=1}^{n} a_{ik} . a_{jk}}{\sqrt{\sum_{k=1}^{n} a_{ik}^2 \sum_{k=1}^{n} a_{jk}^2}} \quad (3)$$

Thus, on the basis of Eq. 2 and 3 we obtain the following matrix for each pair comparison:

$$\Psi = \begin{pmatrix} 1 & \psi_{12} & \dots & \psi_{1n} \\ \psi_{21} & 1 & \dots & \psi_{2n} \\ \dots & \dots & 1 & \dots \\ \psi_{n1} & \psi_{n2} & \dots & 1 \end{pmatrix} \quad (4)$$

The main matrix diagonal **Ψ** is a single one as the cosine of the angle in these elements is defined for two same vectors, the values of other matrix elements correspond to the inequality: $0 \le \Psi_{ij} \le 1$. According to **Ψ** matrix one may estimate the degree of coherence for each pair comparison in relation to the others. In this case, the lowest value of the angle cosine indicate the pair comparisons which is agreed with the others in the least.

Coherence functional: According to **Ψ** matrix one may determine the overall degree of matrix aconsistency. This requires the average value of the angle cosine obtaining in the matrix A. This requires the obtaining of angle cosine average value in **Ψ** matrix and then its deviation from the absolute coherent matrix wherein the average value of the angle cosine takes the value of 1. According to the preceding discussions, let's introduce a functional which is the following coherence measure:

$$F(\psi) = 1 - \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} \psi_{ij}}{n^2} \quad (5)$$

The minimization of the functional (Eq. 5) subject to the limitations associated with the features of MAI scale, results in a more coherent matrix of pair comparisons and in more logical and correct management decision.

In order to develop the process of consistency improvement in an automatic mode, let's use the graph G (Eq. 8):

$$G = \langle V, E \rangle \quad (6)$$

Where:

$V = \{v_1, v_2, ..., v_n\}$ = The set of peaks consisting of comparison elements

$E = \{e_1, e_2, ..., e_m\}$ = The set of edges, characterizing the presence of comparative evaluation for a pair of peaks

n = The number of comparison elements

m = The number of comparisons, equal to n(n-1)/2 if the comparison is performed for all pairs of elements

Let's consider that the graph G (6) is an oriented one, and the edge direction indicates the superiority of one element over the other one. Let's define the sets S and W for E edges. The set S sets the superior comparative assessments:

$$S = \{s_1, s_2, ..., s_m\} \quad (7)$$

The set W sets the weight that determines the degree of the judgment logical consistency equal to the cosine of the **Ψ** matrix angle:

$$W = \{w_1, w_2, ..., w_m\} \quad (8)$$

Let's determine the Pareto optimal comparisons according to calculated matrix of **Ψ** angle cosine to develop the new matrix A'. In order to search the Pareto optimal comparisons let's use the algorithm to obtain the maximum spanning graph of the weighted related undirected graph (Kruskal, 1956). The search is performed on an undirected graph as in this case, keeping the superiority of one element over another is not important.

The addition of the spanning graph is performed by the search of all peak pairs of the spanning graph which have no direct connection, the obtaining of the corresponding values for these pairs and the determination of new assessments $S' = \{s'_1, s'_2, ..., s'_m\}$. The value of comparative assessment s'_i, is obtained by moving along the route of the spanning graph connecting the peaks of the considered pair and by multiplying the comparative assessments. If the motion is performed against the edge direction, we take the reciprocal of the comparative evaluation. Thus, at the calculation of comparative assessments as the property of absolutely coherent matrix is used obtained S' will meet a new W' set will be used all elements of which are single ones.

When you receive a set of comparative assessments S' during the estimate concordance phase the situation occurs often when the values of new estimates are outside the range used in MAI scale. For example, the value $s'_1 = 6$ corresponds to the element 1 excess compared with the element 2 and the value $s'_2 = 3$ corresponds to the fact, that the element 2 exceeds the element 3 moderately. Then it is mathematically correct, that the superiority of the element 1 over the element 3 will be as follows $s'_3 = 18$. As can be seen, the application of MAI scale s'_3 goes beyond the permissible LIMITS (the maximum score is 9).

