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Contents

Editorial

Dear Readers,

Out of the submitted papers, reviewers have selected five papers that will be presented in this issue of JITA journal.

Mirko Stojadinović in his paper titled by *Hybrid Of Hill Climbing And Sat Solving For Air Traffic Controller Shift Scheduling* presents a new hybrid technique for solving Air traffic controller shift scheduling problem. The propossed technique is the combination of the SAT solving and hill climbing approaches. The obtained results indicate that this hybrid technique outperforms previously most efficient developed techniques.

Evgenii Skakov and Vladimir Malysh in the paper *Simulated Annealing and Evolutionary Algorithm for Base Station Location Problem* propose a modification of the evolutionary algorithm and simulated annealing method for solving the base station location problem. Computer simulation shows that modified simulated annealing method gives better results than the evolutionary algorithm.

Božo Vukoja and Vjekoslav Bobar in the paper *Solving The Chief Executive Officer Selection Problem Using The Fuzzy Decision Support System* propose a novel CEO selection algorithm. The authors applied the fuzzy extent analysis method in the process of selecting the most suitable CEO. Proposed system is applied in a real-life case study to evaluate the most suitable person for a CEO position in ICT company dealing.

Viktor Denkovski and all in the paper *Performance Evaluation Of Routing Protocols In A Wireless Sensor Network For Targeted Environmentt,* describe a wireless sensor network application for farm cattle monitoring. A comparison of usage AODV, DSR, and DSDV routing protocols in a wireless sensor network is presented. Having in mind that energy efficiency is a crucial parameter for wireless sensor networks, the experimental results indicate that DSR is the most appropriate choice for this environment.

Meltem Ozturan and all in the paper *A Review on Methods for the Assessment of Information System Project* describe three areas which are systematically considered in the same way, the results of research literature in relation to financial, non-financial and hybrid methods are represented in graphic and tabular manner.

We thank the authors for the effort they have invested in order to present the results of their research in a qualitative manner. We wish for our presented papers to be recognized both by the readers and scientific community.

Hybrid of Hill Climbing and SAT Solving for Air Traffic Controller Shift Scheduling

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Contribution to the state of the art
DOI: **10.7251/JIT1502081S** UDC: **656.7.025**

Abstract: Modern computers solve many problems by using exact methods, heuristic methods and very often by using their combination. Air Traffic Controller Shift Scheduling Problem has been successfully solved by using SAT technology (reduction to logical formulas) and several models of the problem exist. We present a technique for solving this problem that is a combination of SAT solving and meta-heuristic method hill climbing, and consists of three phases. First, SAT solver is used to generate feasible solution. Then, the hill climbing is used to improve this solution, in terms of number of satisfied wishes of controllers. Finally, SAT solving is used to further improve the found solution by fixing some parts of the solution. Three phases are repeated until optimal solution is found. Usage of exact method (SAT solving) guarantees that the found solution is optimal; usage of meta-heuristic (hill climbing) increases the efficiency in finding good solutions. By using these essentially different ways of solving, we aim to use the best from both worlds. Results indicate that this hybrid technique outperforms previously most efficient developed techniques.

Keywords: controller shift schedule, reduction to SAT, hill climbing.

Introduction

The importance of automatic completion of many tasks by using contemporary computers instead of performing tasks manually has been stressed many times (e.g. [9]). Personnel scheduling problems have been extensively studied in the last few decades (e.g., nurse scheduling problem [3], course timetabling [4]). When solving these problems, a schedule needs to be generated satisfying specified constraints (e.g. a worker cannot work more than certain number of days in a row), taking into account some input parameters (e.g. total number of working days, number of workers).

Air Traffic Controller (ATCo) Shift Scheduling Problem (ATCoSSP) [11] consists of finding assignments of controllers to shifts and in each shift assignments to different positions, so that all the specified constraints are satisfied. Besides satisfying constraints, schedule should also take into account wishes of the controllers and the aim is to satisfy as many wishes as possible.

Constraint satisfaction problems (CSP) and *constraint optimization problems (COP)* [8] include large number of problems relevant for real world applications (e.g., scheduling, timetabling, sequencing, routing, rostering, planning). In this paper, we consider only finite linear versions of these problems. Problems are represented by domains of variables and constraints specifying the relations between these variables. CSPs are solved by finding assignments of values from the corresponding domains to variables, such that all constraints are satisfied. COPs are optimization version of CSPs and in case of solving COPs the goal is to find solution with optimal (minimal/maximal) value of some expression.

There are many different approaches for solving CSPs and COPs (e.g., constraint programming, mathematical programming, systematic search algorithms, forward checking, answer set programming). *Propositional satisfiability problem (SAT)* [2] examines if the variables of a given Boolean formula can be consistently replaced by the values *true* or *false* in such a way that the formula evaluates to true. This problem holds a central position in the field of computational complexity. One approach to solving CSP instances is by *reduction to SAT*. It consists of translating input formula to SAT (called *encoding to SAT*), running some of the free and efficient SAT solvers, and translating the solution, if it exists, to the solution of the original problem. Solving COP instances using reduction to SAT can be done by solving several CSP instances using reduction to SAT – one by one, CSP instances having fixed, different values of optimization expression are reduced to SAT.

Hill climbing [10] is a mathematical optimization technique which belongs to the family of local search techniques. It is an iterative algorithm that starts with some solution to a problem and tries to find better solution by changing some of its parts. If the considered change would produce a better solution, then the change is made to the solution. The changes are repeated until no further improvements can be made. The change to be made on the solution can be selected in different ways. *Stochastic hill climbing* selects change to be made at random. The problem with hill climbing method is that it can finish in local optimum and not in the global one. There are many ways of dealing with this problem (e.g. restarting with different solution if the local optimum is found).

Related work. A work introduced by Stojadinović [11] describes ATCoSSP in detail and introduces three encodings of the problem: in two of them ATCoSSP is specified as a CSP and in third as a SAT. Several methods for solving the problem were developed and a variety of different solvers were used for solving. The variant achieving the best results is the one where in each iteration problem specification is reduced to SAT, SAT instance is solved and then local optimum is found by fixing parts of the solution and replacing shift constraints with position constraints.

Contributions. In this paper we present a new hybrid technique for solving ATCoSSP . Each iteration tries to find better solution and consists of several phases. First, the reduction to SAT is used to find a solution. The solution is then improved by using stochastic hill climbing that exchanges shift assignments and then by using encoding to SAT, such that some parts of the solution are fixed. Our hybrid aims at finding good solutions quickly, so we focus on finding solutions by using shorter timeout compared to one used in the paper to which we compare. Results show that the proposed hybrid is more efficient in finding quick and good solutions.

Overview of the paper. In the next section we present the problem being solved. Then, we describe two existing solving techniques for this problem and our modification of the second one. Then, we present experimental evaluation, draw conclusions and present ideas for further work.

PROBLEM DESCRIPTION

ATCoSSP is solved by assigning shifts to controllers in a considered period (usually a month or a year) with respect to some requirements. There are many documents that describe these requirements (e.g., [1], [7], [5]). Some of the requirements are necessary and they are expressed by imposing so called *hard constraints* (these are essential for shift schedule correctness). *Soft constraints* represent staff wishes (or preferences).

Hard constraints

The period consists of a number of days and each day consists of time slots. A controller takes exactly one of three possible types of shifts on each day. In case of *working shifts*, a controller works in an ATCo facility on a given day from the first until the last time slot of that shift and rests in the remaining time slots of that day. Working shifts are of a different length and depending on the first time slot they are separated in morning, day, afternoon and night shifts. The time slots of working shifts are known in advance and therefore fixed prior to making the schedule. Between days in which controller takes working shifts, he has one or more rest days and we say the controller takes a *rest shift* on these days (they are equivalent to weekends for the majority of professions as teachers, lawyers, etc.). A number of paid vacation days is on the disposal to each controller and we say the controller takes a *vacation shift* on these days. Officials approve or disapprove vacations in advance. To get a full wage, controller must work certain number of working hours in the considered period, but should not exceed some maximum threshold value. In case of working shift, the number of *working hours* for controller on one day is equal to the duration of that shift. For each vacation shift, a number of predetermined working hours is counted for the controller. No working hours are counted for rest shifts.

It is not allowed that controller takes more than a specified number of consecutive working/rest shifts (usually 2 or 3). At each working hour, one controller needs to be in charge - this must be one of the controllers that have the license for this duty. Each controller must take at least a minimum number of rest shifts per month. Regulations usually specify a minimum number of rest time slots between working shifts.

When solving ATCoSSP, one also needs to assign controllers to positions within their working shifts. Several types of positions exist in ATCo facilities (e.g., tower, terminal, en route) and depending on a facility size the number of these positions is present. In any time slot of a working shift a controller can either be on position or can have a break. In one time slot a controller can be assigned to maximum one position. A controller can be on two different positions in two consecutive time slots. Some fixed number of consecutive time slots on position is permitted (e.g. 3 hours). For each day in each time slot of working hours of a facility intensity of air traffic is estimated and based on this estimation, it is decided how many controllers are needed for each position. A controller needs certain skills and passed exams in order to obtain a license to work on some position. The licenses of controllers and the number of needed controllers for each time slot are known in advance.

Soft constraints

Controllers may prefer different working shifts (e.g., they may prefer morning shifts), they may prefer to take consecutive working shifts as rarely as possible, etc. The reasons for including the staff to make schedules and some of most usual preferences are described by Arnvig et al. [1].

Problem encoding

Three encodings of the problem were already described in detail [11], so we do not describe them in this paper. We use only the first encoding (it performed approximately the same as the second, but better than the third). The problem is represented by a COP instance consisting of linear arithmetic constraints and global constraints (these constraints describe relations between a non-fixed number of variables) and COP solvers can be used for solving. One way of solving COP instances is by reduction to SAT. Soft constraints are important for the technique introduced in this paper, so we describe them in the following paragraph.

Wishes of the controllers have different importance and each wish is associated with a weight, specifying its importance. Weights for each controller are scaled in order to make sums of weights for each controller equal to some value. The scaling is used to make fairer schedule (e.g. controllers having small number of wishes will have associated greater weights than the ones having greater number of wishes). Number m_c is the number of wishes of controller c, where each wish is associated with the Boolean variables $x_{c,i}$ and each of the corresponding weights is scaled to value $w_{c,i}$. *Controller's penalty* is defined as $c_{penalty} = \sum_{i=1}^{m_c} w_{c\,i} \cdot x_{c\,i}$. The goal is to find the minimum non-negative value of variable *cost*, such that for each controller c, the constraint $c_{penalty} \leq cost$ is satisfied (the maximum of all controllers' penalties is to be minimized).

Solving techniques

We used three optimization techniques; the first two already introduced in literature [11] and the new one. For all of them, instances for different values of variable *cost* (with bounds $cost_l$ and $cost_r$) are generated and for each value these instances are solved by new runs of the associated solver. For each new value of *cost*, new solving is performed on the instance that differs from the previous instance only in this value. In all techniques we use (asymmetric) binary search algorithm, in some cases combined with additional methods.

Asymmetric binary search. The pseudo code of this algorithm is presented in Figure 1. The algorithm gets as arguments the specification of the problem (e.g. number of workers, number of days, etc.) and the maximum value of variable *cost*. The bounds of the optimum are set and the binary search is started. Instance (in case of this paper the SAT instance) is generated such that the maximum controller's penalty is bounded by the value *cost*. After solving the instance, there are two cases. In the first case, a solution is found and the maximum controller's penalty is some value *best_opt* (*best_opt* = $\max_{c=1}^{n_c} c_{penalty}$ is calculated for the found values of $x_{c,i}$). Solution refining is tried (thus possibly further improving the value of *best_opt*), and then the value of the right bound is updated: $cost_r = best\_opt - 1$. In case there is no solution (instance is unsatisfiable), the value of left bound is updated: $cost_l = cost + 1$. In next iteration of loop, instance with the new value of cost is considered: $cost = cost_l + 4/5 \cdot (cost_r - cost_l)$. Number 4/5 indicates that the satisfiable instances are favored as they are usually easier (1/2 would be used in case of symmetric binary search). This number is used as good results were obtained by using it in the original paper [11]. The search is ended and an optimum is found when $cost_l$ becomes greater than $cost_r$.

```
bin_search (problem_spec, cost_max)
   cost_l = 0;
   cost_r = cost_max;
   while (cost_l <= cost_r)
      cost = cost_l + 4/5 * (cost_r - cost_l);
      instance = generate (problem_spec, cost);
      if (run_solver (instance, &best_opt, &solution) == SAT)
         refine_solution (instance, &best_opt, &solution);
         cost_r = best_opt - 1;
         best_solution = solution;
      else
         cost_l = best_opt + 1;
return best_solution;
```

Figure 1. Binary search for solving ATCoSSP

The techniques we present here differ in implementation of the function *refine_solution* and the rest of the search is the same in case of all three techniques.

Basic binary search

This technique does not do anything in the phase of refining solution. After finding one solution, it just continues with generating new instance and solving it.

Position avoiding

For each position, a number of controllers is needed in each time slot. In any found solution to the problem, controllers are assigned to shifts and within these shifts they are assigned to positions. A sufficient number of controllers to each position in each time slot is assigned. This technique aims to get smaller instances that are easier to solve by replacing position requirements with working shift requirements.

There are two phases in solution refinement: the first is used to make the solution schedule less empty and the second is used to find the better solution. We will describe these two phases by following the example given in Table 1.

Table 1. Small example of schedule for short period of 4 days (no position schedule presented). Shifts are 1 (04-12), 2 (08-16), 3 (12-20), 4 (rest), 5 (vacation)

Name	Day 1	Day 2	Day 3	Day 4
Alice	2 (08-16)	4 (rest)	2 (08-16)	3 (12-20)
Bob	4 (rest)	3 (12-20)	3 (12-20)	4 (rest)
Charlie	4 (rest)	4 (rest)	1 (04-12)	2 (08-16)
Dave	4 (rest)	3 (12-20)	5 (vac.)	5 (vac.)
Ethan	1 (04-12)	4 (rest)	4 (rest)	1 (04-12)

Emptying the solution. In each iteration of this phase, two days d_1 and d_2 are found so that they fulfill three requirements. The first is that the same number of controllers is needed for each position in each time slot of these days (we assume this is the case with days $d_1 = 1$ and $d_2 = 3$ in the example). The second requirement is that for each working shift, the number of assigned controllers to that shift on day d_1 is less or equal than the one on day d_2. The third requirement is that for at least one working shift, the number of assigned controllers to that shift on day d_1 is strictly less than the one on day d_2. Different pairs of days are tried and when days are found satisfying three requirements, then position and shift assignments for d_1 are copied to assignments for d_2. If n controllers are assigned working shifts on day d_1 and m controllers are assigned working shifts on day d_2 ($n < m$), then n from m controllers on day d_2 are assigned working shifts and position assignments from day d_1 and the remaining $m - n$ controllers have rest day on d_2. In the example, let $d_1 = 1$ and $d_2 = 3$ be the days that satisfy three requirements. More controllers are assigned to work on day 3 than it is needed. One option of change may be: Bob is assigned shift 1 on day 3, Charlie is assigned rest shift on day 3 and other shift assignments on day 3 are left unchanged. This may open space for Charlie to work on some other day and maybe some of his previously unfulfilled wishes will be possible to satisfy. Note that some constraints may not be satisfied at these moments (e.g. maximum number of rest days in a row). We repeat this until no two days can be found fulfilling three requirements.

Reassigning shifts to controllers. Now, the changed schedule is used as a basis for generating a new one. Constraints specifying position assignments are not considered and only the constraints specifying the number of controllers for each day and each shift are considered. If enough controllers are assigned to each shift on each day, then the positions will be filled as each shift on each day is mapped to certain position assignment in previously found solution. The original encoding is called *complete* and the encoding avoiding position constraints is called *reduced encoding*. A separate asymmetric (inner) binary search is used on the problem now specified only using shift constraints. Optimum on the reduced encoding is not necessary the optimum of the initial problem. However, this optimum can reduce the upper bound of the outer binary search. When refining of the solution is complete, the outer binary search can continue finding better solution on complete encoding.

Position avoiding with hill climbing

Refining solution in case of this technique is done in two phases.

The first phase is stochastic hill climbing algorithm that uses restarting. The algorithm consists of iterative exchanging shifts between any two controllers. Two shifts can be exchanged if neither of them is vacation shift and if the exchange does not violate any of the hard constraints. For the purpose of checking if after exchange all constraints will be still satisfied, special testing software was developed and used. Exchange is actually performed if it does not increase the higher of the penalties of the two controllers involved in the exchange. This way, some number of exchanges (p) is tried. After specified number of trials is completed, the number of exchanges (q) is performed, even in case the higher of the penalties is increased - this enables the escape from a local minimum and continuation of the search from some solution potentially leading to global minimum.

The second phase is the technique 'Position avoiding technique', presented in previous section. It is used to potentially further improve the solution found prior to using the first phase, but starting with the upper bound that was potentially improved (decreased) by the first phase.

EXPERIMENTAL EVALUATION

All the tests were performed on a multiprocessor machine with AMD Opteron(tm) CPU 6168 on 1.9Ghz with 2GB of RAM per CPU, running Linux. The timeout per instance was 60 minutes (1 hour), including both encoding and solving time.

Techniques used. In our experiments, we used three techniques that were described in previous section: Basic binary search (denoted *bs*), Position avoiding (*bsNoPos*) and Position avoiding with hill climbing (*hybrid HC*). When using hybrid hill climbing, after each 9000 iterations of exchanges aimed not to increase the value of greater of the considered sums of penalties, we conducted 50 exchanges possibly increasing greater of the sum of penalties of controllers considered for the exchange (as already stated, the aim is to escape from local minimum).

