XAI-Based Fuzzy SWOT Maps for Analysis of Complex Systems

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***Abstract*—The classical SWOT methodology and many of the tools based on it used so far are very static, used for one stable project and lacking dynamics [1]. This paper proposes the idea of combining several SWOT analyses enriched with computing with words (CWW) paradigm into a single network. In this network, individual analysis of the situation is treated as the node. The whole structure is based on fuzzy cognitive maps (FCM) that have forward and backward chaining, so it is called fuzzy SWOT maps. Fuzzy SWOT maps methodology newly introduces the dynamics that projects are interacting, what exists in a real dynamic environment. The whole fuzzy SWOT maps network structure has explainable artificial intelligence (XAI) traits because each node in this network is a "white box"—all the reasoning chain can be tracked and checked why a particular decision has been made, which increases explainability by being able to check the rules to determine why a particular decision was made or why and how one project affects another. To confirm the vitality of the approach, a case with three interacting projects has been analyzed with a developed prototypical software tool and results are delivered.**

Keywords—Dynamic SWOT analysis, Computing with Words, Fuzzy SWOT Maps, XAI-Based system analysis, SWOT+CWW network

I. Introduction

SWOT analysis is a widespread method, and it applies in many areas [1]. By using SWOT analysis, potential opportunities (potentially positive outcomes) and threats (potentially negative outcomes) can be found in a situation or project under investigation. "S" stands for strengths, "W" for weaknesses, "O" for opportunities and "T" for threats. The components of these four groups, component estimates, and interactions between components, are identified by experts based on their experience or by interpreting the measured values and statistics. In the classic case, component estimates and inter-component influences should be expressed numerically, which makes it difficult for an expert to construct a situation model because it is most convenient for a person to make a verbal description of the situation. The possibilities for experts to express their insights in verbal evaluations in the case of classical SWOT analysis are rather vague, so a new methodology for performing SWOT analysis in verbal terms has been introduced. The methodology of classical SWOT analysis, enriched with the CWW (Computing with Words) paradigm, was proposed in the article [2] and provides more flexibility for experts to express their insights verbally, while also describing uncertainties.

However, more flexible knowledge retrieval from experts can only refine the description of a particular situation but does not solve the problem of the insularity of the model created. The classic SWOT model is a case of static analysis and suitable for a single event or project that is stable and unchanging - i.e. the dynamics of the environment surrounding the project are not considered. Project dynamics in the classical case is the change of one project in the short, long, or medium term. In reality, situations are intertwined and influence each other - i.e. changing parameters of one situation may have a greater or lesser effect on the outcome of another related situation. To solve this problem, we propose a whole new approach of combining several separate SWOT analyzes into a single whole network. This means that opportunities or threats from one SWOT analysis can influence another situation and vice versa, and the dynamics are introduced that projects, stages or ideas considered in separate SWOT analyzes may overlap. The SWOT-enriched CWW analysis engine becomes a single node in the common network, and this network is called fuzzy SWOT maps (FSM), emphasizing the network structure's affinity for fuzzy cognitive maps

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(FCM). fuzzy SWOT maps enable the analysis of complex systems, assessing the opportunities and threats of individual system components, and the interaction between individual components. Fuzzy SWOT maps not only offer new possibilities of dynamic analysis for overlapping parts of interacting projects, but also the similarity of FCM structure provides an opportunity to evaluate the mutual dynamics of projects in iterative steps.

Fuzzy SWOT maps are a network structure with nodes and links between nodes, just as in the case of an artificial neural network we have a group of interconnected artificial neurons. Increasingly, it is accepted in the literature to suggest artificial intelligence models that are explainable [3] - i.e. nodes in the network would not be just a "black box", but user, developer or expert could look inside them, and reasoning could be traced back to the inference mechanism. The fuzzy SWOT maps methodology is based on this XAI (eXplainable Artificial Intelligence [4]) ideology. To validate the fuzzy SWOT maps methodology, a new prototype software tool has been developed to perform SWOT analyzes of interrelated situations or projects and to monitor project results with iterations, which increases explainability and enables the researcher or decision-maker to check a reasoning chain in the decision-making process.

The rest of this paper is organized as follows. The second section describes the current state of fuzzy SWOT maps development in the research field and the basics for extending dynamic SWOT analysis to the mechanism of fuzzy cognitive maps. Section three outlines the structure of fuzzy SWOT maps based on XAI ideology. Section four describes system implementation. Section five describes an experimental simulation performed using the prototypical software tool developed for fuzzy SWOT maps, and finally, section six concludes all with the remarks.