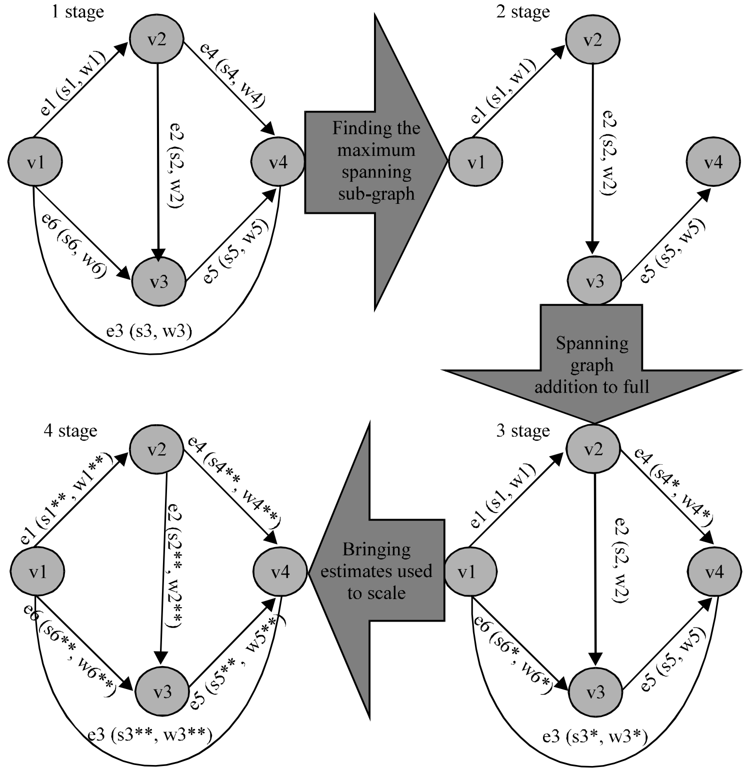

Fig. 3: The process of pair comparison coherence matrix automatic increase

Due to this, it is necessary to transfer the assessment S' into the assessments S'', corresponding to the scale in use. One may propose the step correspondence formula for the transfer according to a new scale for the accepted scale step:

$$h=\frac{\max(S')-1}{\max(S'')-1} \quad (9)$$

Where:

max (S') = The maximum comparative evaluation in a variety of evaluations S' which determines the upper limit of the calculated estimates and

max (S'') = The maximum comparative evaluation in a variety of S'' evaluations of the scale in use

Thus, one may develop the correspondence table of one scale to another one and then obtain on the basis of it S'' according to S'. For example, MAI 3 scale values will correspond to the estimates in the range from 1+h to 1+2h, and the unit of the other scale corresponds with the unit (the equality of two objects being compared).

At the obtaining of S'' with the evaluations corresponding to the scale in use, the A' matrix is filled in. The correspondence of new matrix A' is checked by OS calculation and the functional proposed by us (Eq. 5).

Methods of pair comparison matrix coherence improvement: Thus, the process of improving the pair comparison matrix coherence consists of 4 stages (Fig. 3):

- Pair comparison development of the graph G according to original matrix (Eq. 6)
- The search of the maximum spanning subgraph in column G (6)
  The addition of the spanning graph to complete graph
- The reduction of the obtained estimates to the applicable scale estimates

The adjustment process in fully automatic mode is not always possible as there are cases of low consistency when the analysis of raw data does not provide useful information during adjustment. In the case of a significant initial data mismatch an iterative process is needed to improve the consistency and in some cases the adjustment will not be able to help and an expert survey is necessary to perform again.

The iterative process of adjustment determines a separate element of comparison with the lowest consistency degree and the recommended assessment is