Instances. We used the existing set of 13 hard instances previously introduced [11] (they are called interesting instances and represent the subset not easily solved in the cited paper). This set consists of instances used for generating shift schedule for a small airport in Vršac, Serbia.

Experimental results

Table 2 summarizes the results of the experiments. The new technique (*hybrid HC*) is better than both previously developed techniques in case of solving 10 out of 13 instances. Average objective value also confirms that the new technique is more efficient than the other techniques. Note that the timeout used is smaller than in the cited paper (60 minutes comparing to the original 600 minutes). As already stated, the focus here is on faster search for the solutions.

Table 2. Results of three techniques (timeout 60 minutes): each cell contains objective value and the time needed to achieve this value is given in parenthesis; columns corresponding to different techniques and rows represent different instances

Instance index\	bsBasic	bsNoPos	hybrid HC
2	60 (3)	61 (1)	60 (1)
3	71 (2)	55 (3)	50 (2)
4	32 (30)	34 (7)	30 (5)
5	20 (54)	6 (49)	12 (26)
6	20 (26)	20 (28)	20 (15)
10	28 (12)	22 (5)	22 (4)
14	0 (58)	16 (37)	6 (41)
15	102 (28)	102 (27)	28 (28)
18	24 (15)	20 (13)	16 (30)
19	72 (50)	8 (28)	8 (17)
20	160 (0)	105 (58)	14 (60)
21	160 (0)	160 (0)	160 (0)
22	114 (35)	71 (55)	31 (37)
average	66.4	52.3	35.2

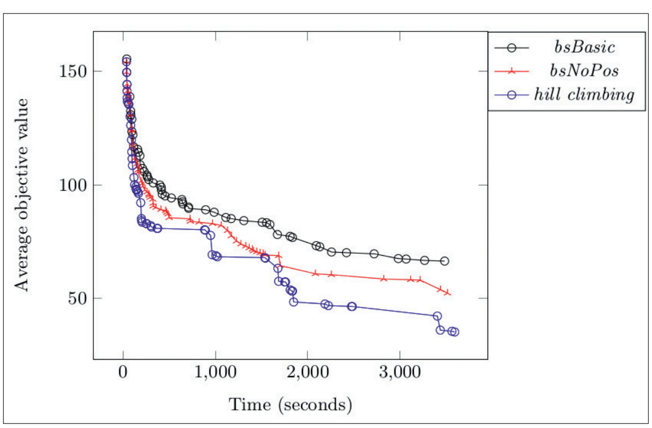

Figure 2. Average objective value achieved in time - each mark on the curves represents one decrease in value.

Figure 2 shows the decrease of the optimum achieved during time. Solutions are found quickly in the first couple of minutes in case of all three techniques (in this period, their solving process is mostly the same). After some time, the new technique manages to improve found solutions more quickly than the other techniques (its graph is closer to the horizontal axis). This means that this technique finds solutions fulfilling more preferences of the employees in shorter time. This trend continues until the timeout is reached.

Conclusions and Further Work

We have introduced technique for solving Air traffic controller shift scheduling problem that is the combination of the SAT solving and hill climbing. These two solving approaches are interleaved and the technique manages to find more quality solutions in less time, comparing to the best technique previously reported in literature.

In the future, we plan to implement more metaheuristic techniques for solving the problem. Comparison and investigating the influence of parameters of the techniques on the quality of the solution is another interesting direction.

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Simulated Annealing and Evolutionary Algorithm for Base Station Location Problem: a Comparison of Methods

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Contribution to the state of the art

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Abstract: A modifications of the evolutionary algorithm and simulated annealing method for solving the base station location problem for creating a wireless data network is introduced in the article. By the way of computer simulation a comparison of speed and accuracy of solutions obtained by the proposed methods and the method of exhaustive search is produced. The study revealed that new simulated annealing method show better results than the modified evolutionary algorithm.

Key words: base station location, evolutionary algorithm, simulated annealing, wireless networks, optimization, SIR.

Introduction

An important part of designing a wireless data network is the synthesis of its topological structure. It implies planning a territorial distribution of base transceiver stations and connection to the customers.

As it is known [3], [7], [9] the problem of designing a network (including wireless) can be reduced to the problem of finding the minimum of a functional present value when probability and time and structural characteristics of the network are limited and the appurtenance requirement for many variants of the network architecture to the field of technically implemented solutions is met. Detailed classification of location algorithms for base stations (BS) in UMTS 3G networks is given in paper [9].

Among the shortcomings of the works on this problem, we should note the following:

- solution to the problem of BS location using methods that do not show high calculation speed (branch and bound method, a heuristic method of Lagrange, etc.);
- absence of limits considering the level of attenuation of signal during propagation from the BS to the client and vice versa;
- most of the studies do not take into account the level of inter-cell interference;
- most of the models do not involve the use of several types of base stations.

This work aims to create a model that does not have the above drawbacks. In it NP-hard problem is solved by placing the BS using metaheuristic optimization methods, namely evolutionary algorithm (EA) and simulated annealing (SA).

Purpose of the work

Formulate a mathematical model of the problem of optimal base stations location; suggest a modifications of the evolutionary algorithm and simulated annealing for solving this problem; compare the effectiveness of the proposed algorithms.

Formulation of the problem

The problem of locating base stations is that we have N_{tp} customers, each of them must be connected to the base station. The base station may be installed at one of the N_{ps} potential sites (candidate places). There are N_{types} types of base stations, different in their characteristics. The problem is reduced to minimizing the total cost of the installed base stations under certain restrictions.

We will present a solution to the problem in the form of a pair of vectors (single dimensional arrays) of integers - Y and X (explanation: here and further recording species $A[j]$ means an appeal to the j-th element of the vector A; array elements are numbered starting with 1):

- Y – a vector containing N_{ps} elements. The elements may take on integer values in the range [0; N_{types}]. If $Y[i]=0$, then a base station is not installed at the i-th position-candidate. If $Y[i]=w$, then base station w-type is set at the i-th potential site;
- X – a vector containing N_{tp} elements. The elements may take integer values in the range [1; N_{ps}]. If $X[i]=w$, then the i-th client is connected to the base station at the w-th potential site.

The client can be connected to the position-candidate only if it has the base station installed:

$$Y[X[i]] \neq 0 \qquad \forall i \in \{1, 2, \ldots, N_{tp}\}. \tag{1}$$

Let b – the vector whose elements are required bandwidth of clients; β – the vector whose elements are the maximum performances of different types of base stations. For each installed BS the total required traffic must not exceed the highest possible performance of the equipment:

$$\sum_{i=1}^{N_{tp}} p_{is} \cdot b[i] \leq \beta[Y[i]] \quad \forall s \in \{1, 2 \ldots, N_{ps}\}$$

$$where \tag{2}$$

$$p_{is} = \begin{cases} 1, & if \; X[i] = s \\ 0, & else \end{cases}.$$

Let $P_{BS}^{\max}$ – the vector whose elements are the maximum powers of base stations of various types; $P_{TP}^{\max}$ – the vector whose elements are the maximum powers of customers; P_{BS}^{tar} – the vector whose elements are the sensitivities of the base stations of different types; P_{TP}^{tar} – the vector whose elements are the sensitivities of clients; G – a two-dimensional array (matrix) of dimension $N_{tp} \times N_{ps}$, each element of which $0 \leq G[i][s] \leq 1$ reflects the level of attenuation between the client i and the candidate place s.

Despite the attenuation of the signal along the path from the BS to the client, the power reaching the transmitter from receiver must exceed the minimum target power:

$$\frac{G[i][X^{GA}[i]] \cdot P_{BS}^{\max}[Y^{GA}[X^{GA}[i]]]}{P_{TP}^{tar}[i]} \geq 1 \qquad \forall i \in \{1, 2, \ldots, N_{tp}\}. \tag{3}$$

Restriction (3) is compiled for the downlink mode. A similar restriction for the uplink mode (despite signal attenuation along the path from the client to the BS, the power reaching from the client to the BS must exceed the minimum target power) is as follows:

$$\frac{G[i][X^{GA}[i]] \cdot P_{TP}^{\max}[i]}{P_{BS}^{tar}[Y^{GA}[X^{GA}[i]]]} \geq 1 \qquad \forall i \in \{1, 2, \ldots, N_{tp}\}. \tag{4}$$

According to sources [7] and [9], the objective function to be minimized must be as follows:

$$F = \sum_{s=1}^{N_{ps}} Cost[Y[s]], \tag{5}$$

where Cost – the vector of prices (including installation) for different base stations types.

However, this idea has an obvious disadvantage. The problem of locating the BS may have multiple admissible solutions with the same value of the total equipment cost. In this case, it is not clear which of them is considered to be the best. In this paper, we propose to calculate an objective function as follows:

$$F=\left(\sum_{s=1}^{N_{ps}} Cost\left[Y[s]\right]+\sum_{i=1}^{N_{tp}} SIR_{dB}^{i}\cdot k\right). \quad (6)$$

The first summand is the total cost of the complex. The second summand is responsible for keeping the level of SIR for all customers of the system. SIR is the signal-to-interference ratio [5]. In the general case, it is calculated as follows:

$$SIR_{dB}=10\log_{10}\left(\frac{P_{signal}}{P_{interference}}\right). \quad (7)$$

According to our problem, we calculate SIR for each client. The received signal from the BS, which is connected to our client, appears in the numerator. Signals from other BS that interfere appear in the denominator:

$$SIR_{dB}^{i}=10\log_{10}\frac{G[i][X[i]]\cdot P_{BS}^{\max}[Y[X[i]]]}{\sum_{s=1,s\neq X[i]}^{N_{ps}} G[i][s]\cdot P_{BS}^{\max}[Y[s]]}. \quad (8)$$

k – a coefficient with simultaneous consideration two factors in the objective function: the cost of creating the network and the SIR-level of customers. *k* has the dimensions of the complex of base stations cost, thereby keeping the dimension constant in the formula (6), as SIR - a dimensionless quantity. *k* should provide a "penalty" for the low level of SIR and a "reward" for the high one. In this paper, taken *k*=-10 conventional units (*k* is a negative value, because we solve the minimization problem, and therefore, a good high level of SIR is to reduce the objective function).

Evolutionary algorithm for the problem of base stations location.

A population considered in the evolutionary algorithm "exists" for a predetermined number of generations N_{gen}. The population consists of N_{pop} individuals, each of them in our case corresponds to a solution of the base stations. Each individual solution comprises two chromosomes *Y* and *X*, which have been described above.

The basis of the evolutionary algorithm work is the evaluation operation of an individual's fitness in the population. According to the principle of natural selection, the higher is the fitness level, the greater is the probability of an individual to reach the next generation. In our problem, the level of fitness of an individual is inversely proportional to the value of the objective function that this individual presents. Accordingly, the smaller is the objective function *F*, the higher is the fitness of the individual.

In the evolutionary algorithm, each of its iterations (generation) consists of a selection operation from the initial parent population and breeding operation (includes crossover and mutation). As the best solution the best individual in the last generation of the population concerned returns. Figure 1 (flowchart) gives a general view of the evolutionary algorithm.

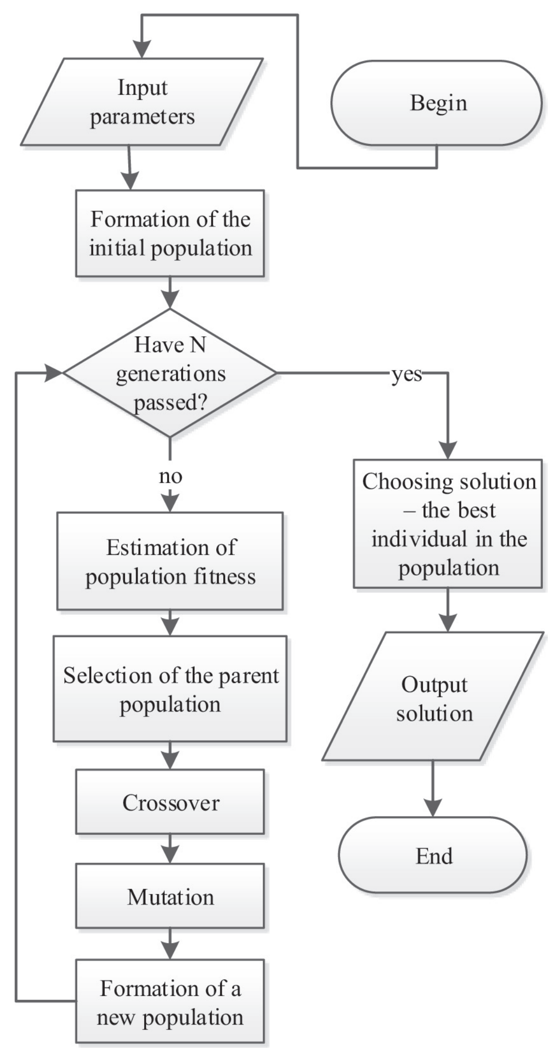

Figure 1. Flowchart of the evolutionary algorithm

All decisions will be checked for validity, i.e. matching constraints (1), (2), (3) and (4). Only "viable" individuals will be included in the new population, i.e., those that satisfy all constraints.

Selection of the parent population.

Selection means to choose (based on fitness of individuals) those chromosomes that will participate in the creation of the next generation. The most common are 3 selection methods:

1) Roulette method. The method for minimizing problems can be briefly described as follows: "If the value of the objective function *i*-th individual *k* times smaller than the objective function value of the *j*-th individual, then probability of inclusion of the *i*-th individual to the parent pool must be *k* times greater than the probability of similar *j*-th individual".

2) Tournament method. It implements a sequence of tournaments to choose *N* individuals. Each tournament is built on a random choice from a population of *k* elements and selecting the best individuals among them. The most common tournament selection with *k*=2.

3) Ranking method. The probability of getting into the parent pool is not proportional to a fitness function value, but is proportional to a spot that is taken by an individual in a population that value-ordered by objective function.

Suppose that we have *N* individuals. Then the rank of the *i*-th individual will be assigned for the following reasons: the worst individual has rank 0, next to the "quality" – 1... the best individual has rank (*N*-1). The probability of finding the *i*-th individual in the parent population is:

$$p_i = \frac{2r_i}{N(N-1)}. \quad (9)$$

The so-called elitist strategy should be mentioned as well. It is about protecting the best individuals in the transition from one generation to another. In the classical evolutionary algorithm the fittest individual of *i*-th generation does not always go to generation (*i*+1). The elitist strategy is used to prevent the loss of the best individual, which is guaranteed to be included in the new population. In this paper we will use the elitist strategy in addition to the selection methods discussed above.

Reproduction procedure.

Creating descendants is made using genetic operators. In the evolutionary algorithm two genetic operators are usually used: crossbreeding operator (crossover) and mutation operator.

Each solution to our problem of locating the BS is encoded by two chromosomes, so the procedure will differ from classic crossover.

It can be seen that for each solution vector *X* completely determines nonzero elements in vector *Y*. Vector *Y* only determines what type of BS is set to a specific location.

Since chromosomes *X* and *Y* are dependent on each other, we cannot cross them individually (as there would be many wrong decisions) [7]. Therefore, we will only cross vectors X_1 and X_2 of parental species.

Crossover operator runs as follows: a pair of individuals is randomly chosen from the parent population. Next, for each pair of individuals selected this way a position of a gene in chromosome *X* is randomly selected, the position, which determines the so-called crossover point. This point is an integer in the interval [1, *L*-1], where *L* – length of chromosome *X* (in our case $L=N_{tp}$). As a result of crossing two parental chromosomes there appears a descendant with X_{child} chromosome which consists of the genes of the first parent in positions from 1 to l_c, and it consists of the genes from the other parent in positions from (l_c+1) to *L*. Modification of the one-point crossover is an *n*-point (eg, multi-point) crossover. It is similar to the one-point, but crossbreeding is held for *n* points in it.

For the obtained descendant vector X_{child} the mutation operation will be applied. The operation of mutation means that with some small probability one of the elements of the vector changes its value to a random integer from the range [1; N_{ps}].

After receiving the vector X_{child} of descendant-individual, we must form its chromosome Y_{child}. Chromosome X_{child} uniquely determines which elements of the vector are nonzero. For example, we have 5 potential sites, 4 clients and 3 types of BS (and the smaller the serial number of the type of BS is, the cheaper such stations are). Let X_1=[1 5 2 3] and X_2=[2 5 5 3]. As a result of crossover we got X_{child}=[1 5 5 3] for the child. This means that the child chromosome Y_{child} will have the form Y_{child}=[V 0 V 0 V] where V - is an integer from the range [1; N_{types}].

The non-zero elements of the vector are recommended to be chosen in the following way:

1) if $Y_1[i]=w$ and $Y_2[i]=0$, then $Y_{child}[i]=w$;
2) if $Y_2[i]=w$ and $Y_1[i]=0$, then $Y_{child}[i]=w$;
3) if $Y_1[i]=Y_2[i]=w$, then $Y_{child}[i]=w$;
4) if $Y_1[i]=w$, and $Y_2[i]=z$ ($w \neq z$), then we have several methods of selecting the type of BS, which will be situated in the descendant at the i-th place:

a) take the type that has minimal cost (to minimize the objective function);

b) take the type of BS with greater productivity;

c) take any w type, or take randomly z type with 0.5 probability.

Another form of solution representation.