II. Preliminaries

The dynamic approach to SWOT analysis was firstly proposed in [9] and [10]. By developing fuzzy SWOT maps methodology, SWOT-enriched Computing with Words (CWW) [1] has been expanded to use fuzzy cognitive maps (FCM) networking capabilities. FCMs are fuzzy-graph structures for representing causal reasoning. FCM fuzziness allows hazy degrees of causality between hazy causal objects (concepts). FCM graph structure allows systematic causal propagation, in particular forward and backward chaining, and it allows knowledge bases to be grown by connecting different FCMs. FCMs are especially applicable to soft knowledge domains [11] and fuzzy systems are good to deal with approximate knowledge. Even more, there is big data, which could be systemized for fuzzy SWOT maps system inputs in a separate subprogram. Such systems would be useful for medical diagnosis, financial problems, security systems and would boost transparency and the ability to trust the output of the system.

Fuzzy Rule-Based Systems (FRBS) are composed of fuzzy IF-THEN rules where both antecedents and consequents usually contain fuzzy sets and have the highest explainability but lowest accuracy. There is a growing interest in developing FRBS that are both accurate and interpretable [7], [8] to obtaining XAI models. The aim is to increase explainability without reducing accuracy or even increase both. For this purpose, synergies between FRBS and fuzzy cognitive maps are utilized, which should provide great potential for a good trade-off between accurate and explainable models. XAI's key areas are transportation, finance, security, legal, medicine, and military [3].

If the created fuzzy SWOT maps system is not sufficiently explainable by itself, additionally a separate subroutine can be created to interpret the solution data and provide explanations. It is important to emphasize that the solution and explanation are conceptually different. From technical information, the rationale for the decision (reasoning chain) must be clarified in a human-readable form so that no technical knowledge is needed, and the result can be interpreted in general.

III. XAI-Based fuzzy SWOT maps

When preparing the situation description according to the SWOT analysis, environmental opportunities (OP), threats (TH), strengths (ST) and threats (WK) are assessed (1), (2), (3) and (4).

$$\overrightarrow{OP} = (\{OP_1\}, \cdots, \{OP_o\}, \cdots, \{OP_O\}),\ o=1, \dots, O \quad (1)$$

$$\overrightarrow{TH} = (\{TH_1\}, \cdots, \{TH_t\}, \cdots, \{TH_T\}),\ t=1, \dots, T \quad (2)$$

$$\overrightarrow{ST} = (\{ST_1\}, \cdots, \{ST_s\}, \cdots, \{ST_S\}),\ s=1, \dots, S \quad (3)$$

$$\overrightarrow{WK} = (\{WK_1\}, \cdots, \{WK_w\}, \cdots, \{WK_W\}),\ w=1, \dots, W \quad (4)$$

After evaluating the impact (c) and value of truth (ρ) of each opportunity and threat, the influences of strengths and weaknesses to each opportunity and threat needs to be evaluated. A SWOT evaluation matrix is composed of those evaluations as shown in Fig. 1.

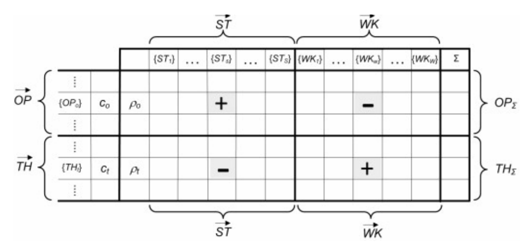

Fig. 1. SWOT evaluation matrix

Total values of opportunities and threats are calculated according to formulas (5) and (6).

$$OP_{\Sigma} = \sum_{o=1}^{O}\{c_o(\rho_o + \sum_{s=1}^{S} ST_{os} + \sum_{w=1}^{W} WK_{ow})\} \quad (5)$$

$$TH_{\Sigma} = \sum_{t=1}^{T}\{c_t(\rho_t + \sum_{s=1}^{S} ST_{ts} + \sum_{w=1}^{W} WK_{tw})\} \quad (6)$$

This classical SWOT analysis enriched with the CWW paradigm has already been described in an individual project analysis [2]. Individual analysis data comes from its defined environment as shown in Fig. 2.

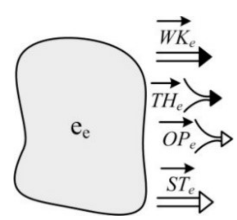

Fig. 2. An element e_e of the environment

The analysis of one single environment can be treated as a node in the network - the SWOT-engine$_e$, as shown in Fig. 3.

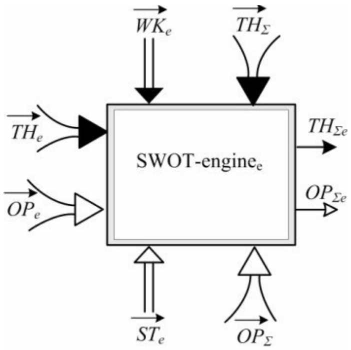

Fig. 3. The SWOT-engine$_e$

In the context of a complex environment, several projects and their interconnections are considered simultaneously as shown in Fig. 4.