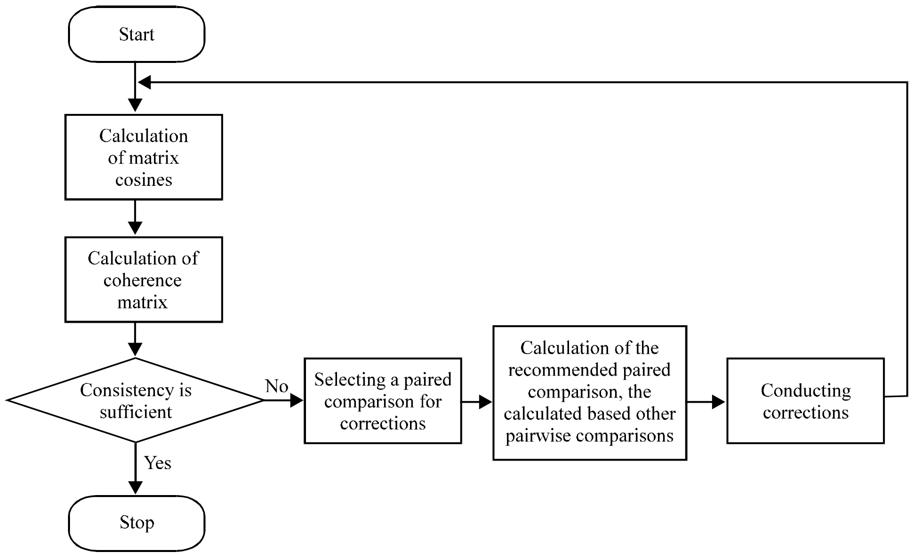

Fig. 4: The algorithm enhancing the coherence of pair comparison matrix in the iterative mode

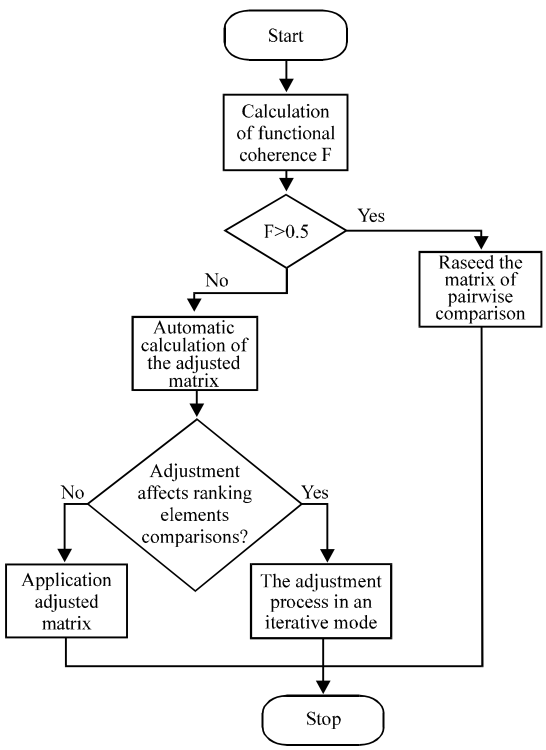

Fig. 5: Selection algorithm of paired comparison Matrix Adjustment Method

presented. At that the final value is determined by a user independently. The algorithm of the coherence degree increase in the iterative mode is shown by Fig. 4.

In order to address the issue of pair comparison coherence increase method let's obtain the decision rule by which determines one of the adjustment methods: automatic, iterative or repeated expert survey.

The condition of automatic adjustment implementation possibility is the stability of the element ranging result after the matrix correction in an automatic mode. At that the degree of consistency decreased. The iterative process of adjustment is possible when the initial data keep useful information and are sufficiently harmonized. In practice, the iterative process is reasonable if the proposed coherence functional value (Eq. 5) is <0.5. In other cases, you can not rely on expert evidence, as they contradict each other and it is necessary to carry out an expert survey again. This decision rule is implemented as an algorithm (Fig. 5).

SUMMARY

Thus, the ACSOL life cycle has been analyzed and the processes were identified that require decision making support. In order to rank ACSOL functions a criterion system was developed. It was found that during the decision-making procedures the difficulties appear at the achievement of the expert data desired consistency and the approach to their adjustment is proposed in an automatic and iterative modes. A decisive rule was developed for the new method application. This rule selects an adjustment procedure. The developed techniques allow to rank ACSOL functions during the stage of its design and development. The described methods and algorithms were implemented by researchers in the DSS Resolution (Lifirenko and Lomakin, 2013). The resulting tools will enhance the validity of administrative decisions during the preparation of project implementation and ACSOL upgrade within all LC stages.

CONCLUSION

The decision support during the design and development stages will allow to enhance the ACSOL quality and determine the actual functions. The system of criteria for ACSOL function ranking is developed. The developed algorithms enhancing the coherence of expert judgment allow to simplify the decision-making process and to inform an expert about its inaccuracies. The developed tools may be useful to solve other weakly structured applications.

ACKNOWLEDGEMENTS

This study is realized with the support of the Russian Science Foundation, project No. 14-38-00047 "The pursuance of the fundamental scientific research and investigative scientific study by the joint scientific laboratories, newly established by the scientific organization and the higher educational establishment" under the title "social risk management and forecasting of the technology-related human-like systems development in the dynamic process of transformation of the human environment" (with the lead of the professor Zubok Yu.A.) 2014-2016.

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