To describe the solution of the BS location task for solving by simulated annealing we need to use such a unit of data as a structure. The structure is a composite data type that stores a set of different variables (fields), united by one name. In our case structure contains three fields:

- variable *type*, indicating what type of BS is located in the potential site (if *type* = 0, the BS is not located);
- variable *cl_nbr* – the number of clients connected to this site;
- one-dimensional array (vector) of integers *CL* (dimension cl_nbr), containing the number of customers connected to this place.

We will present the solution as a vector *Sol*, whose elements are the records that correspond to the potential sites. Appeal to a separate variable recording (so-called field) is denoted with the symbol '.'. That is *Sol[3].type* means the type of BS third potential site, and, for example, *Sol[4].CL[2]* is the number of the 2-nd customer connected to a BS in a place №4.

The customer can be connected to the candidate place only if it is already installed at the base station. So, for each location, whose *Sol[s].cl_nbr≠0*, we must have *Sol[s].type≠0*.

Then the restrictions (2)–(4) take the form (10)–(12) respectively:

$$\sum_{i=1}^{Sol[s].cl\_nbr} b\big[Sol[s].CL[i]\big] \le \beta\big[Sol[s].type\big] \quad \forall s \in \{1,2,\dots,N_{ps}\} \tag{10}$$

$$\frac{G\big[Sol[s].CL[i]\big]\big[s\big] \cdot P_{BS}^{max}\big[Sol[s].type\big]}{P_{TP}^{tar}\big[Sol[s].CL[i]\big]} \ge 1 \quad \forall s \in \{1,2,\dots,N_{ps}\}, \quad \forall i \in Sol[s].CL. \tag{11}$$

$$\frac{G\big[Sol[s].CL[i]\big]\big[s\big] P_{TP}^{max}\big[Sol[s].CL[i]\big]}{P_{BS}^{tar}\big[Sol[s].type\big]} \ge 1 \quad \forall s \in \{1,2,\dots,N_{ps}\}, \quad \forall i \in Sol[s].CL. \tag{12}$$

The objective function (6) takes the form

$$F = \sum_{s=1}^{N_{ps}} Cost\big[Sol[s].type\big] + \sum_{s=1}^{N_{ps}} \sum_{i=1}^{Sol[s].cl\_nbr} SIR_{dB}^{si} \cdot k. \tag{13}$$

We need to sort out the types of base stations according to the ascending price. Then we assume that the i-th type of BS is more expensive than (i-1)-th and cheaper than (i+1)-th.

Simulated annealing for the BS location problem

Simulated annealing based on the simulation of physical processes that occur during crystallization of substances from liquid to solid (for example, during the annealing of metals) [1]. The process takes place at a gradually decreasing temperature. The transition of an atom from one cell of the crystal lattice to another occurs with some probability, and the probability decreases with the decreasing of temperature [2].

Kirkpatrick has applied the above ideas for solving the optimization problems [4]. The simulated annealing method belongs to the class of local search algorithms. At each step of the algorithm in the neighborhood of the current solution *x* a solution *w* is chosen. As in the local descent algorithm, if the objective function *f(w)* of the solution *w* will be better (in the case of minimization – less) than *f(x)*, then *w* replaces *x* as the current solution. However, the method of the SA has a feature that helps it to avoid "getting stuck" in the local optima: there is some probability of transition to the solution w, even if *f(w)* is worse than *f(x)*. This probability is given by [6]:

$$P(t) = exp\left((f(w) - f(x))/t\right), \quad (14)$$

where the parameter t in analogy with the physical process is known as the temperature. Obviously, the higher the temperature, the greater the probability of transition to a worse solution is. In the course of the algorithm the parameter t is decreasing constantly. In this paper we consider exponential annealing, and therefore the temperature at the (k+1)-th step can be calculated using the temperature on the k-th step with the formula:

$$t_{k+1} = \alpha t_{k}, \quad (15)$$

where the parameter $\alpha \in (0;1)$ is a cooling factor. The algorithm stops working when the temperature becomes close to zero.

Separately, let us talk about choosing the initial temperature t_0, as this parameter is very important for the correct operations of the method. Kirkpatrick, the author of the SA method [4] gives only general advice, which means that the value t_0 should be chosen very large. However, in [1], the authors derived a formula for the calculation of t_0. Let p_0 – the objective probability of making the worst decisions in the early steps of the algorithm, Δf_{max} – the maximum possible difference between the values of the objective function of two neighboring solutions. Then the formula for the t_0 takes the form:

$$t_0 = -(\Delta f_{max} / Ln(p_0)). \quad (16)$$

Obviously, it is very difficult to calculate Δf_{max} previously, so we have to use a rough estimate of this value in the calculation. In our task the parameter Δf_{max} should be approximately equal to the cost of the most expensive BS.

Solution neighborhood.

The concept of "neighborhood" is the most interesting in the method of simulated annealing. It is badly formalized and for each specific optimization problem is distinctive. In the base station location problem we have the solution presented in the form of a number of base stations with customers connected to them. We must decide which solutions are closest to ours. We devised a method of forming a neighborhood solution through implementing small changes in the current solution. The new solution from the neighborhood of the current solution can be obtained by one of six methods (operations) [8]:

1) Change the type of one BS to another BS, which is cheaper.

This kind of operation (*Sol[s].type=Sol[s].type*-1) is possible for each element of the array *Sol*, which has *Sol[s].type*>1. After changing we must check new configuration for compliance with limitations (10)–(12).

2) Change the type of one BS to another BS, which is more expensive.

This operation (*Sol[s].type=Sol[s].type*+1) is possible for each element of the array *Sol*, and which has *Sol[s].type*≠N_{types} and *Sol[s].type*≠0.

3) Reconnect one client (i.e. the connection to another BS).

This operation is possible for each client. If we are seeking for a new BS for the *i*-th customer, we have to try consistently to connect it to one of the potential sites (except his current location), starting with the neighbor to the customer *i* and checking for compliance with limitations (10)–(12). Obviously, the place *w*, to which we want to connect the customer must have an active BS (*Sol[s].type*≠0).

4) Deletion of one BS.

This operation is enabled for each active potential site. For each of the customers leaving the station *s* we launch the operation 'reconnect one client'. If all the *s*-th station customers can be connected to other BS, deleting means *s*-th station is possible.

5) Addition of one BS. This operation is available for each empty space (*Sol[s].type*=0). We set in place *s* a new station and try to connect it to the closest customer (let his number be *i*). If such a connection is possible (for the *s*-th site run constraints (10)–(12)), then new solution *Sol* is allowable. Customer with number *i*, of course, must be disconnected from the old BS.

6) Relocation of one BS. This operation is enabled for each active potential site. Let us relocate BS from the place *s*. Then we must consistently try to fit it into the empty potential sites, starting with the closest to the site *s*. At the new place *w* constraints (11) and (12) must be performed.

Pseudo-code for the SA algorithm.

Below is the general scheme of simulated annealing algorithm for the base station location problem [8].

1. Build *Curr* (initial potential solution).

Notations: *t* – initial temperature; *t_min* – temperature is which annealing is terminated; *N_iter* – number of iterations at each temperature; *Sol* – solution from *Curr* neighborhood; *Best* – the best solution.

2. *Best=Curr*.
3. *Sol=Curr*.
4. Apply to *Sol* one of the 6 steps described above (selecting operation performed randomly).
5. If *Sol* – forbidden solution (does not satisfy one of the constraints (10)–(12)), then move to step 3.
6. If *F(Sol)<F(Curr)*, then move to step 8.
7. Let *w* – a random number in the range [0; 1]; *P(t)*=exp((*F(Curr)* – *F(Sol)*) / *t*). If *w>=P(t)*, then move to step 3.
8. *Curr=Sol*.
9. If at this value of *t* was done *N_iter* iterations, then decrease *t*.
10. If *F(Curr)<F(Best)*, then *Best=Curr*.
11. If *t>t_min*, then move to step 3, otherwise move to step 12.
12. Return *Best*.

Computer simulation

The developed algorithm was implemented as software in the programming environment Embarcadero Delphi XE5. With this software, some computational experiments on finding the optimal location of the base stations and connection of customers to them were carried out. The simulation was performed on a computer with Intel Core i5-3470 processor and 6GB of RAM.

The first series of computational experiments was devoted to the study of the performance and accuracy of proposed methods by comparing them with the exhaustive search method (ES) for the problems of small dimension. The principle of the exhaustive search algorithm is very simple: we must try all possible solutions of the task, we must remove all the wrong solutions, and choose the best among the remaining (in terms of the objective function). In our problem, the total number of combinations of chromosome pairs *X* and *Y* is equal to $N_{ps}^{Ntp} \cdot ((N_{types}+1)N_{ps}-1)$. It is obvious that exhaustive search method does not solve the problem of base stations in polynomial time.

We fix the parameters of the EA (according to [7]): ranking method of selection, 2-point crossover, N_{gen}=100, N_{pop}=100, the elitist strategy was used. We fix the parameters of simulated annealing algorithm (according to [8]): α=0.97, p_0=0.95, *N_iter*=20. The results of the experiment are shown in Table 1. Each cell in the table contains two lines: the top line is the time of the algorithm's operation in seconds, the bottom line is the value of the objective function in conventional units. Here and later the time of solving the problem and the objective function value are given as the average of 100 runs of the algorithm.

The presented data suggest that for the small dimensional problems both evolutionary algorithm and simulated provide accurate values of the objective function as well as the exhaustive search method, which gives an exact solution for each run of the algorithm. The developed modifications of EA and SA methods allows to find the solution of base station location problem in a reasonable time, many orders of magnitude faster than the exact method of exhaustive search

Table 1. Comparison of EA, SA and ES methods on small-size problems

Size of task ($N_{tp}\times N_{ps}\times N_{types}$)	Method		
	ES	EA	SA
3×5×2	0,030 sec 27382	0,093 sec 27382	0,015 sec 27382
3×7×2	0,710 sec 26784	0,093 sec 26784	0,015 sec 26784
3×10×2	65,19 sec 26516	0,109 sec 26516	0,015 sec 26516
5×5×2	0,606 sec 26776	0,096 sec 26776	0,015 sec 26776
5×7×2	31,59 sec 26570	0,093 sec 26570	0,016 sec 26570
5×10×2	5140,7 sec 26776	0,109 sec 26776	0,017 sec 26776
7×5×2	14,65 sec 26458	0,097 sec 26458	0,016 sec 26458
7×7×2	1390 sec 26396	0,100 sec 26396	0,016 sec 26396
7×10×2	455798 sec 26230	0,111 sec 26230	0,018 sec 26230

Then, a series of computational experiments to compare the effectiveness of the proposed evolutionary algorithm and simulated annealing method for solving various size problems was carried out. We fix the parameters of the EA (according to [7]): ranking method of selection, 2-point crossover, N_{pop}=100, the elitist strategy was used. We fix the parameters of simulated annealing algorithm (according to [8]): α=0.97, p_0=0.95, *N_iter*=20. The results are shown in Table 2. Each cell in the table contains two lines: the top line is the time of the algorithm's operation in seconds, the bottom line is the average deviation of the solutions from the best known solution.

Simulation was performed as follows: first, each of the tasks we solved by simulated annealing method. Next, we solve the same problems by the EA, limiting it work time by the time that it took the SA to solve those problems. The presented data suggest that modified simulated annealing method shows better results than the evolutionary algorithm (at a same fixed runtime).

Table 2. Comparison of evolutionary algorithm (EA) and simulated annealing (SA)

Size of task ($N_{tp}\times N_{ps}\times N_{types}$)	Method	
	EA	SA
50×50×3	0,247 sec 8,293 %	0,247 sec 3,698 %
100×100×3	0,695 sec 12,177 %	0,695 sec 8,515 %
150×150×3	1,415 sec 9,329 %	1,415 sec 5,267 %
200×200×3	2,539 sec 12,050 %	2,539 sec 9,262 %
500×500×3	16,83 sec 6,602 %	16,83 sec 4,426 %

Conclusions

Provided computer simulation allows the following conclusions to be made:

- proposed modifications of the evolutionary algorithm and simulated annealing can solve the problem of base station location;
- EA and SA can find a solution of our task within a reasonable time;
- for the problems of small dimension the EA and SA results coincide with the method of exhaustive search. Moreover evolutionary algorithm and simulated annealing method require much less time than ES;
- SA shows better results than the EA (at a same fixed runtime).

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Solving the Chief Executive Officer Selection Problem Using the Fuzzy Decision Support System

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Contribution to the state of the art

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Abstract: Chief Executive Officer (CEO) selection as a subset of personnel selection asks for different characteristic compared to a selection of other personnel. The reason for this is the polymorphic nature of the CEO role. The complexity and importance of the selection problem, call for analytical methods rather than decisions based on intuition. The multi-criteria nature and the presence of both qualitative and quantitative factors make the entire selection more complex. As such, the CEO selection is a multi-criteria decision making problem decision making problem, affected by several qualitative and quantitative, often conflicting criteria which are usually uncertain. This paper proposes a CEO selection approach based on the fuzzy decision support system developed by using JAVA technology and extent analysis method. This system is applied in a real-life case study to evaluate the most suitable person for a CEO position in information and communication (ICT) company dealing with the rating of both qualitative and quantitative criteria, and testing appropriate consistency to ensure quality of selection.

Keywords: CEO selection, fuzzy numbers, extent analysis method, decision support system.

Introduction

A chief executive officer (CEO) describes the position of the most senior corporate officer, executive, or administrator in charge of managing a non-profit or profit organization. The CEO of a corporation or company typically reports to the board of directors and is charged with maximizing the value of entity.

The responsibilities of an organization's CEO are set by the organization's board of directors or other authority, depending on the organization's legal structure. They can be far-reaching or quite limited and are typically enshrined in a formal delegation of authority.

Typically, the CEO has responsibilities as a director, decision maker, leader, manager and executor. The communicator role can involve the press and other people, as well as the organization's management and employees; the decision-making role involves high-level decisions about policy and strategy. As a leader of the company, the CEO advises the board of directors, motivates employees, and drives change within the organization. As a manager, the CEO presides over the organization's day-to-day operations.The term refers to the person who takes all the decisions regarding the upliftment of the company, which includes all sectors and fields of the business like operations, marketing, business development, finance, human resources, etc. The CEO of a company is not necessarily the owner of the company.

CEOs perform key activities related to managerial and executive positions. They establish rules, define the order of performance of business activities, control and monitor executive bodies. They perform their business activities in companies that deal with services, trade or manufacture, in pre-school and other educational institutions, medical institutions etc. Depending on the area in which they operate they asign duties, coordinate tasks, and perform the control of results. In order for them to be able to define employees' duties effectively, it is necessary that they first draft short-term and long-term plans with a clear and precise list of tasks and finally distribute tasks effectively among the employees. Task monitoring is necessary and an integral part of their work. If they notice any irregularities on time the right measures can be taken to correct the flaws.

In order to notice irregularities and establish rules, CEOs have to be familiar with the rules and regulations within the area of business they operate in, as well as tasks with tasks, necessary to work and achieve positive results. If CEOs perform their activities within service, trade or manufacturing companies it is necessary they should keep up with the market movements, the development of technology, their competition from the same or similar area of business, the development of business tools used in the given area of business and all other factors that could influence the development of the company, in a positive or negative way.

In order to be a successful CEO, one needs to possess an array of skills. It should be someone with a vision, or to be long-sighted, to possess the ability to think a few steps ahead, which helps lead their teams into a guaranteed sucess. They can very often see through people, understand what kind of a person is standing opposite them, what are that person's capacities, motivations, wishes, etc. This is extremely important not only for new business projects, but also for appointing people within a team to work at appropriate job positions and delegating tasks suitable for them. What also characterizes them is optimism and the possibility to trust others. Why is this imporant? Mainly because, their position requires productivity and capability to lead people which means deep motivation and faith in success. They are also prone to action and constructively decisive. These are some of the characteristic that are also very useful for someone who holds a managerial position. Regardless of the vision, long-sightedness and other characteristics they possess, leaders will not be successful directors unless they are ready to adopt a solid stance at a crucial moment and take concrete actions. It is something that will distinguish successful CEOs from the ones who will not excell at this position and thus not lead the company into success.

Because of aforementioned reasons, the CEO selection is a very important activity for Human Resources Management (HRM) and requires adequate selection criteria. When applying for CEO positions in a company, the basic purpose of candidates selection is to single out those with necessary up-to-date knowledge, business experience, and language skills. The CEO selection process includes many different factors such as candidates for CEO position, criteria for selection and Human Resources Commission (HRC). It is not easy for the HRC to select appropriate CEOs who satisfy all the requirements among various criteria. As such, the CEO selection is a multi-criteria decision making problem which is affected by several qualitative and quantitative, often conflicting criteria which are usually uncertain. For this reason, CEO selection can be treated as a selection under uncertain conditions. The problem of uncertainty emerges from errors in measuring, vagueness and ambiguity in natural languages, social intercourse, etc., and dealing with it is essential to human beings on all levels of their interaction with the world [2, 22]. The turning point in the uncertainty evaluating is introducing fuzzy logic [28] and fuzzy sets [29].

As in many decision problems, the CEO selection problem is too complicated in real life; humans generally fail to make a good prediction for quantitative problems, while having a good guess in qualitative forecasting [10]. In many situations of human resources selection, individuals from the HRC prefer to express their feelings with verbally. Fuzzy linguistic models permit the translation of verbal expressions into numerical values [10]. For that reason, these models can help to HRC in solving CEO selection problem when this problem is treated as a specific kind of personnel selection.