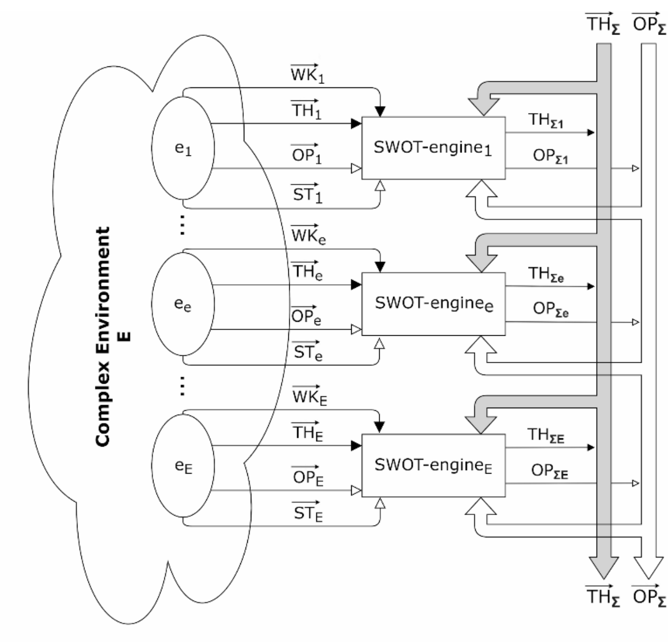

Fig. 4. Fuzzy SWOT maps

Each project (element of a complex environment) has its own lists of strengths, weaknesses, opportunities, and threats that are analyzed by the appropriate SWOT-engine. The result of each individual analysis performed by the SWOT-engine is the total opportunities and threats of the project. In the structure of fuzzy SWOT maps, a single SWOT-engine analysis becomes a network element. Network nodes (situations) can influence each other's results in such a way that the total opportunities or threats of one project can supplement the list of opportunities or threats coming from the complex environment for another project. This structure allows for an indirect assessment of the overall opportunities and threats of a complex environment, as well as identifies changes in the results of individual interaction projects.

IV. Implementation of Fuzzy SWOT Maps System

Each situation has its own strengths, weaknesses, opportunities, and threats. Single SWOT-engine calculates optimistic, pessimistic, and average aggregated opportunities (OP) and threats (TH) values based on the resulting matrix of influences. The same mechanism is applied to each situation under consideration. Each situation analysis can influence the other situation under consideration. Once the experts have identified who is affected, the relationships are established. The aggregate OP or TH values of one project may influence the aggregate OP or TH of another project, and vice versa. The relationship can be direct—one project aggregated OP by influencing another project aggregated OP increases them (the same applies to TH), or inverse when one project's aggregated OP decreases another project's aggregated OP. When establishing the relationship, a degree of certainty is selected. Certainty can be specified in three different ways:

- Absolute certainty—the strength of one project's influence on another project is maximum.
- Digital certainty—the strength of the project influence is expressed in numerical form (from 0 to 1).
- Verbal certainty—the strength of the project's influence is expressed in verbal form using the same vocabulary used to describe the situation.

For each project, the total TH and OP values are calculated from the SWOT matrix. As long as the relationships are not entered in the calculations, this step is considered a zero iteration. Each successive iteration is calculated based on the results of zero iteration, by adding or subtracting the values of the related projects, thus obtaining the results of the new iteration.

To test the vitality of an idea, an existing prototypical software tool [2] has now been extended to add relationships. The connection can be made between two projects OP or TH. OP or TH of one project can optionally act positively or negatively on OP or TH of another project. The degree of certainty of the connection can also be specified verbally. The number of iterations can be changed to monitor project results change. For intermediate values, a graph is plotted showing the results of each iteration. From this graph trends, cyclicities, convergences, divergences can be seen. The results of the last iteration, as in the case of CWW enriched SWOT analysis, are expressed numerically and verbally.

All project connections data is saved to the array of vectors. Vectors count matches the number of projects under investigation and each vector length matches the number of connections to that particular project. Each vector element is an object, which has the following parameters:

- Component—specifies the relationship between two project components (opportunity or threat).
- Polarity—specifies whether the connection affects the linked project directly or contrary to.
- ID_from—the project ID from which the connection is derived
- ID_to—the project ID to which the connection is directed.
- Certainty—integer number varying from 0 to 106. Numbers from 0 to 100 is used for absolute and digital certainty case, and numbers from 101 to 106 are used for verbal certainty notation.