This paper describes a specific fuzzy decision system which is developed by using fuzzy extent analysis method proposed by Chang [4]. The method is known as an extended analytical method. The fuzzy decision support system is used for CEO selection problem solving. The rest of the paper is structured as follows: the second section describes the main characteristics of CEO and its importance in organization. In third section an introduction of fuzzy sets and fuzzy numbers is given. The fourth section explains the steps of extent analysis method. The fifth section analyses the real-life problem of selecting CEO by using fuzzy decision support system. The obtained results are discussed in the sixth section. Finally, the paper concludes with the seventh section where the conclusive considerations and discussion of future work are presented.

The Main Characteristics and Importance of Ceo Selection

The job of CEO is one of the most important leadership positions in society, and a better understanding of the job is vital for a better functioning economy. Chief Executive Officer (CEO) is the highest ranking executive manager in a corporation or organization. A CEO is responsible for overall success of the entire organization. He or she has the ultimate authority to make final decisions for an organization.

A CEO has specific responsibilities depending on the needs of his or her organization. The job description of a CEO varies by organization.

A CEO has overall responsibility for creating, planning, implementing, and integrating the strategic direction of an organization. This includes responsibility for all components and departments of a business.

A CEO assures that the organization's leadership maintains constant awareness of both the external and internal competitive landscape, opportunities for expansion, customers, markets, new industry developments and standards, and so forth.

Because the CEO role bears significant responsibility, accountability, and authority within an organization, a CEO also has additional responsibilities as he or she leads the business.

The responsibilities of a CEO include [31]:

- Creating, communicating, and implementing the organization's vision, mission, and overall direction. Leading the development and implementation of the overall organization's strategy.
- Leading, guiding, directing, and evaluating the work of other executive leaders including presidents, vice presidents, and directors, depending on the organization's reporting structure.
- Soliciting advice and guidance, when appropriate, from a Board of Directors.
- Formulating and implementing the strategic plan that guides the direction of the business or organization.
- Overseeing the complete operation of an organization in accordance with the direction established in the strategic plans.
- Evaluating the success of the organization.
- Maintaining awareness of both the external and internal competitive landscape, opportunities for expansion, customers, markets, new industry developments and standards, and so forth.
- Representing the organization for civic and professional association responsibilities and activities in the local community, the state, and at the national level. (Other executive leaders bear responsibility for these ventures as interested or assigned as well.)
- Demonstrating the leadership necessary to make the organization's mission a success. This leadership includes providing leadership vision, leadership that attracts followers, and all other aspects of successful leadership.

An organization's CEO is a key player in whether and how well an organization will succeed. If they carry out these job responsibilities effectively, it will magnify the probability of the organization's success.

A high degree of organization is expected from a CEO, as well as the ability for quick and analytical decision making, and intuitive reasoning in reaching important decisions for which we do not have specific information. Timely planning and organization of work is cruicial, equally as good coordination and the ability to work in large teams. A great CEO carefully listens to others, has the ability to negotiate and is tactful.

Among personal qualities, directors should possess perseverance, confidence, ability to manage the work of others and set high goals in order to achieve better results. Verbal capacities of a CEO are very important, considering possible direct communication with representatives of other companies. In addittion, knowledge of several languages is seen as an advantage, since it enables cooperation with foreign companies and possible customers.

The CEO position requires a university degree in the relevant field. Also, years of experience are a prerequisite, as well as attendance on various seminars and lectures that aim to enhance the work of the CEO. The demand for employees within this profile is significant, but the turnout is rather weak, given the stringent requirements of the competition, and the not so vast number of highly skilled people available. It is very important to possess a high level of qualifications, and more importantly a long professional experience and passed professional exams. In addition, the organizational, leadership and analytical skills are highlighted, as well as the ability for communication, planning and multitasking, knowledge of language and computer skills.

The mentioned responsibilities and described CEO tasks are main reasons why the company needs to make a good CEO choice because, if company selects a bad CEO, in that case the results of the company's effort to make success in business will be missed.

Fuzzy Set Theory and Fuzzy Numbers

In many situations decision makers have imprecise/vague information about alternatives with respect to attributes. It is well known that the conventional decision making analysis using different techniques and tools has been found to be inadequate to handle the uncertainty of fuzzy data. To overcome this problem, the concept of fuzzy approach has been used in the evaluation of decision making systems [24].

One of the methods which describe imprecise cases is the fuzzy set introduced by Zadeh [28] as an efficient way to mathematically represent uncertain and imprecise human assessments which are generally characterized for its linguistic terms that are based on words such as "equally", "moderately", "strong", "very strong" and "exceptional" [28, 30].

Therefore, the application of fuzzy theory by decision-makers enables them to successfully deal with uncertainties. Furthermore, fuzzy logic can be the basis for numerous methods through which qualitative assessments can be expressed through quantitative data [20]. Fuzzy sets generally employ triangular, trapezoidal and Gaussian fuzzy numbers, converting uncertain numbers into fuzzy numbers.

To solve the problem of CEO selection, in this paper triangular fuzzy numbers will be used according to following definition:

Definition 1. A triangular fuzzy number is denoted simply by a triplet *(l|m, m|u)* or *(l, m, u)*. The parameters *l, m* and *u*, respectively, define the smallest possible value, the most promising value and the largest possible value that describes a fuzzy event. The triangular type membership function of $\widetilde{M}$ fuzzy number can be described as Eq. (1) [7, 17]:

$$\mu(x|\widetilde{M}) = \begin{cases} 0, & x < l \\ \dfrac{x-l}{m-l}, & l \le x \le m \\ \dfrac{u-x}{u-m}, & m \le x \le u \\ 0, & x > u \end{cases} \quad (1)$$

Definition 2. The operational laws of two triangular fuzzy numbers $\widetilde{M}_1 = (l_1, m_1, u_1)$ and $\widetilde{M}_2 = (l_2, m_2, u_2)$, as follows:

$$\widetilde{M}_1 + \widetilde{M}_2 = (l_1 + l_2,\ m_1 + m_2,\ u_1 + u_2),$$

$$\widetilde{M}_1 - \widetilde{M}_2 = (l_1 - l_2,\ m_1 - m_2,\ u_1 - u_2),$$

$$\widetilde{M}_1 x \widetilde{M}_2 = (l_1 x\, l_2,\ m_1 x\, m_2,\ u_1 x\, u_2),$$

$$\widetilde{M}_1 / \widetilde{M}_2 = (l_1 / u_2,\ m_1 / m_2,\ u_1 / l_2),$$

$$(\widetilde{M}_1)^{-1} = (1 / u_1,\ 1 / m_1,\ 1 / l_1).$$

Commonly triangular fuzzy numbers are displayed with the usage of the linguistically significance scale, shown in Table 1 [3, 16].

Table 1. Linguistic scale of importance.

Linguistic scale of importance	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Equal	(1,1,1)	(1,1,1)
Weak	(1/2,1,3/2)	(2/3,1,2)
Fairly strong	(3/2,2,5/2)	(2/5,1/2,2/3)
Very strong	(5/2,3,7/2)	(2/7,1/3,2/5)
Absolute	(7/2,4,9/2)	(2/9,1/4,2/7)

Available reading and texts offer numerous methods of gradation by means of fuzzy numbers. Such methods may yield different gradation results and require complex mathematical calculations.

One of the useful methods which use to solve multi-criteria decision-making problems based on fuzzy numbers is an extent analysis method. This method is used to consider the extent of an object to be satisfied for the goal, that is, satisfied extent. In the method, the "extent" is quantified by using a fuzzy number.

Methodology of the Extent Analysis Method

Let $X=\{x_1,x_2,...,x_n\}$ be an object set and $G=\{g_1,g_2,...,g_m\}$ be a goal set. According to the method of Chang extent analysis [3], each object is taken and extensive analysis for each goal g_i is performed, respectively. Therefore, m extent analysis values for each object can be obtained as $M^1_{g_i}, M^2_{g_i},...,M^m_{g_i}$, *i=1,2,..n*. All of the $M^j_{g_i}$, *j=1,2,..,m* are the triangular fuzzy number. The steps of Chang's extent analysis are:

Step 1: The value of fuzzy synthetic extent with respect to the i^{th} object is defined as Eq. (2):

$$S_i=\sum_{j=1}^{n}M^j_{g_i}\otimes\left[\sum_{i=1}^{n}\sum_{j=1}^{m}M^j_{g_i}\right]^{-1} \quad (2)$$

To obtain $\sum_{j=1}^{n}M^j_{g_i}$ it is necessary to perform the fuzzy addition of numbers in the matrix such that $\sum_{j=1}^{n}M^j_{g_i}=\left(\sum_{j=1}^{m}l_j,\sum_{j=1}^{m}m_j,\sum_{j=1}^{m}u_j\right)$ and to obtain $\left[\sum_{i=1}^{n}\sum_{j=1}^{m}M^j_{g_i}\right]^{-1}$ which is performed by using the operation of fuzzy addition of all values such that $M^j_{g_i}$, *j=1,2,..,m*

$$\sum_{i=1}^{n}\sum_{j=1}^{m}M^j_{g_i}=\left(\sum_{i=1}^{n}l_i,\sum_{i=1}^{n}m_i,\sum_{i=1}^{n}u_i\right) \quad (3)$$

The vector from Eq. (2) is determined in Eq. (4):

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m}M^j_{g_i}\right]^{-1}=\left(\frac{1}{\sum_{i=1}^{n}u_i},\frac{1}{\sum_{i=1}^{n}m_i},\frac{1}{\sum_{i=1}^{n}l_i}\right) \quad (4)$$

Step 2: The degree of possibility of $M_2=(l_2,m_2,u_2)$ and $M_1=(l_1,m_1,u_1)$ is defined in Eq. (5):

$$V(M_2\geq M_1)=y\geq x\left[\min\left(\mu_{M_1}(x),\mu_{M_2}(y)\right)\right] \quad (5)$$

and can be equivalently expressed as follows Eq. (6):

$$V(M_2\geq M_1)=hgt(M_1\cap M_2)=$$

$$=\mu_{M_2}(d)=\left\{\begin{array}{ll}1, & f \quad m_2\geq m_1\\ 0, & f \quad l_1\geq u_2\\ \frac{l_1-u_2}{(m_2-u_2)-(m_1-l_1)} & other\end{array}\right\} \quad (6)$$

where d is the ordinate of the highest intersection point D between μ_{M1} and μ_{M2}. To compare M_1 and M_2, we need both the values of $V(M_1\geq M_2)$ and $V(M_2\geq M_1)$.

Step 3: The degree of possibility for a convex fuzzy number to be greater than k convex fuzzy numbers M_i, *i=1,2,..,k* can be defined by Eq. (7):

$V(M\geq M_1, M_2,..., M_k)=\min V(M\geq M_i)$, *i=1,2,..,k* (7)

Assume that $d'(A_i)=V(S_i\geq S_k)$ $k\neq i$, *k=1,2,..,n* (8)

and then the weight vector is given as

$$W'=\left(d'(A_1),d'(A_2),...,d'(A_n)\right)^T \quad (9)$$

where A_i, *i=1,2,..,n* is a matrix with n elements.

Step 4: Via normalization, the normalized weight vectors is given by Eq. (10):

$$W=\left(d(A_1),d(A_2),...,d(A_n)\right)^T \quad (10)$$

where W is a non-fuzzy number [15].

Calculation of the Consistency Ratio

When we have a selection which is based on described methodology, we need to ensure a decision's quality, and in for this purpose, the consistency of the evaluation has to be analyzed. For testing consistency, there is a need to calculate Consistency Ratio (CR). In his study, Saaty proposed utilizing consistency index (CI) and consistency ratio (CR) to verify the consistency of the comparison matrix [6, 26]. CI and RI can be defined as follows:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{11}$$

$$CR = \frac{CI}{RI} \tag{12}$$

where *RI* is a random index, which depends on *n* criteria [9, 14] as given in Table 2.

Table 2. A random index of random matrix [9]

n	3	4	5	6	7	8	9
RI	0.58	0.9	1.12	1.24	1.32	1.41	1.45

If the *CR* of a comparison matrix is equal to or less than 0.1, it may be acceptable. When the *CR* is unacceptable, the decision-maker is encouraged to repeat the pairwise comparisons [9].

In order to calculate value of λ_{max} from Eq. (11), there is a need to perform an operation of converting a fuzzy number into a crisp number. This operation usually called "defuzzification". Various defuzzication methods are available in the literature. At this place, we mention some significant methods for defuzzification, for example, the weighted distance method of Saneifard [25], the simple centroid method of Chang and Wang [5] to get the best nonfuzzy performance value, the method for converting of fuzzy data into crisp scores which is defined by Opricovic and Tzeng [23], the fuzzy mathematical programming method introduced by Mikhailov [21] and the lambda-max method proposed by Csutora and Buckley [8]. The defuzzification method which is adopted in this article was derived from Hus and Nian [12], as well as Lious and Wang [19].

Let $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ is a triangular fuzzy number. This number can be converted to a crisp number using Eq. (13) as follows:

$$a_{ij} = \left[\lambda * l_{ij}^{\alpha} + (1-\lambda) * u_{ij}^{\alpha}\right], 0 \le \lambda \le 1, 0 \le \alpha \le 1 \tag{13}$$

where are:

- α is exhibited preferences of the decision makers;
- λ is risk tolerance of the decision makers;
- l_{ij}^{α} is the left-end value of α-cup for α_{ij} which is calculated as follows $l_{ij}^{\acute{a}} = (m_{ij} - l_j) * \acute{a} + l_j$
- $u_{ij}^{\acute{a}}$ is the right-end value of α-cup for a_{ij} which is calculated as follows $u_{ij}^{\acute{a}} = u_{ij} - (u_j - m_j) * \acute{a}$

At this point, we should mention that α can be viewed as a stable or a fluctuating condition [13]. The range of uncertainty is the greatest when α = 0. Meanwhile, the decision making environment stabilizes when increasing α while, simultaneously, the variance for decision making decreases [6]. Additionally, λ can be considered as the degree of a decision-maker's optimism and its range is between 0 and 1 [9]. When λ=0, the decision maker is highly optimistic. When λ=1, the decision maker is pessimistic [9]. In this paper, we use value α=0.5 to denote that environmental uncertainty is steady, while λ=0.5 denotes that the future attitude is fair. When we made conversation fuzzy numbers to crisp numbers using to describe methodology, we can determine value of λ_{max} from Eq. (11) where

$$A * W = \lambda_{max} * W, \tag{14}$$

$$[A - \lambda_{max}] * W. \tag{15}$$

where *w* denotes eigenvector of the matrix *A*.

Application of Fuzzy Decision System for CEO Selection

Using the described steps of extent analysis method and using JAVA technology, a fuzzy decision support system based on fuzzy triangular numbers is developed.

Figure 1 shows a UML class diagram of developed fuzzy DSS. Basic elements of this module are classes *Criteria* and *Alternative*. They are generalized from abstract class Element. Class *FuzzyNumber* represent a triangular fuzzy number. Classes Degree, *SyntheticExtent, Result* and *FinalResult* help classes for calculation of fuzzy AHP. *Calculate* is an abstract class which represents the template method software pattern. It is generalized to classes *FuzzyAHP* and *ChangFuzzyAHP*. Because of this template method, this software module can be extended with new methods, not only fuzzy AHP's, but methods like fuzzy TOPSIS or any other method that requires pairwise comparison of each pair of factors in the same hierarchy level. *Util* class is a singleton that provides a single point of access to this module [1].

owner takes participation in conducting the interview and in selection of the most suitable candidate. In this selection, company's owner considers selection criteria according to his requirements and relates to the specific job description. The criteria are: Personnel Characteristics (PC), Foreign Language (FL), Education Background (EB), Business Experience (BE), Leadership (LS), Team Working (TW) and Project Management Knowledge (PMK). The hierarchical tree is given in Figure 2.

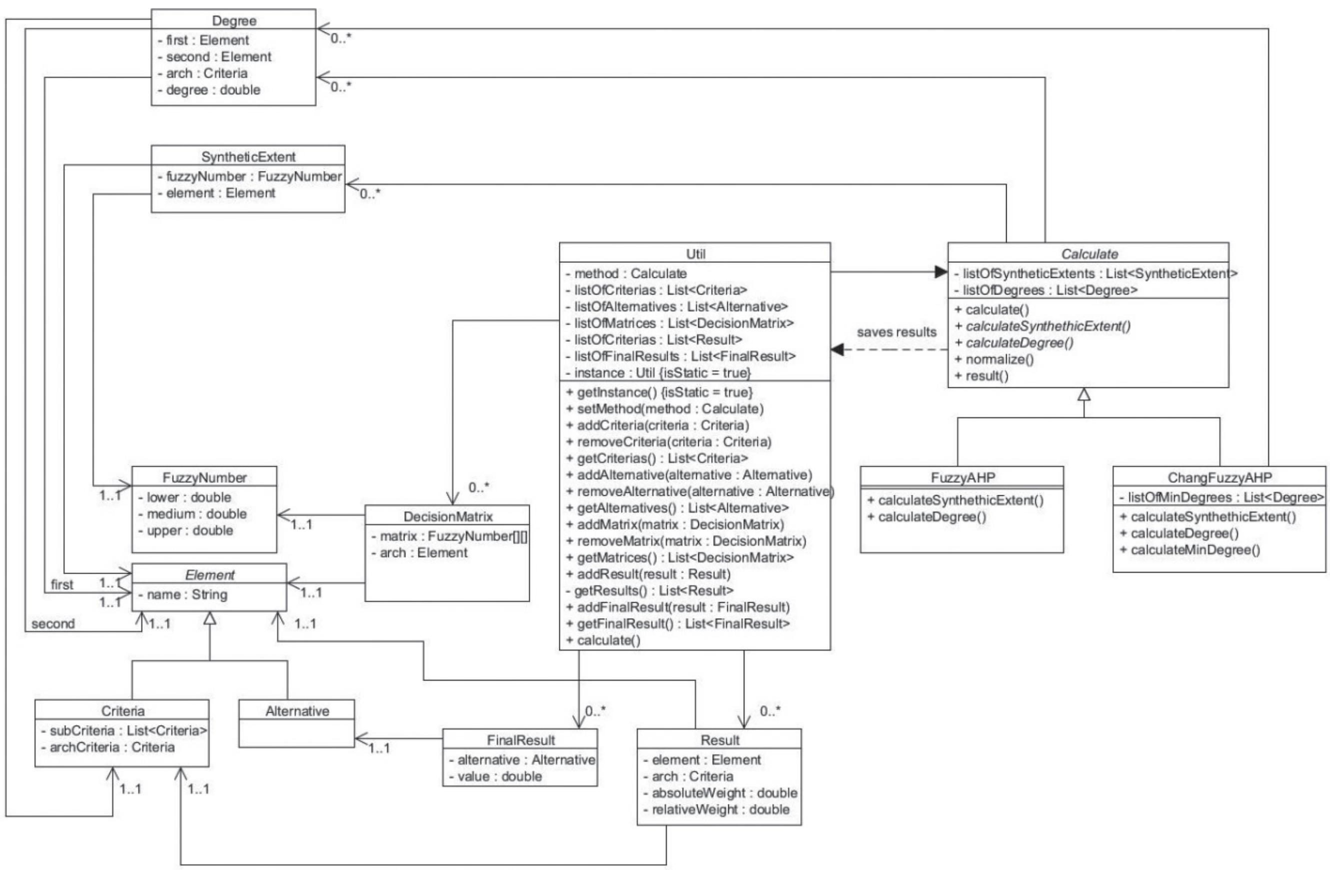

Figure 1. The class diagram of fuzzy decision support system.

This fuzzy decision support system is created to help HRD make quick and good decision for personnel selection in the recruitment process.

Selecting a suitable CEO is a success critical factor in every company. The importance of CEO role is described in previous section 2.

In this case study, an ICT company needs to hire a person for CEO position. After preliminary screening, three candidates, namely CEO1, CEO2 and CEO3 remain for further evaluation. A company's

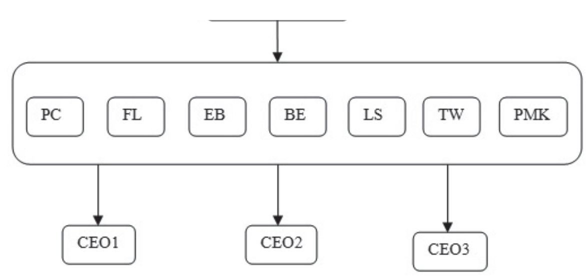

Figure 2. The hierarchical tree of CEO selection problem

The ratings of three CEOs by the company's owner (expressed in fuzzy numbers) under all criteria are given in Table 3.

Table 3. The ratings of three CEOs by company's owner under all criteria (in linguistic variables)

Decision maker	criteria	PC	FL	EB	BE	LS	TW	PMK
Company's owner	PC	equal	Weak	Weak	Fairly strong	Weak	Fairly strong	Very strong
	FL	Weak	equal	Fairly strong	Fairly strong	Very strong	Weak	Fairly strong
	EB	Weak	Fairly strong	equal	Fairly strong	weak	Fairly strong	weak
	BE	Fairly strong	Fairly strong	Fairly strong	equal	Fairly strong	Fairly strong	weak
	LS	Weak	Very strong	Weak	Fairly strong	equal	Fairly strong	Fairly strong
	TW	Fairly strong	Weak	Weak	Fairly strong	Fairly strong	equal	Fairly strong
	PMK	Very strong	Fairly strong	Weak	weak	Fairly strong	Fairly strong	equal

The ratings of three CEOs from Table 3 can be converted to triangular fuzzy numbers which is given in Figure 3.

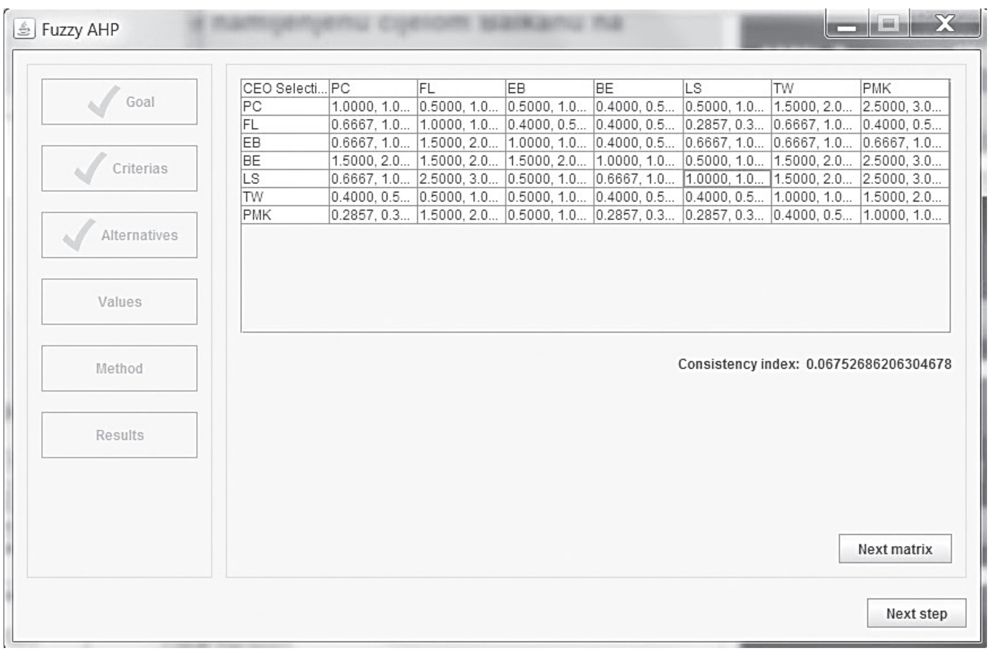

Figure 3. Creation of fuzzy matrix of criteria comparison

When the DM's from HRD committee created the fuzzy matrix of criteria comparison, the fuzzy decision support system automatically calculates the Consistency Ratio (CR) to ensure a decision's quality. In this case, CR is under 0,1 and quality of decision matrix is excellent.

In order to calculate local weights of alternatives (CEOs) with respect to all criteria, the fuzzy decision support system gives possibilities for creating the singular fuzzy matrix for every criterion (see Figure 4 for PC criterion, for example).

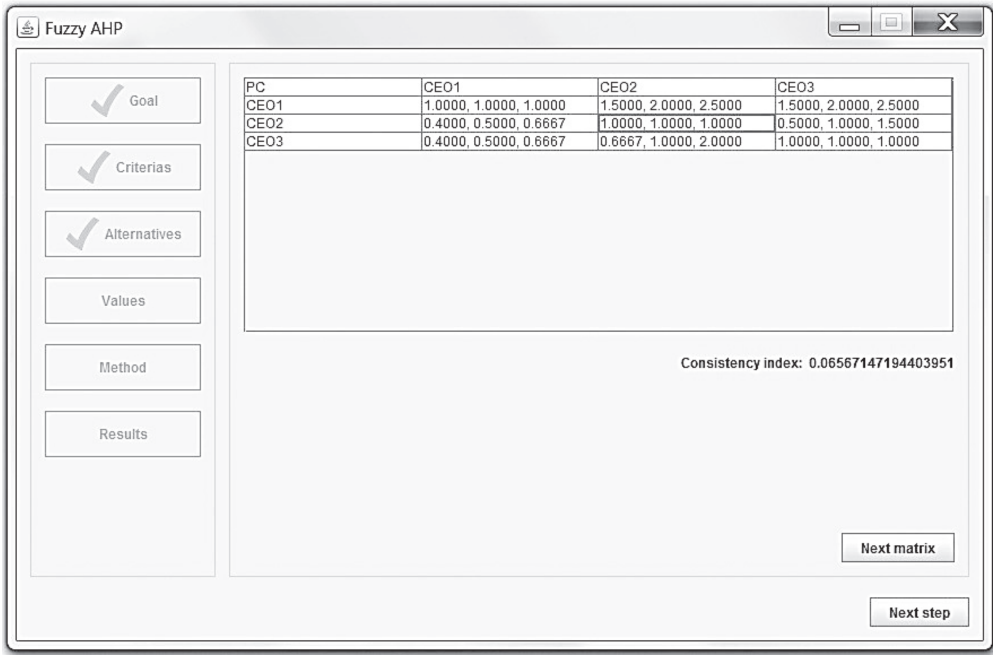

Figure 4. The singular fuzzy matrix for calculating the local weights of alternatives with respect to the criteria

After entering all data for all criteria using singular matrices which are similar to matrix from Figure 4 but with different values, the fuzzy decision support system gives possibilities for selecting the method of calculation (see Figure 5).

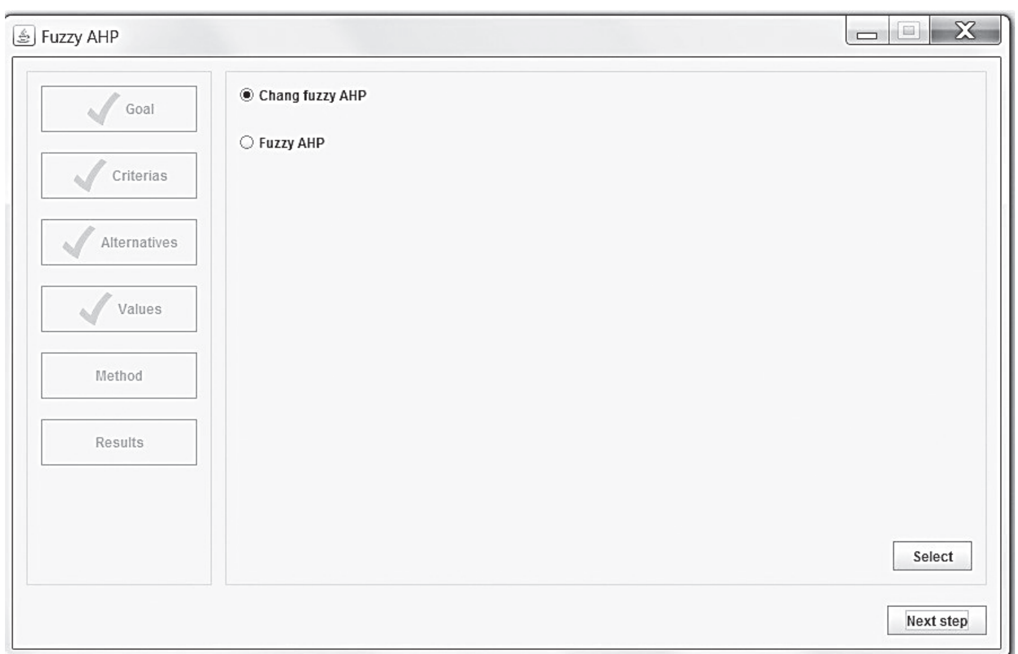

Figure 5. The selection of calculation method

For the purpose of this paper, we select Chang Fuzzy AHP option from Figure 5. After finishing this selection, the fuzzy decision support system automatically creates final results (see Figure 6).

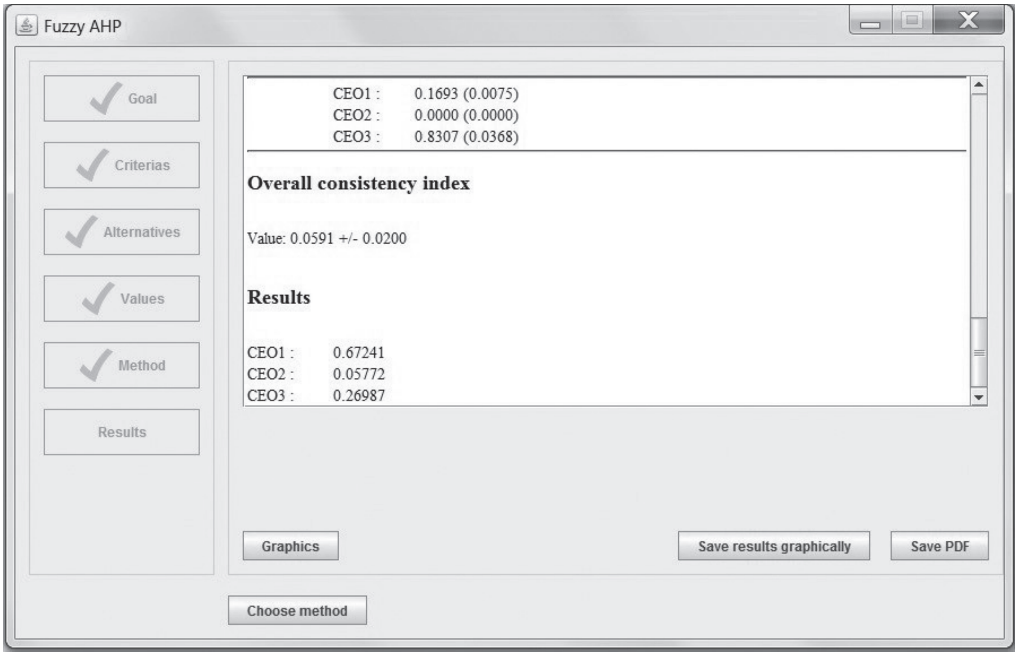

Figure 6. The results of CEO selection

The fuzzy decision support system gives possibilities to show results graphically when decision maker selects options '*'Graphics"* from Figure 6. In this case, the final results are shown in Figure 7.

Figure 7. The results from fuzzy decision support system: Weights of criteria

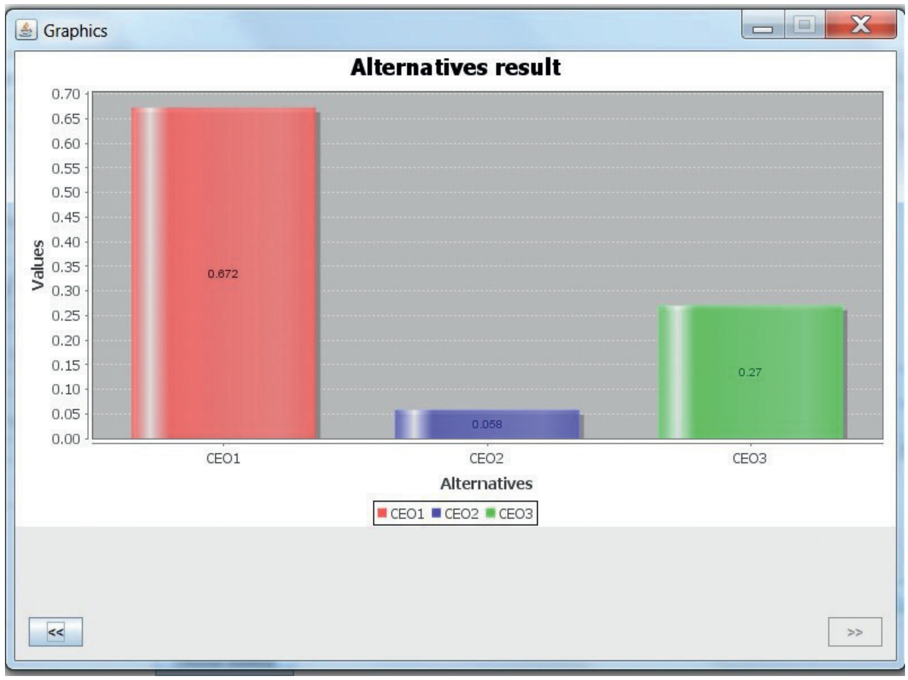

Figure 8. The results from fuzzy decision support system: Rank of CEO candidates

The Analysis of Obtained Results

It has been determined that the CEOs weights are (0.672, 0.270 and 0.058). According to the final result, the most suitable candidate for CEO is CEO with the highest priority weight. If we consider obtained results from Figure 6, we can conclude the following: for company's owner very important criterion for CEO selection is Business Experience in CEO area with priority weight 0.249. It is a logical fact, because CEO should be an ''experienced person" who is responsible for company development and success. For that reason, the CEO1 has got very high weights for BE criterion from company's owner. At the same time, the CEO1 has a good leadership characteristics which in combination with Business Experience guarantees that the company's owner made the best choice. Based on data from Figure 5, we can conclude that this CEO selection is very good because obtained CR for criteria and alternatives is under 0.1 which indicates good decision quality. Such obtained results suggest that the CEO selection problem is extremely complex in real life because humans generally fail to make a good prediction for quantitative problems, in contrast, they may make accurate guesses in qualitative forecasting [14]. The CEO selection problem generally concerns with important and complex issues such as [18]:

- How to properly set the importance weights of criteria to reflect the situations in which not all personnel attributes/characteristics are equally important?
- How to use linguistic and/or numerical scales to evaluate the applicants under multiple criteria?
- How to aggregate the evaluation results and then rank the applicants? The inherent importance and complexity of the CEO selection problem as a subset of personnel selection problem requires effective analytical methods to provide an operational/tactical decision framework.

In order to give a solution for previous issues, we have applied here a specific kind of decision support system based on the fuzzy extent analysis method. This method gives possibilities to include qualitative criteria in the CEO selection process. It allows mathematical calculation criteria weights which leads to the reduction of subjective judgments in the process of distinguishing between an appropriate and inappropriate employee for a job position. For this reason, many decision makers from HRD in Serbian companies are very satisfied with the applied method.