When creating a new connection, the degree of certainty, as in the case description, can be chosen in three ways: absolute, numeric, and verbal. The results of the project from which the connection is derived will have a corresponding effect (increase or decrease) on the component (opportunity or threat) of the other project to which the connection is derived. Because we have the results (pessimistic and optimistic), the polarity (direct or inverse) and certainty of the project from which the connection of the relevant component is derived (pessimistic and optimistic), the values to be added to the results of the corresponding component of the receiving project are calculated based on following algorithmic pseudocode (*resWithConn)*:

```
if cert is equals to or less than 100 then
  connVal[pess] = projRes[pess] * (cert/100) * pol
  connVal[opt] = projRes[opt] * (cert/100) * pol
else
  set verbDigMap to [0, 0.04, 0.16, 0.36, 0.64, 1]
  set ind to (cert - 100)
  set min to 1
  set max to 0
  foreach val in projectResults do
    set valAndCerts = getValAndCert*(verbDigMap[ind],
val)
    foreach valAndCert in valAndCerts do
      set valueMultipliedByCertainty = val * valAndCert
      if valueMultipliedByCertainty is less than min then
        min = valueMultipliedByCertainty;
      endif
      if valueMultipliedByCertainty is greater than max then
        max = valueMultipliedByCertainty;
      endif
  if component is opportunity then
    connVal [pess] = min * pol
    connVal [opt] = max * pol
  else
    connVal [pess] = max * pol
    connVal [opt] = min * pol
  endif
endif
```

Abbreviations for pseudocode variables: cert – certainty, connVal - connectionValue, projRes – projectResults, pol – polarity, pess – pessimistic, opt – optimistic, verbDigMap – verbalDigitalValuesMap, ind – index, valAndCerts – valuesCombinedWithCertainty, val – value, valAndCert – valueWithCertainty.

**getOptimisticAndPessimisticValuesFromValueAndCertainty* is a function from the article [2].

Similar to the case of all connection vectors, a data structure is prepared for storing iteration results, which has the following parameters:

- ID—project identification number.
- Title—the title of the project.
- Acronym—short name for the project.
- Results—A three-dimensional array that stores the results of project iterations. The first dimension stores iteration, the second dimension stores component (opportunity or threat), and the third dimension stores pessimistic, optimistic values, and the normalization coefficients.

Current project results are calculated by function from the article [2].

When we have our model constructed and all relationships are set, fuzzy SWOT maps results are calculated based on the following algorithmic pseudocode:

```
set projResAll to an empty array of vectors for results storing
set iterCnt to value of iterations count set from user
set cfInd to the index of OP/TH coefficient in the results array
for i:=0 to iterCnt do
 for p:=1 to length of projResAll array do
   set projId to projResAll[p].id
   set connToThisProj = allConnectionsData[projId]
   projResAll[p].res[i+1] = projResAll[p].res[0]
   for c:=1 to length of connToThisProj do
     set comp = connToThisProj[c].component
     set pol = connToThisProj[c].polarity
     set id_from = connToThisProj[c].id_from
     set cert = connToThisProj[c].certainty
     set iterRes to projResAll[id_from].res[i].[comp]
     set resToAdd to resWithConn(iterRes, pol, cert, comp)
     projResAll[p].res[i+1][comp] += resToAdd
     if comp is opportunity then
       set opCf to projResAll[p].res[i+1][OP][cfInd]
       projResAll[p].res[i+1][OP][cfInd] =
1/(1+round(1/opCf))
     else
       set thCf to projResAll[p].res[i+1][TH][cfInd]
       projResAll[p].res[i+1][TH][cfInd] =
1/(1+round(1/thCf))
     endif
set commonOpThCoef to max(single project OP or TH
coef)
```

Abbrevations for pseudocode variables: projResAll – projectResultsForIterations, iterCnt – iterationsCount, res – results, connToThisProj – connectionsToThisProject, comp – component, pol – polarity, cert – certainty, iterRes – otherProjectCurrentIterationResults, cfInd – coeffIndex.

The normalized project results are obtained by multiplying the aggregated values by the common normalization coefficient. This way we get the values in the interval [0-1]. In the process, all negative values received are evaluated as 0. As a result, we have a set number of iterations for each project optimistic, pessimistic, and average results, which can be expressed numerically and graphically. With a history of result changes, graphics can be drawn.

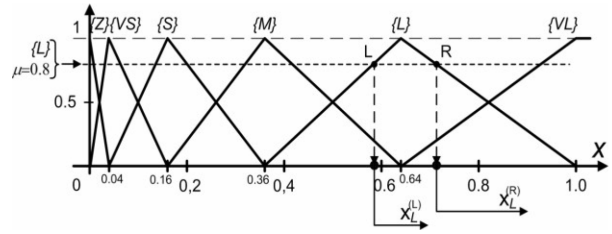

Fig. 5. Pessimistic and optimistic results

Fig. 5 displays, how pessimistic and optimistic values are obtained from a verbal estimate “Large” ({L}) with a digital certainty degree of 0.8 (μ = 0.8). In this way, pessimistic and optimistic fuzzy SWOT maps results are obtained, and the average results are derived by averaging optimistic and pessimistic results. Numerical values are extracted from the fuzzy terms according to the methodology from the article [2].