Conclusion

Selecting the most suitable CEO person is a key success factor for an organization. The complexity and importance of the problem, call for analytical methods rather than intuitive decisions. The specificity of this problem consists in dealing with imprecise data, difficulties in retrieving information and expressing an explicit opinion. CEO selection is a process that also contains uncertainties. The decision - makers face rising and complex environments today, and also decision makers are often uncertain in assigning the evaluation scores in crisp value. This problem can be overcome by using fuzzy numbers and linguistic variables to achieve accuracy and consistency. Fuzzy logic is considered ideal to deal with this type of problems. In this paper, we applied the fuzzy extent analysis method in the process of selecting the most suitable CEO. Unlike other decision methods, the described method can adaptively find a suitable CEO for the required job. For making uniform consensus of the decision makers, we converted all pair-wise comparisons into triangular fuzzy numbers to adjust fuzzy rating and fuzzy attributes weight, and used fuzzy operators in order to select the best alternative. In the future research, the authors suggest developing electronic fuzzy decision support system in which we will include other multi-criteria decision technique as TOPSIS or Interpolative Boolean Algebra. It will be subject of the future works of authors.

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Performance Evaluation of Routing Protocols in a Wireless Sensor Network for Targeted Environment

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Case study

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Abstract: This paper investigates the performance of reactive and proactive routing protocols in a wireless sensor network for targeted enviroment. AODV and DSR are chosen as representatives for the reactive routing protocols and DSDV for the proactive. A wireless sensor network application for farm cattle monitoring is created. The proposed solution meets a desired requirement for periodically observing the condition of each individual animal, processing the gathered data and reporting it to the farmer. However, an implementation of a WSN needs to meet particular technical challenges before it can be suitable to be applied in cattle management. For this, multiple scenarios are presented with various situations to evaluate the performance of routing protocols in the WSNs. Finally, the results concerning data transportation from the mounted sensory devices to the mobile nodes are discussed and analyzed.

Key words: wireless sensor network, herd management, cattle health monitoring, routing protocol, cattle monitoring application, mobile nodes.

Introduction

A wireless sensor network (WSN) consists of a group of sensor nodes that use radio signals to communicate among them. They can send and forward packets to other nodes in the network, which means that they also act as routers in the network. There are usually a large number of nodes in a WSN. They can be distributed in arbitrary locations and can move independently in any direction. The nodes are responsible for the tracing of the other nodes in the network [2]. The routing protocols that are used in WSN have to be highly dynamic to be able to rapidly respond to the topology changes [13].

In this paper, a WSN-based solution for cattle health monitoring is investigated. Such a solution would provide a reliable monitoring system that would allow regular assessment of herd health data. A model for a WSN based health care system was developed. The main aim of the research was to establish a routing protocol that will provide the best performance for this targeted application. For this purpose three different ad-hoc routing protocols were evaluated: AODV (Ad-hoc On-Demand Distance Vector Routing) [11], DSDV (Destination-Sequenced Distance Vector) [12] and DSR (Dynamic Source Routing) [5]. Their functionality was assessed in terms of several performance metrics: Packet Delivery Ratio, End-To-End Delay, Normalized Routing Load, Total Routing Packets, Generated Packets, Received Packets, and Dropped Packets.

The study presented in this paper examines and compares the performance of ad-hoc routing protocols in a herd monitoring system using simulation as an instrument for investigation. Given the very high costs of conducting such a research in real setting, simulation is a more feasible method for initial implementation and evaluation. The models can be quickly developed, allowing complete access and control of their internals. The simulator of choice was ns-2 which is a discrete event simulator specifically designed for research of computer networks and network protocols [1].

This paper is organized as follows: Section 1 is the introduction to the field of research and the paper itself. Section 2 describes the ad-hoc routing protocols background with emphasis to the evaluated protocols. Section 3 describes the simulation environment. Section 4 contains the simulation results and discussion. Section 5 presents the conclusions.

Background

Routing in ad-hoc wireless networks is a task different from routing in wired networks. An ad-hoc network does not have a devoted router node so the ad-hoc routing protocol runs at each node in the network. A routing protocol that operates in an ad-hoc wireless network cannot rely on wired paths and has to deal with mobility, frequent disconnections, power source constraints, range limitation etc.

There is a large diversity of proposed ad-hoc routing protocols. In the early classifications they were generally categorized as proactive, reactive and hybrid. A recent extensive ad hoc routing protocols study [3] presents a classification with five more categories: location aware, multipath, hierarchical, multicast, geographical multicast and power-aware. However, the research in this study is performed with protocols belonging to the proactive and reactive categories, since they suffice the needs of this research.

Proactive protocols periodically propagate routing updates in order to maintain routing information from each node to every other node in the network. Routes are available at any moment. In contrast, reactive routing protocols find the path to a node only when there are packets to be sent. After a restricted period of time, those routes become invalid.

Ad-hoc On-Demand Distance Routing (AODV)

AODV belongs to the reactive protocols category. It uses routing tables to maintain route information. If there is a node seeking to send a data packet to a destination node and there is no established route to the destination node, a route discovery process is started [6]. During that process several kinds of messages are exchanged. A Route Request (RREQ) message is flooded to all the nodes in the network until the destination is found or a node with a valid route to the destination is found with a sequence number that is greater than or equal to the sequence number contained in the RREQ. Each node that forwards the RREQ creates a reverse route for itself back to the initial node.

When the destination receives the RREQ packet, it sends back a "Route Reply" (RREP) message through the established reverse path. As long as a route remains active it will be maintained. A route remains active as long as there are packets passing through it. After a period of idleness the route will time out and will be removed from the routing tables of the neighboring nodes. During route maintenance, if the node discovers that the route to the neighbor is not valid, it removes the routing entry and sends a "Route Error" (RERR) message to inform the active neighbors that use it. This procedure is repeated in all the active nodes that will receive the RERR message [9, 10]. A route is considered active if there are packets that periodically traverse the route.

Dynamic Source Routing (DSR)

DSR is categorized as a reactive routing protocol. It operates through route discovery and route maintenance stages. Route discovery is initiated when a route to a destination is needed and no known routes to that destination exist. A node that needs to send packets to a destination node broadcasts a RREQ packet to its neighbors. All the nodes that receive the RREQ packet do the following:

1. If the packet was already received, it is discarded;
2. If the address in the RREQ packet is equal to its own address, then the packet has reached its destination;

3. If 1) and 2) do not apply, the node adds its own address in the list of the visited nodes in the RREQ packet and broadcasts the modified RREQ packet.

The nodes maintain the routes by periodically sending packets through them. If a route becomes invalid, route discovery is initiated again [4].

Destination Sequenced Distance Vector (DSDV)

DSDV is a proactive routing protocol based on the Bellman-Ford algorithm. The main advantage of this protocol is that it provides route loop freedom which is not the case in the Bellman-Ford algorithm [2, 10]. DSDV is a table-driven protocol. Every node in the network maintains a routing table which contains all possible destinations with associated next hop and sequence numbers. The sequence numbers are used to mark the routes. A route with a larger sequence number is preferred to a route with a smaller sequence number. If two routes have equal sequence numbers, then the one with the smaller number of hops is preferred. If there is an error in a route, its number of hops is set to infinity and the sequence number is increased to an odd number, whereas even numbers are reserved for the connected routes. The routing table is maintained with a periodical exchange of messages between the nodes. A node that receives a message will update its routing table only if it had received a new or a better route. Routing updates are performed periodically to maintain route consistency. They can be performed through full dumps or by smaller, incremental updates. The property of constant sending of routing table updates creates additional network overhead and increases energy consumption which makes DSDV less appropriate for highly dynamic networks.

Simulation Environment

Finding ways to improve farming methods and enhance animal health care is becoming essential for the farming industry [7]. Utilizing a WSN cattle health monitoring system would greatly improve and facilitate the work at a cattle farm. By adding sensor nodes to each animal, the farmer would be able to monitor its health parameters without the need to approach it, and it would be able to roam freely in the open farm. The farmer can obtain different evidence about the animals: location, distance from the central stables, health parameters, hormonal statuses etc. Moreover, the system can interconnect the local veterinarians, who may receive information about the change in the health of the animals and react instantly if needed. Thus, a more immediate contact between a farmer and a veterinarian would be established.

In order to obtain information (data, statistics) for the performance of the routing protocols, a simulation model for ns-2 was built. Hence, the network parameters for the simulation in ns-2 are given in (Table 1).

Table 1. Network parameters for the simulation of a farm using ns-2

Parameter	Value
Routing protocols	AODV, DSDV and DSR
Traffic type	CBR
Transport type	UDP and TCP
Mobility model	Random Waypoint
Channel type	Channel / Wireless Channel
Radio propagation model	Propagation / TwoRayGround
Network interface type	Phy / WirelessPhy
MAC type	Mac/802_11
Type of interface queue	Queue / DropTail/ PriQueue
Data link type	LL
Antenna type	Antenna / OmniAntenna
Channel capacity	2 Mbps
Packet size	512 KB

In contrast to analytical data gathering, the simulation model will enable the possibilities to test different types of scenarios. These scenarios for the simulation model reflect the txypical habitual movement of the animals during their daily stay on a farm [7, 8]. The details and the guidelines for the simulation were defined and set as follows:

- The size of the area of the farm ranges from 1000 m² to 10 000 m²;
- Animal behavior is surveyed during 24 hours.
  - In the barn/stable:
    - 2 hours of additional feeding and milking of the cows;
    - The feeding and milking occurs twice within 24 hours, for example at 06:00 and 18:00;

- o In the field:
  - 1 – 4 hours of slow movement for grazing with average speed of 1-2 meters in a minute;
  - 2 – 3 hours of resting and rumination.

During 24 hours:
1. an animal spends in average 40 – 70 minutes in stillness in the barn (this is repeated twice);
2. an animal moves every 1 – 4 hours in the field in an arbitrary direction and remains stationary for a period of 2 – 3 hours. This is repeated twice during a period of 24 hours;
3. data is collected every 2 hours.

The values given in 1. – 2. are averaged and used as limitations for the intervals where the random parameters in the simulations vary. The size of the simulation area is 2000 m². There are 50 equally spaced stationary sensor nodes that cover the area and one of them is used as a destination node. The number of mobile nodes is 15, 35 and 75 respectively in three different sets of simulations (Table 2).

Table 2. Area and Node parameters of the simulation

Parameter	Value
Farm area	2000 m × 2000 m
Number of stationary nodes	49
Number of destination nodes (barn)	1
Number of moving nodes	15, 35 and 75
Direction of node movement	random
Speed of node movement	1.5 m/min
Duration of node movement	2.5 hours
Duration of node's immobility	2.5 hours

The mobile nodes represent the cattle and mimic their movements according to the described scenario (Table 3). Because the pattern of the activities repeats in 12 hours and the cattle spends 1 of those hours in the farm and it is on standby, the duration of the simulations is set to 11 hours.

The main goal of the simulations was to evaluate the performance of different routing protocols for wireless mobile networks and find out which one will be the best suited for use in the application for herd monitoring. The choice was to test AODV, DSDV and DSR. Every 2 hours data is collected from every mobile node to the destination (Table 3). Regarding the possible synchronization of the nodes that may occur at that time, random delay to the packet sending was introduced and the performance of the routing protocols was examined in four different schemes, presented in Table 3.

Table 3. *Data sending parameters*

Parameter	Value
Simulation duration	39600 seconds (11 hours)
Time of packet sending	every 7200 seconds (2 hours)
Duration of packet sending	5 seconds
Packet sending schemes	1. All nodes send packets at the same time 2. Nodes send packets interchangeably, spaced with a random time in the interval from 0 to 10 seconds 3. Nodes send packets serially 4. Nodes send packets serially with a 5 second spacing between

All the tests were repeated 10 times with different random initial positions and different random movements of the mobile nodes. The analysis of the results is based on the averaged measured values obtained in the simulations.

Performance metrics

During the simulations, several metrics that reveal the routing protocol performance were observed:
- Total Number of Routing Packets (TNRP) – the total number of routing packets;
- Generated Packets (GP) – the total number of generated packets;
- Received Packets (RP) – the total number of received CBR packets;
- Total Dropped Packets (TDP) – the total number of dropped packets;
- Packet Delivery Ratio (PDR) – the ratio of total number of delivered packets versus the total number of sent packets. This ratio shows how successful the routing protocol is in data delivery and reflects its accuracy and reliability, where

$$PDR = \frac{Number\ of\ sent\ packets}{Number\ of\ delivered\ packets} \times 100 \qquad (1)$$

- Average End-To-End Delay (AEED) – the average time needed by the data packets to travel from the source to the destination. It contains the route discovery time and the delay caused by queuing in the intermediate nodes. Smaller value of AEED means a better routing protocol performance. It is calculated using the formula:

$$AEED = \frac{\sum_{i=1}^{N} (TimeDeliveredPacket_i - TimeSentPacket_i)}{Number\ of\ delivered\ packets} \quad (2)$$

where N is the total number of sent packets;

- Normalized Routing Load (NRL) – is the normalized load of the nodes with routing packets against data packets. It is calculated as a ratio of the total number of routing packets divided by the total number of data packets.

$$NRL = \frac{Number\ of\ routing\ packets}{Number\ of\ data\ packets} \quad (3)$$

A lower value of NRL denotes a better performance.

Results and Discussion

Scenario comparison

A set of simulations was performed for every single parameter setting (15, 35 or 75 mobile nodes, routing protocol AODV, DSDV and DSR, packet sending schemes 1 to 4). The tests were performed using TCP for packet transport, because the reliability of communication was chosen to be a key design factor for our system and TCP provides guaranteed delivery of packets. The simulations for each setting were repeated 10 times with different randomization seeds. The performance metrics were collected and studied. The results of the examination and the comparison of the results are discussed in terms of the routing protocols.

- AODV performs the best when the nodes send packets interchangeably spaced with a random time in the interval from 0 to 10 seconds for all given values of the number of the mobile nodes (15, 35, 75).
- DSDV gives the best results for 15 and 35 mobile nodes when scheme 2 for packet sending is used. For a network with 75 mobile nodes, the best outcomes are obtained when the nodes send packets consequently with 5 seconds spacing between them (i.e. scheme number 4 is used).
- The outcome of the tests performed with DSR was that it performed the best for a network with 15 mobile nodes if scheme 4 was used for packet sending. For networks with 35 and 75 nodes, scheme 2 was the most suited.

After this analysis was completed, the choice was made to execute all further experiments using scheme 2 for the packet sending order and collect all the performance metrics using this setting, because it gives the best overall outcome.

Comparison of performance metrics for AODV, DSDV and DSR

Total Number of Routing Packets

This parameter reflects the participation of the protocol in the overall communication overhead. It is proportionally related to the energy consumption and therefore should be kept as low as possible. Figure 1 represents the comparison of TNRP values for AODV, DSDV and DSR for networks with 15, 35 and 75 mobile nodes. For this metric, DSR shows the best results and DSDV shows the worst.

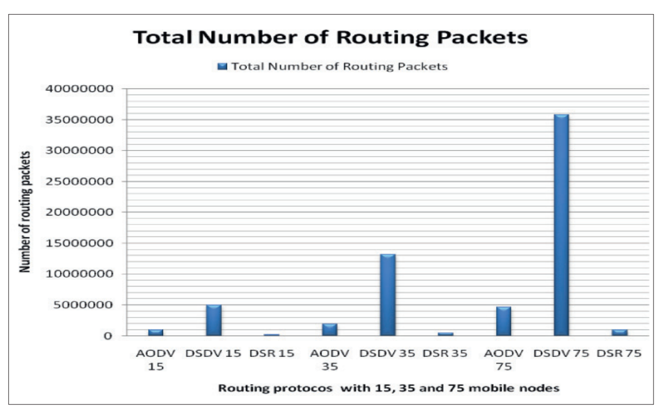


Figure 1. Comparison of TNRP for AODV, DSDV and DSR for 15, 35 and 75 nodes

Number of generated packets as opposed to the number of received packets

Figure 2 depicts a comparison of GP and RP values for AODV, DSDV and DSR for networks with

15, 35 and 75 nodes. It shows that AODV and DSR have similar performances, while DSDV has a much greater number of generated packets compared to the number of delivered packets.

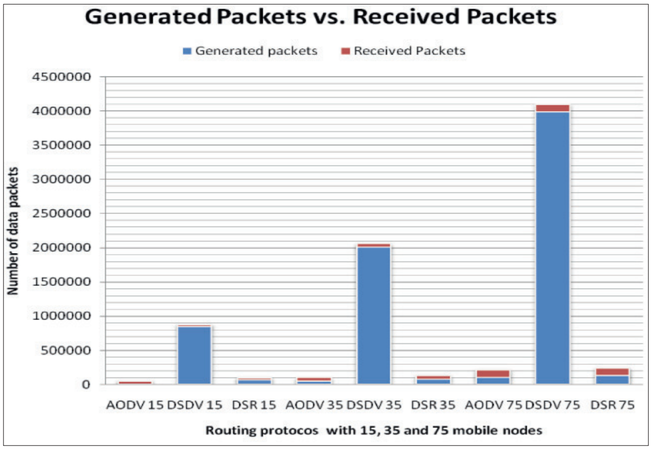


Figure 2. Comparison of GP versus RP for AODV, DSDV and DSR for 15, 35 and 75 nodes

Total Dropped Packets

The lowest value for TDP is obtained when DSR is used in the simulations, which is true in all cases with different numbers of nodes. Next comes DSDV and the last is AODV which has the biggest number of dropped packets. Figure 3 presents the TDP as a function of network size for the three protocols.