V. Experimental simulation

Not much research has been done yet based on the newly created fuzzy SWOT maps methodology for dynamic SWOT analysis, so we only demonstrate the vitality of the idea by using the prototypical software tool newly developed in the Centre of Real Time Computer Systems, Kaunas University of Technology. Researchers wishing to collaborate and use the tool we have developed to replicate the research, research other projects, or conduct more extensive research based on this tool can always contact and the authors will provide information, help, and support to use this tool.

To test the validity of the idea, we use the developed software tool for the construction of a new gas station in Palanga situation analysis [2], along with the already analyzed new hotel construction in Palanga city situation [9], and adding an additional third situation in the same Palanga city—lobbying (three interacting projects in the complex environment). In this fragment, the new approach to FCM extension is emphasized on the SWOT engines' networking level. Fuzzy SWOT-engines were delivered in section III and we consider them as fuzzy SWOT nodes. The whole net of fuzzy SWOT-engines we call a fuzzy SWOT map.

The situation estimates are only used to confirm the vitality of the system. The focus is more on the network of projects than on the intrinsic properties of a single project. The number of iterations is set to 3, to reflect the variation in results when calculating results with connections.

Further, we present a short description of those three projects. The first one is the construction and opening of a new gasoline station in a certain district of the city Palanga (Lithuania). Its acronym—GAS STATION. The simplified description of SWOT entities under evaluation in the GAS STATION project is given in Table I.

TABLE I. Constructing and opening a new gasoline station

SWOT entity	Description	Abbreviation
ST_{11}	Experience of the company	*{EX}*
ST_{12}	Sufficient financial support	*{FS}*
WK_{11}	Lack of personnel	*{LoP}*
WK_{12}	Shortage of time	*{SoT}*
OP_{11}	Expected high revenue	*{RV}*
OP_{12}	Improved infrastructure	*{IS}*
OP_{13}	Convenience of service	*{CoS}*
$OP_{\Sigma2}$	Total opportunities of SWOT-engine$_2$ (HOTEL)	*{$OP_{\Sigma2}$}*
$OP_{\Sigma3}$	Total opportunities of SWOT-engine$_3$ (LOBBY)	*{$OP_{\Sigma3}$}*
TH_{11}	Additional pollution of the city	*{PL}*
TH_{12}	Unnecessary competition	*{UC}*
TH_{13}	Additional obstacles for pedestrians	*{OfP}*
$TH_{\Sigma3}$	Total threats of SWOT-engine$_3$ (LOBBY)	*{$TH_{\Sigma3}$}*

The second project HOTEL is directed to an erection of a hotel complex in the area of recreation on the Baltic coast (Palanga, Lithuania). Description of SWOT entities of that project is given in Table II.

TABLE II. Erection of hotel complex in the area of recreation

SWOT entity	Description	Abbreviation
ST_{21}	Significant financing	*{SF}*
ST_{22}	High quality of personnel	*{QoP}*
WK_{21}	Lack of infrastructure	*{LoI}*
WK_{22}	High level of storms	*{LoS}*
WK_{23}	Increasing protests of local community	*{PoC}*
OP_{21}	Erection of modern hotel complex	*{HC}*
OP_{22}	Developed modern infrastructure	*{MI}*
OP_{23}	Perspective of high revenue	*{HR}*
$OP_{\Sigma3}$	Total opportunities of SWOT-engine$_3$ (LOBBY)	*{$OP_{\Sigma3}$}*
TH_{21}	Increased erosion of dunes	*{EoD}*
TH_{22}	Increased pollution of environment	*{PoE}*

The third project is connected with the task to fasten and facilitate the two projects mentioned above, and to discover new additional possibilities for the development of the whole recreational region under consideration. This project is called LOBBY, and its SWOT description is given in Table III.

TABLE III. Organizing governmental lobbying

SWOT entity	Description	Abbreviation
ST_{31}	High quality of personnel	*{QoP}*
ST_{32}	Effective communication network	*{CN}*
WK_{31}	Lack of personnel	*{LoP}*
WK_{32}	Shortage of time	*{SoT}*
OP_{31}	Governmental support	*{GS}*
OP_{32}	Foreign investments	*{FI}*
OP_{33}	Flexibility of law	*{FoL}*
TH_{31}	Negative press reaction	*{NP}*
TH_{32}	Loss of reliability	*{LoR}*
$TH_{\Sigma2}$	Total threats of SWOT-engine$_2$ (HOTEL)	*{$TH_{\Sigma2}$}*

This paper presents a unified vocabulary for the verbal evaluation of all possible entities of SWOT analysis. According to the so-called "Miller's law" (The Magical Number Seven, Plus or Minus Two) [12], a human can differentiate approximately up to seven different verbal evaluations, so the following set consisting of six words, described below, has been applied in the research:

{Z} – None / Zero
{VS} - Very small
{S} - Small
{M} - Medium
{L} - Large
{VL} - Very large

Algorithms from the article [2] are used for verbal values encoding and decoding (fuzzification and defuzzification). According to the selected vocabulary, three SWOT+CWW evaluation matrices are constructed for each situation analysis: Table IV, Table V and Table VI. $OP_{\Sigma p}[n]$ and $TH_{\Sigma p}[n]$ values are the total OP and TH results on current iteration (n) of the project *p* and those values are marked in the SWOT evaluation matrices as additional elements impacting the result.

TABLE IV. SWOT+CWW EVALUATION MATRIX FOR THE PROJECT "CONSTRUCTING AND OPENING A NEW GASOLINE STATION"

	C	ρ	EX	FS	LoP	SoT
RV	VL	VL	VL	L	VL	L
IS	L	VL		M	M	L
CoS	VL	VL	VL		VL	L
$OP_{\Sigma 2}$	+L	$OP_{\Sigma 2}$[n]				
$OP_{\Sigma 3}$	-M	$OP_{\Sigma 3}$[n]				
PL	L	L	M	L		
UC	VL	VL	L		L	S
OfP	L	L	L	L		M
$TH_{\Sigma 3}$	-S	$TH_{\Sigma 3}$[n]				

TABLE V. SWOT+CWW EVALUATION MATRIX FOR THE PROJECT "ERECTION OF A HOTEL COMPLEX IN THE AREA OF RECREATION"

	C	ρ	SF	QoP	LoI	LoS	PoC
HC	VL	VL	VL		M		M
MI	L	L	L		L	VS	
HR	VL	VL	L	VL	M		S
$OP_{\Sigma 3}$	+L	$OP_{\Sigma 3}$[n]					
EoD	M	L				VL	Z
PoE	L	M	M	M	M		S

TABLE VI. SWOT+CWW EVALUATION MATRIX FOR THE PROJECT "ORGANIZING GOVERNMENTAL LOBBYING"

	C	ρ	QoP	CN	LoP	SoT
GS	VL	L	L	VL	M	L
FI	VL	L	VL	VL	L	L
FoL	L	L				L
NP	VL	VL	L	L	M	L
LoR	VL	VL	VL	L	L	M
$TH_{\Sigma 2}$	+L	$OP_{\Sigma 2}$[n]				

Three projects that are under investigation are abbreviated using acronyms, as noted in Table VII.

TABLE VII. PROJECTS AND ACRONYMS

Project title	Project acronym
Constructing and opening a new gasoline station	GAS STATION
Erection of a hotel complex in the area of recreation	HOTEL
Organizing governmental lobbying	LOBBY

The SWOT engines' networking and constructing the corresponding FSM (fuzzy SWOT map) is based on the following considerations of the expert team:

1) It is agreed that the summarized opportunities ($OP_{\Sigma 2}$) of the project HOTEL has a positive influence on the project's GAS STATION success (increases $OP_{\Sigma 1}$).

2) The summarized threats ($TH_{\Sigma 2}$) of the project HOTEL has a negative influence on the project's LOBBY success (increases $TH_{\Sigma 3}$).

3) On the other hand, it is agreed that the summarized opportunities of the project LOBBY ($OP_{\Sigma 3}$) have a positive influence on the project's HOTEL success (increases $OP_{\Sigma 2}$) and the negative influence on the project's GAS STATION success (decreases $OP_{\Sigma 1}$).

4) It is agreed that the summarized threats of the project LOBBY ($TH_{\Sigma 3}$) positively influence the success of the project GAS STATION (decreases $TH_{\Sigma 1}$).

Connections between those projects are listed in Table VIII.

TABLE VIII. CONNECTIONS BETWEEN PROJECTS

From	To	Certainty
HOTEL *OP*	GAS STATION *OP*	+ Large
HOTEL *TH*	LOBBY *TH*	+ Large
LOBBY *OP*	HOTEL *OP*	+ Large
LOBBY *TH*	GAS STATION *TH*	- Small
LOBBY *OP*	GAS STATION *OP*	- Medium

For the better representation of an example of those three interacting projects under investigation, the starting point (the iteration number n=0) of connections among the projects is displayed in Fig. 6. Initial opportunities and threats are shown for pessimistic, optimistic, and medium approaches.