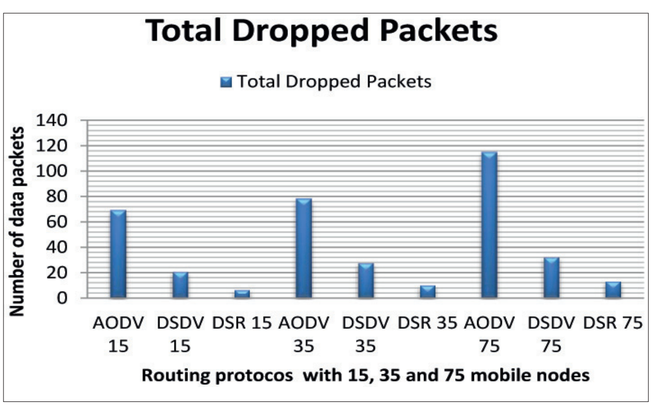


Figure 3. Comparison of TDP for AODV, DSDV and DSR for 15, 35 and 75 nodes

Packet Delivery Ratio

AODV has the highest average PDR in all cases and DSR gives results comparable to AODV. PDR for DSDV is far below PDR for the other two protocols. Figure 4 plots PDR against protocol and network size.

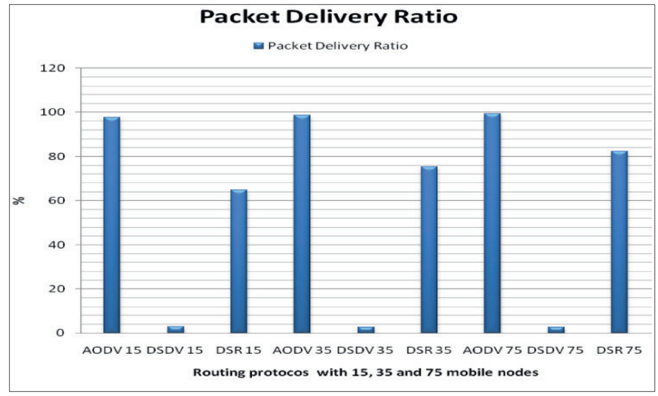


Figure 4. Comparison of PDR for AODV, DSDV and DSR for 15, 35 and 75 nodes

Average End-To-End Delay

In all cases in the simulations with networks with sizes 15, 35 and 75, mobile nodes DSDV and DSR have AEED higher than AEED for AODV. The difference is especially large in the case with 75 nodes. Furthermore, AEED for AODV tends to decrease with the increase of the network size. Hence, AODV shows superior performance compared to the other two protocols, which is presented in Figure 5.

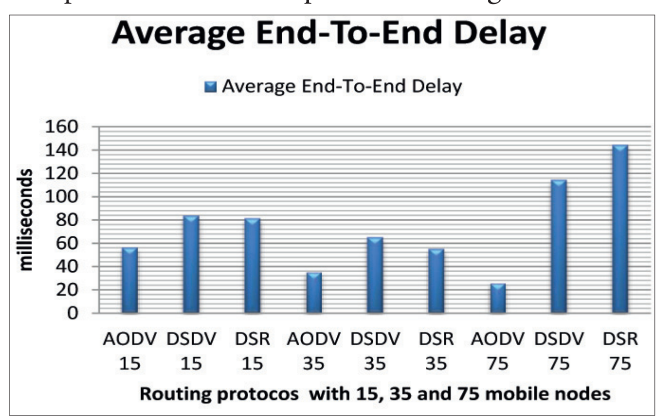
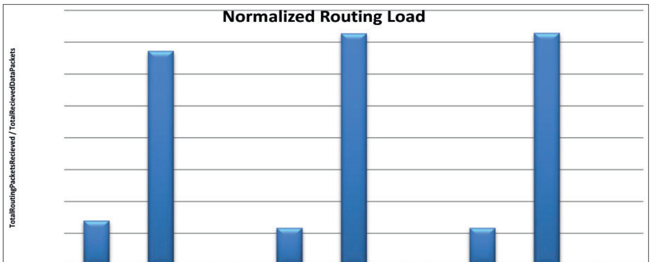


Figure 5. Comparison of AEED for AODV, DSDV and DSR for 15, 35 and 75 nodes

Normalized Routing Load

The larger the routing load is, the more the network is burdened with routing packets. This leads to greater energy consumption of the wireless nodes, which is an essential factor in a wireless sensor network. Wireless sensor nodes depend on a limited source of energy. For that reason it is very important for a routing protocol to have as small routing load as possible. In the simulations, the smallest value for NRL is obtained when DSR was used. AODV causes larger routing load than DSR. The case is similar with DSDV, but the difference is much greater. Figure 6 represents NRL plotted versus protocol and network size.



	AODV 15	DSDV 15	DSR 15	AODV 35	DSDV 35	DSR 35	AODV 75	DSDV 75	DSR 75
P.O.	13,978	67,234	0,2991	11,695	72,7671	0,1842	11,699	72,889	0,125

Figure 6. Comparison of NRL for AODV, DSDV and DSR for 15, 35 and 75 nodes

Conclusion

In this paper, a comparison of three routing protocols in a wireless sensor network for herd monitoring is presented. AODV and DSR were chosen as representatives of the reactive group and DSDV was chosen as a representative for the proactive group. The aim was to find which protocol is the most suitable for the targeted application. The results confirm the expectations based on the theoretical analysis: reactive routing protocols show superior performances to proactive protocols. The experimental results indicate that DSR has the smallest routing load and the smallest number of lost packets. AODV has slightly better packet delivery ratio and smaller average end-to-end delay. Since energy efficiency is a crucial parameter for wireless sensor networks, it can be concluded that DSR is the most appropriate choice for this environment.

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A Review on Methods for the Assessment of Information System Projects

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Critical review

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Abstract: Recently, it is inevitable that businesses invest in many information system (IS) projects in order to gain a competitive advantage within the internal industry and global environment. The important point is the selection of the appropriate IS environment, hence the optimal IS investment methods with respect to changing technological needs. In this respect, both empirical and conceptual studies are reviewed to identify the relevant IS/IT investment methods. After an extensive literature review, 51 relevant articles are identified. The IS/IT investment methods studied in these articles are classified and examined within the three categories: financial, non-financial, and hybrid. The results reveal that most of studies focus on a mixed usage of financial and non-financial methods called hybrid methods, whereas financial methods are used more frequently when compared to non-financial methods during the selected research period. On the other hand, the usage of pure financial methods decreases in recent years, while the usage of hybrid and non-financial methods increases in the same period.

Keywords: IS/IT investment methods, IS/IT investment, financial methods, non-financial methods, hybrid methods.

Introduction

Businesses invest in assets and projects several times in order to gain competitive advantage in the global business environment. Most of the time, businesses invest in real estate and machinery, people and information systems (IS). Among those, investment decision for IS are the most complicated and require more sophisticated decision making processes.

Advances in information technologies (IT) catalyze new competitors to enter existing markets which has encouraged the paradigm of global competitiveness. Third platform solutions such as mobile, cloud, social business, big data analytics are reinventing and continuously transforming every major industry (IDC, 2014). In such environment, investments in IS projects play a key role in remaining competitive and surviving in the long term in the marketplace. At the same time, the expanded usage of the third platform solutions drive businesses to evaluate their IT operations and quantify IT benefits due to increasing economic pressures. There is a dilemma between business performances and IS expenditures. Business benefits, which are gained from IS investments do not increase with the same momentum of the increase in IS expenditures. Brynjolfsson's [10] productivity paradox which states that there is an apparent contradiction between measures of investment in IS and measures of output at the national level, gives reasonable explanations for this dilemma.

Although businesses invest largely in IS projects to improve business performance and to gain competitive advantage, researches reveal that selecting appropriate methods in decision making in which IS projects to invest, is not an easy task. Therefore, researchers have focused on the evaluation of IS investment methods for many decades. Nowadays, efficient IT investment methods gain a pace to rebalance strategic benefits and IT expenditures. The main challenges that decision makers face are avoidance of perceived risk, unavailability of precise measurement methods and lack of detailed identification and assessment of the costs and benefits of IS project investments [25].

According to Karadag et al. [25], there are mainly two research trends related to IS investment decisions within the literature. While the first trend focuses on IT productivity and benefit measurement issues by empirical data gained from case studies from different industries, the second trend concentrates on literature reviews on evaluation methods and processes. This study follows the second trend and reviews the literature by evaluating and comparing different investment assessment methods for IS/IT projects.

The primary motivations of this study are the evaluation of the relevant studies on IS project investment methods, their assessment criteria, and in which decision environment to use a specific method. Moreover, this study identifies future research directions by elaborating each investment assessment method and showing the gap among different types of investment methods.

This paper is divided into three sections. The first section covers the methodology of the study. The second section deals with the results obtained from the literature review. The last section is the conclusion section which consists of the important and significant results of the study and future directions.

Methodology

In order to identify relevant studies, an electronic search is conducted and a number of index databases of academic journals is searched without any time limitation. Then, the titles and abstracts of the studies are investigated to identify more proper and relevant studies in the given field. The databases, which are included to the study are ABI/INFORM Complete and ScienceDirect. The keywords and phrases, which are used in the literature review are "IS/IT investment methodology/method" and "evaluation of IS/IT investment methodology/method". In addition to keyword searching, recommended articles based on research criteria by the given databases are also included in the study.

Out of 154 articles, 51 articles are selected as the most relevant papers from 2000 to December 2014. Within the scope of this study, both empirical and conceptual articles and other types of papers in English language are investigated. Inspired with the classification of the IS investment assessment methods stated in the book by the Schniederjans et al. [45] the paper analyzes these methods within three categories: (1) financial, (2) non-financial, and (3) hybrid.

Results

According to Bacon [6], IS/IT investment is defined as "cost incurred with any acquisition of computer hardware, network facilities, or pre-developed software or any in-house systems development project, that is expected to add to or enhance an organization's information system capabilities and produce benefits beyond the short term". Khallaf [26] states that IT investments are a collection of many components such as: IT personnel, system software, IT hardware, and application software. Realizing these sub components enlightens the nature of IS investment whether it is tangible or intangible and organizes each type of IS investment methods according to their performance measures.

After the definition of IS/IT investment, its assessment could be defined as the weighing up process of benefits and costs to rationally assess the value of any IS subcomponent acquisition, which is expected to improve the business value of an organization's information systems or decrease its operational costs [31]. According to literature, some businesses use financial, some non-financial, and others multi-criteria approach as IS investment decision method. Table 1 and Figure 1 show the distribution of the studies on IS investment assessment methods based on three categories.

As seen in Table 1, hybrid methods are the most popular methods in the literature followed by financial and then non-financial methods. Most studies in the hybrid category realize a combination of financial and non-financial methods or propose a model which stems from financial and non-financial measures. According to Figure 1, it is obvious that hybrid methods gain acceleration in recent years.

Moreover, financial methods are more handled than non-financial methods. Despite the common applications of financial methods, recently, many researchers claim that the intangible benefits/costs of IT should be also included in the decision-making process. As it can be seen in Figure 1, a positive trend is observed in the application of non-financial methods whereas there is a dramatic decrease in the application of pure financial methods. Besides, all IS/IT investment methods are mostly studied between 2004 and 2008.

Table 1. The summary of studies by method and year (n=51)

Years	Financial Methods	Non-financial Methods	Hybrid Methods	Grand Total by Year
2000	2	-	-	**2**
2001	-	-	1	**1**
2002	3	-	-	**3**
2003	1	1	1	**3**
2004	4	1	2	**7**
2005	-	2	4	**6**
2006	2	1	3	**6**
2007	-	1	-	**1**
2008	1	2	4	**7**
2009	-	-	3	**3**
2010	1	1	-	**2**
2012	-	1	1	**2**
2013	1	2	1	**4**
2014	1	1	2	**4**
Grand Total by Method	**16**	**14**	**21**	**51**

Table 2 points out journals which are mostly interested in IS/IT investment methods during 2000-2014 period.

Table 2. Mostly interested journals in IS/IT investment methods (n=51)*

Journal Name	Count of Studies
Information & Management	5
Decision Support Systems	4
International Journal of Production Economics	4
European Journal of Operational Research	3
International Journal of Information Management	3
Automation in Construction	2
Information Resources Management Journal	2
Journal of Information Science and Technology	2

**Journals, which publish only one study about IS investment methods from 2000 to 2014, are excluded from Table 2.*

Furthermore, it is concluded that studies on IS/IT investments are especially focused on technology, construction, manufacturing, finance, e-commerce, services, fast moving consumer goods (FMCG), government and healthcare sectors as can be seen in Figure 2. The size of the companies spans from small-medium enterprises (SME) to FTSE 500 companies.

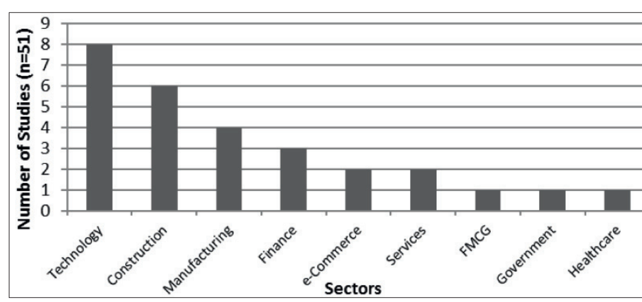

Figure 2. Number of analyzed sectors (n=51)

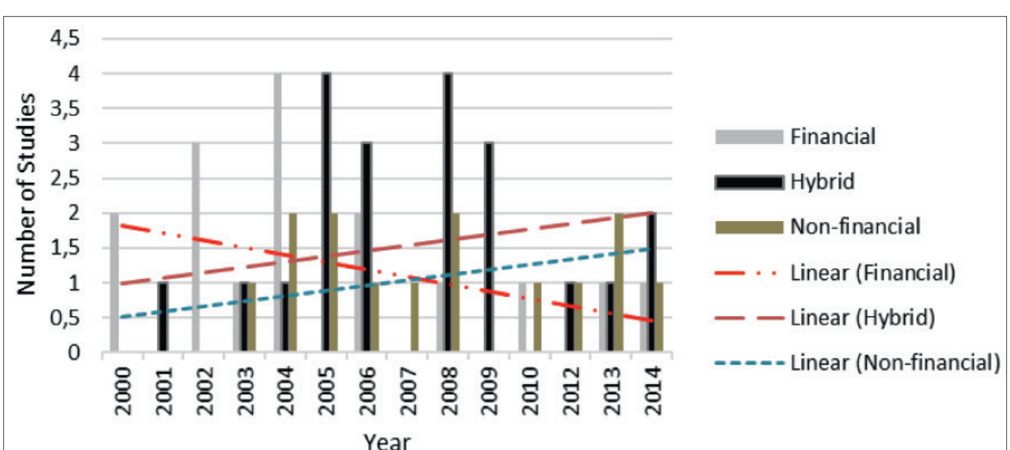

Figure 1. IS investment method trend by year (n=51)

Financial Methods

Schniederjans et al. [45] mention that financial methods are based on subject areas of finance and accounting. These methodologies are used in "capital budgeting decisions" traditionally for decades. Table 3 includes the list of financial methods and models that are used in the given studies. According to Table 3, the studies are mainly focused on real options theory, cost benefit analysis and data envelopment analysis.

Table 3. A brief summary of financial methods (n=51)

Method and Model Name	Frequency	Reference
Real options theory	4	Kim and Sanders, 2002; Li and Johnson, 2002; Wu and Ong, 2008; Dimakopoulou et al., 2014
Cost benefit analysis	4	Wang et al., 2003; Love and Irani, 2004; Lee and Lee, 2010; Huang and Behara, 2013
Data envelopment analysis	3	Shafe and Byrd, 2000; Shao and Lin, 2002; Chen et al., 2006
Growth in net sales	1	Stratopoulos and Dehning, 2000
Gross profit margin	1	Stratopoulos and Dehning, 2000
Operating profit margin	1	Stratopoulos and Dehning, 2000
Net profit margin	1	Stratopoulos and Dehning, 2000
Return on assets	1	Stratopoulos and Dehning, 2000
Return on equity	1	Stratopoulos and Dehning, 2000
Return on investment	1	Stratopoulos and Dehning, 2000
Fixed assets turnover	1	Stratopoulos and Dehning, 2000
Total assets turnover	1	Stratopoulos and Dehning, 2000
Return on security investment	1	Cavusoglu et al., 2004
Multivariate adaptive regression splines	1	Osei-Bryson and Ko, 2004
Option pricing model	1	Sing et al., 2004
Constant elasticity of substitution stochastic production frontier model	1	Lin and Shao, 2006
Mean variance model	1	Wu and Ong, 2008

Real options theory: Real options valuation or theory uses option valuation techniques to capital budgeting decisions. This concept consists of net present value (NPV), which considers future opportunities. Li and Johnson [30], Wu and Ong [56] and Kim and Sanders [27] state that this approach has a key role in a highly uncertain digital economy and involves many potential opportunities. Dimakopoulou et al. [17] also emphasize that IT investments have uncertain outcomes, so it makes real options approach appropriate method for IT investment decision making. Moreover, Wu and Ong [56] point out that real options approach can be beneficial for the evaluation of information technology projects which take long times for the implementation.

Cost benefit analysis: Cost benefit analysis compares indirect and direct costs and benefits of the technology [45]. In their studies, Wang et al. [53], Love and Irani [36], Lee and Lee [28], and Huang and Behara [21] apply cost benefit analysis for different industries and IS projects, while Wang et al. [53] focus on primary care and Love and Irani [36] concentrate on construction industry. On the other hand, Lee and Lee [28] only investigate the investment of RFID technology. All of the studies reveal the benefits and costs of IT investments for the given industries and technologies.

Data envelopment analysis: Shafe and Byrd [46], and Shao and Lin [47], and Chen et al. [12] apply data envelopment analysis which is a mathematical programming technique that empirically measures productive efficiency of decision making units. This technique is mainly used for the evaluation of efficiency of IS investments. In their study in order to measure the efficiency and effectiveness of IT, Shafe and Byrd [46] consider the overall spending on IS, organization's total processor value that indicates the organization's current IT status, and organization's willingness to train their IT stakeholders as inputs for applying data envelopment analysis. It is obvious that this methodology is flexible, because it only includes relevant inputs and outputs for a specific investment project. Shao and Lin [47] test the relationship between IT investments and technical efficiency in the firm's production process by applying this method. They find a positive relationship between them.

Other financial methods: Stratopoulos and Dehning [50]; Cavusoglu et al. [11], Osei-Bryson and Ko [40], Lin and Shao [35] and Wu and Ong [56] study different financial methods for the assessment of IS/IT investments.

Stratopoulos and Dehning [50] use the following methods in their study:

- Growth in net sales: It is determined by "net sales for the current period minus net sales from the prior period divided by net sales from the prior period".
- Gross profit margin: It stands for the gross profit divided by net sales.
- Net profit margin: It represents the income from ongoing operations divided by net sales.
- Operating profit margin: It represents the income from operations divided by net sales.
- Return on assets: It is calculated as income available to common shareholders from ongoing operation divided by average total assets.
- Return on equity: It is calculated as income available to common shareholders from ongoing operations divided by common shareholder's equity.
- Return on investment: It represents income available to common shareholders from ongoing operations divided by total invested capital.
- Fixed assets turn over: It is net sales divided by average property, plant and equipment.
- Total assets turn over: It represents net sales divided by average total assets.
- Inventory assets turnover: It is the cost of goods sold divided by average inventory.

On the other hand, Cavusoglu et al. [11] focus on return on investment from a different perspective. They investigate return on security investment. They state that defining the value of security investments is challenging. They point out that using risk analysis or cost effectiveness analysis are of limited value in an IT security setting due to that these analyses work with high level aggregate data. In order to overwhelm these problems, they propose a comprehensive model to only analyze IT security investments.

Osei-Bryson and Ko [40] define multivariate adaptive regression splines, which they apply as a financial method, as "highly adaptive and automatically selects locations and degree of knots. It builds a model in a two-phase process, using a forward stepwise regression selection and backwards stepwise deletion strategy."

Lin and Shao [35] use constant elasticity of substitution stochastic production frontier model which enables jointly and critically investigate the business value of IT investments, productivity paradox, and inputs substitutions by using the technical efficiency measures at three levels: firm, sector, and industry.

Lastly, Wu and Ong [56] deal with mean variance model which is a traditional financial theory that ranks assets with regards to returns and risks.

Non-Financial Methods

Non-financial methods are focused on broader issues of IS investment decision making area, such as larger portions or whole IS system. The main differentiation point of non-financial methods from financial methods is the scope of IS investment. Financial methods are focusing on one piece of IT or single system decision, whereas non-financial methods are considering indirect benefits/costs and strategic effects of investment, where the scope of evaluated system would be larger [45].

Non-financial methods, which are derived from the literature review, are agency theory model, business case, knowledge mapping, benchmarking, IT investment portfolio, and benefit/risk analysis as listed in Table 4. There are also six studies in the literature, which analyze IS investment methods, deploying case study, questionnaire and action research techniques for revealing the critical non-financial enablers of successful implementation of IS investment assessment methods.

Table 4. A brief summary of non-financial methods (n=51)

Method and Model Name		Frequency	Reference
IT investment portfolio		2	Gunasekaran et al., 2001; Bardhan et al., 2004
Agency theory based model		1	Khallaf, 2012
Business case		1	Berghout and Tan, 2013
Fuzzy expert system based knowledge mapping		1	Irani et al., 2014
Benchmarking		1	Alshawi et al., 2003
Benefit/risk analysis		1	Love et al., 2005
Investment spend optimization		1	Smith et al., 2010
Value analysis		1	Joshi and Pant, 2008
Studies about IS investment evaluation	Case study	2	Love et al., 2006; Lin et al., 2007
	Questionnaire Surveys	4	Love et al., 2004; Lin et al., 2005; Lin et al., 2007; Suh et al., 2013
	Action Research	1	Fox, 2008

The details of the non-financial methods obtained from literature review are as follows:

***IT investment portfolio*:** Gunasekaran et al. [20] and Bardhan et al. [7] propose IT investment portfolio approach in order to justify IT project investments by examining benefits such as competitive advantage and securing future business by assisting appropriate management change. For valuation and prioritization decisions in IS/IT investments, project interdependencies and business value are considered, which provide the managerial flexibility to launch future projects.

Agency theory based model: Khallaf [26] proposes a framework that utilizes nonfinancial measures to link IT investments to their intangible benefits and applies the agency theory to examine the contribution of IT investments by tying managerial compensation to firm value.

Business case: Berghout and Tan [8] construct a theoretical model that suggests the impact of IT business case elements on the initial cost estimates of technological investments. Their findings indicate that the richness of business cases enables more initial costs to be identified in technological investments, by this means keeping resources for the organization through informed investment decisions.

***Fuzzy expert system based knowledge mapping*:** Irani et al. [23] state that a knowledge map will reveal the principal relationships and knowledge within IS/IT investment evaluation by a blend of managerial and user perspectives, by which knowledge, exploration in IS/IT investment evaluation process is enabled. This is realized through conceptualizing the explicit and tacit investment decision drivers.

Benchmarking: Alshawi et al. [2] deploy benchmarking method in order to reveal best practices in benefit extraction of IT investments focusing on true cost identification by considering socio-technical (human and organizational) dimensions associated with IT deployment. They suggest the alignment of IS/IT investment decisions to a corporate strategy and keeping the relevant people closely informed as to what and why an IT investment is needed.

Benefit/risk analysis: Love et al. [38] develop a pragmatic ex-ante IT evaluation framework based on benefit/risk analysis for evaluating and justifying IT investment decisions. Their framework considers strategic, tactical and operational benefits with relation of technology cost.

***Investment spend optimization*:** Smith et al. [49] focus on investment spend optimization, which is a "disciplined, business-driven, enterprise-wide approach to evaluating and managing IT investments". It has five steps which are strategic alignment of the IT development portfolio with enterprise objectives, rigor in the IT planning and business case processes, accountability for delivering value, transparency at all levels and stages of development, and collaboration and cross-group synergies.

Value analysis: Joshi and Pant [24] develop a framework to evaluate different IS/IT project investments through a mix of suitable methods. The non-financial one of these methods is value analysis. Value analysis is a detailed method comprised of eight steps grouped in prototyping and surveying phases that is focused on assessing intangible benefits of IT on a low-cost, trial basis before deciding whether to commit to a larger investment in an IS/IT project.

After shedding light on critical non-financial methods, the studies that consider the enablers of those methods are explained in the following paragraphs.

Suh et al. [51] find that strategy integration with IT is positively related to IT investment decision. Fox [18] reports that disbenefits, reliability and utilization can be critical to the performance of investments in a new technology, so assessment of intangible benefits has become an explicit requirement of investment evaluation techniques. Love et al. [37] state that organization types are effective on strategic benefits and the monetary amount of IS investments; however user adaptation of IT investments are mostly effected by firm size. As a result of their study, it could be stated that non-financial criteria, namely organization type and size should be considered in IT investment evaluation methods. Love et al. [39] propose a conceptual IT evaluation framework that focuses on hidden or indirect costs and social considerations.

The study of Lin et al. [33] reveals that IS/IT investment evaluation methodology usage is relatively high, on the other hand usage of IS/IT benefits realization approaches is low in Taiwainese SME's. Lin et al. [32] work on IT investment evaluation and benefit realization methodologies and concluded that IT investment evaluation and benefits realization processes should be a part of overall strategy to elevate the importance of IT investments in supporting business processes.

Hybrid Methods

In this group of studies, while some of the papers deal with both financial and non-financial methods as summarized in Table 5, some of the articles also propose custom models.

Table 5. A brief summary of hybrid methods (n=51)

	Reference	Methods
Hybrid Methods	Angelou and Economides, 2009a	Real options theory; analytical hierarchy model
	Angelou and Economides, 2009b	Real options theory; analytical hierarchy model; game theory
	Karadag et al. 2009	Net present value; return on investment; payback period; cost saving analysis; best fit; previous contacts; new version; instruction from senior management
	Bojanc et al., 2012	Net present value; return on investment; risk analysis; internal rate of return
	Lee and Kim, 2006	Return on capital; return on equity; lag model
	Roztocki and Weistroffer, 2004	Activity based costing; value analysis
	Wang and Campbell, 2005	Cost benefit analysis; multi criteria decision making model
	Schniederjans and Hamaker, 2003	Goal programming
	Wernz et al., 2014	Multi criteria decision making model
	Ünal and Güner, 2009	Analytical hierarchy model
Custom Models	Derric Huang et al., 2008	Expected utility theory
	Ou et al., 2009	Model of Ou et al.
	Ahn and Choi, 2008	Simulation based AHP
	Chou et al., 2006	Fuzzy multi criteria decision model
	Demirhan, 2005	Demirhan's framework
	Dehning et al., 2005	Firm value framework
	Lin and Chuang, 2013	Time-varying stochastic CES production frontier
	Al-Yaseen, et al.,2006	Operational use (OU) evaluation
	Gunasekaran et al., 2001	Investment justification framework
	Roztocki and Weistroffer, 2005	Fuzzy activity based costing

The details of the studies are given in the following paragraphs:

Karadag et al. [25] focus on net present value, payback period, cost savings as financial methods and best fit, previous contacts, new version, and instruction from senior management methods as non-financial methods in their study. Karadag et al. [25] define net present value as a financial metric for investment evaluation. It is stated that net present value is used for long term projects and in capital budgeting. This method considers inflation and returns. On the other hand, payback period shows the amount of time that it takes for an investment to recover its initial costs. Moreover, cost savings analysis is similar to cost benefit analysis but it only analyzes financial costs and savings. Furthermore, they investigate best fit to technical requirements in their study. This method includes previous contacts or track records of vendors/consultants approach, when a system's track record is with a particular vendor. New version is another method in their study. They conclude that new version approach is followed by an operator, if a new version of an IT application of a particular vendor is available. This approach is preferred because of higher vendor switching cost, or costs of re-training IT employees. Moreover, Karadag et al. [25] state that the usage of IT investment assessment method by affiliated properties is dictated by senior management.

Lee and Kim [29] study return on capital, return on equity, and lag model. Return on capital is calculated as after tax operated income divided by the book value of invested capital. Besides, they propose that businesses in the information intensive industries need to be more cognizant of performance factors when investing in IS/IT than in the low information intensive industries. A distributed lag model considers the time lag between IT investment and firm performance.

Bojanc et al. [9] focus net present value, return on investment, risk analysis, and internal rate of return methods. They state that internal rate of return "enables the calculation of the discount rate at which the NPV equals zero, or in other words, the discount rate at which the present value of inflows equals the present level of outflows." In addition, they propose a mathematical model for an optimal security-technology investment evaluation and decision-making process based on quantitative analysis of the security risks and digital-assets assessment in an organization.

Roztocki and Weistroffer [42] apply activity based costing method. They state that companies invest in IT in order to protect their cost advantages. This method identifies activities within the company and assigns the cost of each of this activity. In addition, they study on value chain analysis. They point out the usage of value chain model in IS/IT investment problems, which serves as a guide in identifying areas for improving profitability through lowering costs or increasing productivity.

Wang and Campbell [51] study cost benefit analysis and multi criteria decision making model. They put the strategic view at first in their proposal. These multiple criteria are considered with assigned weights in the IS/IT decision making.

Wernz et al. [55] also focus on multi criteria decision making model. They put cost-effectiveness as the most important criterion and three further objectives are as follows: technology leadership, profitability, and value for community.

In one of their studies, Angelou and Economides [4] study real options theory and analytical hierarchy model. In addition to this study, Angelou and Economides [5] focus on real options theory, analytical hierarchy model, and game theory together. This study combines these methods for ICT decisions analysis under the threat of competition. Game theory serves for studying uncertainty environments where a first mover may commit in order to prevent entry by a new comer. It shows the effects of incomplete information about demand on prevention and explored the tension between competitive pressure to invest in IS/IT.

Furthermore, Ünal and Güner [52] focus on analytical hierarchy model. Analytical hierarchy model handles both qualitative and quantitative multi-criteria problems, organizes tangible and intangible factors in a systematic way, and provides a structured relatively simple solution to the decision-making problems.

Lastly, Schniederjans and Hamaker [44] concentrate on goal programming. They define goal programming as a deterministic and multi criteria satisfying methodology.

Furthermore, some papers propose their own custom models. Gunasekaran et al. [20] propose an investment justification framework. This framework deals with strategic, tactical, operational, tangible, and intangible considerations. They state that for investment justification return on investment are not sufficient. On the other hand, this framework also considers intangible, tactical, operational, and strategic measures.

In addition, Derric Huang et al. [16] apply expected utility method which concerns people's preferences with regard to choices that have unclear outcomes. Ou et al. [41] propose a framework for the investment of ATMs. They investigate investment from three different perspectives: scale, deposit service, and cost. They found the positive impacts of these perspectives on ATM investment.

Furthermore, Ahn and Choi [1] apply a simulation based analytical hierarchy model for ERP system selection. This model enhances analytical hierarchy model for a real problem. Selection criteria are functionality and coverage, supporting service, technology, total costs, and vendor credentials.

Chou et al. [13] identify 26 criteria for IT/IS investment based on following 5 domains: (1) External criteria, (2) Internal criteria, (3) Risk criteria, (4) Cost criteria, and (5) Benefit criteria. Their simple, cost-effective, and handy evaluation model considers the existing IT portfolio to address possible duplicate investment and compatibility issues, and is based on MS- Excel calculations.

Demirhan [15] proposes a conceptual framework considering both financial (e.g. IT cost decline, relative IT efficiency, switching cost) and non-financial (e.g. competition intensity, firm characteristics) measures.

Dehning et al. [14] framework recognizes the complex and diverse implications of IT investments on firm value. The implications of the firm value approach include forcing IT managers to think in terms of both industry and company-specific effects of IT investments, to consider both the magnitude and duration of competitive advantage due to IT investments, and the implications of the effect that IT investments have on risk and its relation to firm value.

Lin and Chuang [34] investigate the dynamic patterns of IT value over time in connection with the issues of inputs substitution and complement and the productivity paradox. Their approach represents a new contribution to the understanding of the dynamic influence of IT investments upon the value of IT over time by paying attention on IT capital, ordinary capital, and ordinary labor.

Al-Yaseen et al. [3] conduct a study in order to understand issues related to IT evaluation after project completion and suggest the usage of operational use (OU) evaluation for assessing deviations from IT investment plans. OU evaluation is based on criteria from system completion, system information, system impact, and other criteria domains; and compromises direct, indirect and hidden costs, tangible and intangible benefits, and performance and security aspects of technology.

Roztocki and Weistroffer [43] apply fuzzy activity based costing analysis. In other words, they integrate activity based costing method. They create fuzzy set membership functions. They propose an approach which is suitable for businesses in emerging economies in where economic and political developments are particularly difficult to predict.

Conclusion

Although businesses invest largely in IS/IT projects to improve business performance and to gain competitive advantage, researches reveal that selecting appropriate methods in IS/IT investment decision making is a complicated task. The main challenges that decision makers face are unavailability of precise benefit/cost measurement methods, lack of detailed identification and assessment of the costs and benefits of IS project investments and avoidance of perceived risk [25] In order to find a solution to this problem, researchers propose different IS/IT investment assessment frameworks, which could be organized under three categories, namely financial, non-financial and hybrid.

In this study, a comprehensive literature review is performed by evaluating investment assessment methods for IS/IT projects, by revealing their assessment criteria, and by indicating in which decision environment to use a specific category. It is found that hybrid methods are the most popular methods in the literature. Most studies in the hybrid category realize the combination of financial and non-financial methods or propose a model which stems from financial and non-financial measures. The expansion of hybrid methods could also be explained with the growth of technology expansion in every phase of business environment. It augments the scope of IS/IT projects, where the application of non-financial or hybrid evaluation methods are more appropriate.

Moreover, financial methods are more handled than non-financial methods. Despite the common applications of financial methods, recently, many researchers claim that the intangible benefits/costs of IT and its strategic alignment should be included in the decision-making process, so a positive trend is seen in the application of non-financial methods, where there is a dramatic decrease in the application of pure financial methods.

As a conclusion of this comprehensive literature review, it is recommended that hybrid investment evaluation frameworks should be expanded as a future research area since the competition in markets is getting tougher and grounded strategy is gaining more importance. Therefore one aspect to recommend might be the inclusion of every strategic view of business in the IS/IT investment evaluation framework. With the same strategic purpose, every direct/indirect/hidden costs and benefits might be included in the methods for making the right move according to chosen strategy. By this way, IS/IT could prevent its position as the most important enabler of the business strategy.

One different aspect on future research in IS/IT investment methods lies in user experience. IS/IT users are demanding simplicity in performing highly complicated tasks on computers. Therefore, in order to obtain effective and efficient IS/IT investment decision, users' opinions should also be considered besides all other criteria. Thus, incorporation between psychological studies about the user acceptance of technology and IS/IT investment decision methods might be another interesting topic to engage in future.

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