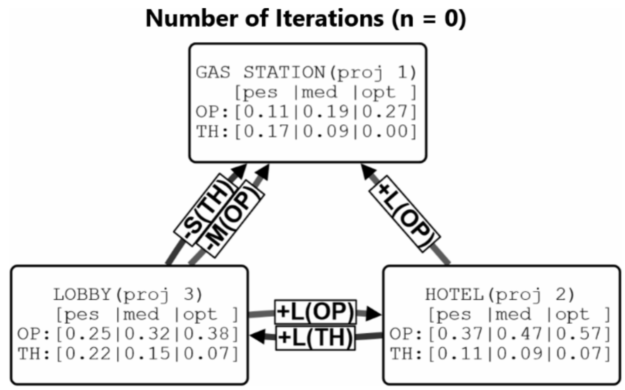

Fig. 6. Projects' interconnection graph with data at the starting point (n=0)

Each node represents a separate SWOT enriched CWW project, and the interrelationships between the projects are indicated by arrows. The arrows indicate how strongly one project affects another project and which component is affected (opportunity or threat). The strength of the influence is marked in verbal form, using a previously defined vocabulary, and adding polarity in front - whether one project affects another project directly or vice versa. The whole graph displays the results of all projects in the given iteration. The results of the third iterations are displayed in Fig. 7.

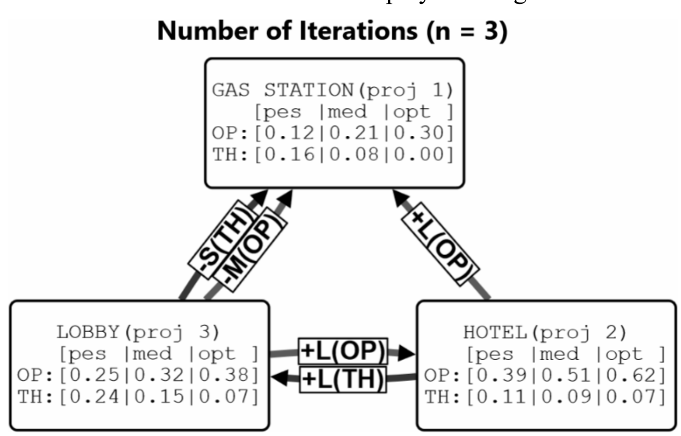

Fig. 7. Projects' interconnection graph with data after three iterations (n=3)

The results of each individual project can be analyzed in a specific iteration or the change of results between iterations can be monitored. The results of one iteration of a single project are shown in Fig. 8.

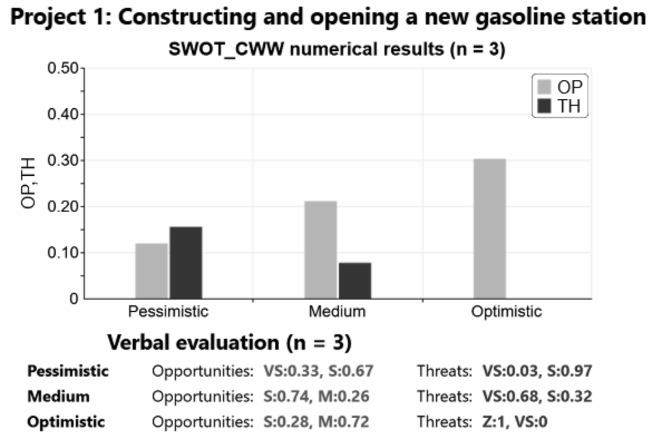

Fig. 8. "GAS STATION" numerical and verbal results after three iterations

The bar chart displays third iteration results (total opportunities and total threats) for the project GAS STATION from three different perspectives (pessimistic, medium and optimistic). It is worth mentioning that the vertical axis scaling in the chart is adaptive and it is not the height of the results column that should be considered, but the vertical scale values. The columns in the graph represent the results in numerical form, and below the graph, the same results are presented in verbal expression (the word of the defined vocabulary that corresponds to the result and the numerical degree of certainty). Verbal interpretation of results is often more comprehensible to a person and can help in decision-making or further analysis.

Line charts (Fig. 9, Fig. 10 and Fig. 11) show the change of results between iterations for each project separately.

Fig. 9. Graph of project "GAS STATION" iterations results

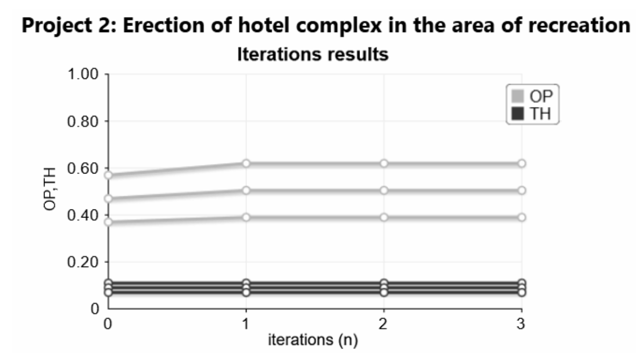

Fig. 10. Graph of project "HOTEL" iterations results

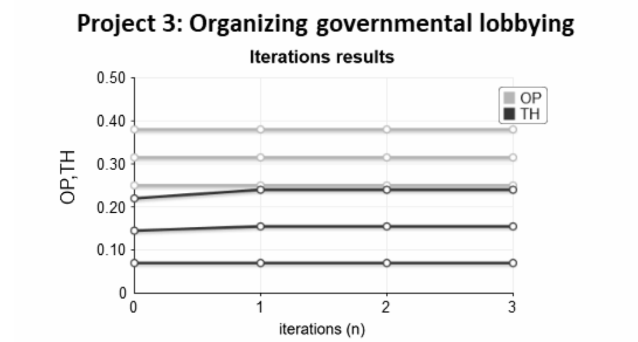

Fig. 11. Graph of project "LOBBY" iterations results

The result curves are close to horizontal, as only three small, interoperable projects were considered. A larger number of projects, larger projects, more interconnections, and higher results of projects would result in greater fluctuation of results across iterations. The purpose of this example is to test the validity of an idea and to derive from the results the tendency of the results to change in iterations.

Each line graph presents the total opportunities and threats of a separate project from a pessimistic, medium and optimistic perspective (three lines each). The vertical axis represents the values of total opportunities and threats results, and the horizontal axis represents iterations. Using this method of representation, it is possible to estimate the change of results in iterations. To increase visibility, all changes in the results can be represented in a single graph in the form of vectors. Fig. 12 shows the change of all project results between initial and third iterations.

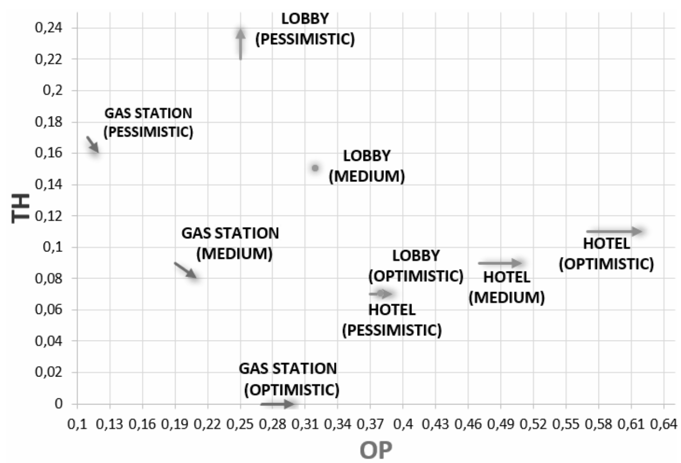

Fig. 12. All project results (OP and TH) change in 3 iterations

A total of 9 vectors are plotted on the common graph (3 vectors for each project for the pessimistic, medium and optimistic perspectives). The horizontal axis indicates total opportunities, and the vertical axis represents total threats. Each vector is represented as an arrow showing change of both total opportunities and total threats (direction and how strongly the results changed). A dot instead of an arrow indicates that the results remained unchanged.

The results show chains of influence: HOTEL summarized threat and LOBBY summarized opportunities remain stable. HOTEL summarized threats increases LOBBY's summarized threats, which in turn reduces the GAS STATION's summarized threats. This means that the GAS STATION summarized threats are only getting reduced. LOBBY summarized opportunities reduce GAS STATION summarized opportunities and also increase HOTEL summarized opportunities, which increases GAS STATION summarized opportunities. Consequently, the GAS STATION summarized opportunities are subjected to two opposing forces, one of which tilts to one side - the GAS STATION summarized opportunities rises. HOTEL summarized opportunities, and LOBBY summarized threats are intermediate elements in the link chain. The optimistic and the pessimistic results of the HOTEL summarized threats differ little because there is little variation - the threats are inherently small, so the difference between an optimistic and a pessimistic result is less obvious.

Even preliminary glans at those results permit us to extract several conclusions concerning the adequacy and possible reliability of the projects' interaction at this stage of investigation and reasoning. It must be concluded that projects HOTEL and LOBBY is acceptable while project GAS STATION is not attractable or doubtful in general. Thus, even the results of such a small analysis based on fuzzy SWOT maps provide useful insights for decision-making.

Team of experts and possible users of the complex environment could exploit the complexity of those three interacting and supporting each other projects, but we consider that the results of those actions are beyond the target of this paper. On the other hand, the answers to the listed above questions require additional research in the field of modeling of virtual reality of the whole complex environment itself, and sophisticated interface tools with the real environment in case of the functioning of the concept in full-fledged scale in the real-time control.

VI. Concluding Remarks

In this paper, a brand new concept of combining CWW enriched SWOT analysis and FCM was introduced. Results may not perfectly reflect reality, but at least they confirm the effectiveness of the developed methodology. In future research, a more complex and complete data model can be constructed for a more accurate analysis of the real situation. This article provides only a general base. The output of the FSM system is more adequate than the output of a single isolated SWOT analysis and can be used as a basis for further research (e.g. risk assessment).

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