A New Evaluation Model for Vertical Handoff Algorithms

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ABSTRACT
A variety of vertical handoff algorithms (HVA) that allow mobile users to remain connected to the best available network without losing the connection when switching from one wireless network to another have been proposed. Given the amount of proposed algorithms, different methodologies for evaluating VHA have been proposed. This issue has interesting challenges because the HVA have evolved to become more sophisticated, thus evaluation models must be considered different parameters. In this paper, we address this issue by proposing a new evaluation model for VHA, that has been designed based on specific concepts taken from the multicriteria evaluation and operational reliability. The proposed evaluation model allows analyzing VHA using measured values of some defined parameters, which can be obtained from simulating VHA on a network simulation tool. We present as a case study an evaluation of two VHA, which shows the new model functionality and results.

Keywords

1.INTRODUCTION
The next generation wireless networking (4G) is focused on achieving interoperability between different network technologies in a seamless manner and to facilitate user mobility, maintaining permanent wireless connection anywhere and anytime [1][30].

Currently, there is an emerging trend that most of the smartphones are equipped with multiple network interface cards, which are capable of connecting to different wireless networks. But this advance poses an interesting challenge, as is the handoff between heterogeneous wireless networks in a seamless way. To make this possible, various solutions have been proposed in the research literature [2][30] and even a new technology was proposed by a wireless technology maker [3].

One of the most important issues of the vertical handoff problem is the strategic that helps the mobile terminal to decide when to perform the handoff between different wireless networks that are available in the environment [2].

The handoff problem between heterogeneous wireless networks has been much studied by researchers and several solutions, known as Vertical Handoff Algorithms (VHA) have been proposed [4, 5, 6, 7, 8, 9, 10]. These solutions have been tested primarily using simulation tools.

In the research literature a few studies as [11, 12, 13, 14] were found. They have established different simulation models to better understand the implications of the handoff decision stage.

Based on the different proposed algorithmic solutions, some researches have focused on defining which of these solutions may be optimal for the vertical handoff. In this sense, there are researches, such as [15, 16, 17] that use different evaluation methodologies to accomplish this purpose, becoming the problem of evaluation of VHA in an interesting challenge given the amount of proposed algorithms and the need for an objective assessment of these solutions.

This paper reviews several researches that have been published about the evaluation of VHA, which differ in the methodologies used for evaluation and also in used metrics. For example, in [18] and [19], algorithms are evaluated based on the handoff performance measures, such as the number of handoffs executed, the number of unnecessary handoffs and the handoff delay. While in [16, 17, 20, 21] algorithms are compared using network performance measures as the use of wireless resources, the available bandwidth and the delay/packet loss.

Evaluation methodologies for VHA proposed in the research literature have a mathematical support, use specific methods as Analytical Hierarchy Process (AHP) [16], and some of them include concepts from other areas, such as fuzzy logic [17], which can be used to define the valuation scales. Even in one of the proposed evaluation models, statistical concepts as the standard deviation are used to define an ideal network interface, which facilitates the evaluation of VHA based on mobility [21].

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However, the proposed evaluation models are not so flexible for defining the parameters to evaluate, and some of them are complex to apply in performance evaluation of VHA.

In order to generate a new evaluation model for VHA, that is flexible and facilitates the evaluation process to researchers, such concepts and models as multi-criteria evaluation methodologies and the maintenance of equipments or systems were studied.

The rest of the paper is organized as follows. Section 2 presents some topics related to VHA evaluation and concepts that were studied to generate a new evaluation model. In section 3, we explain our proposed evaluation model. In section 4, a case study of performance evaluation of two VHA using the proposed model is presented. Finally, conclusions are given in the last section.

2. RELATED WORKS
2.1 VHA Evaluation
Various recent researches show interest in the evaluation of VHA. However, some of them do not evaluate the whole algorithm and they only study the decision stage, which is considered as the core component of the handoff process [15, 16, 17].

Based on the different proposed algorithmic solutions, some studies and researches have focused on defining which of these solutions may be optimal for the network selection process. In this sense, there are researches that use different evaluation methodologies to accomplish this purpose.

2.1.1 Analytic Hierarchy Process (AHP)
Within the multicriteria decision analysis is the method called Analytic Hierarchy Process, AHP [22], which allows constructing a hierarchical model that represents the problem and alternatives initially proposed, to then deduce what are the better alternatives and to make an optimal decision.

In [16], the authors compare the performance of four VHA, namely, MEW (Multiplicative Exponent Weighting), SAW (Simple Additive Weighting), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) and GRA (Grey Relational Analysis). They used the AHP method to determine the relative importance or weights of each parameter to evaluate, and the fundamental 1-9 AHP scale to answer to a sequence of comparisons between a pair parameters. Four traffic classes were considered: conversational, streaming, interactive and background. Each traffic class was associated with four different QoS parameters: available bandwidth, end-to-end delay, jitter, and bit error rate (BER).

One of the advantages of AHP method over other methods of multicriteria decision is that it provides a solid mathematical basis that allows analyzing any problem and measure quantitative and qualitative criteria by a common scale. However, it requires the participation of different people to generate a consensus and the introduction of a new alternative can changes decision maker preference structure or shows inconsistencies.

2.1.2 Fuzzy logic
In [17], the authors propose a performance evaluation of five VHA: SAW, TOPSIS, GRA, MEW and UA (Ubique’s Algorithm). In this work, the authors used the concept of fuzzy logic to build their own valuation scale and compare different parameters used in handoff process. They also used the AHP to determine the weights of the parameters: available bandwidth, BER, average delay, security level for access network and monetary costs, associated with two classes of traffic, conversational and streaming.

Fuzzy logic can be applied when certain parts of the problem are unknown and can not be measured reliably. For some time the fuzzy logic has become the object of interest to provide support for multicriteria decision problems. However, there is no theoretical guarantee that a fuzzy system is stable and the definition of the measurements is not always easy and requires extensive testing.

2.1.3 Use of simulation tools in the analysis
In [20], the authors consider that the handoff can be predicted according to the user’s movement; therefore a basic requirement is to simulate the movement of mobile node in the access networks and deduce from these movements (user’s location), the QoS parameters, such as network traffic, BER and packet transmission delay. Then, these parameters become inputs of VHA that are used to define the most appropriate network interfaces. The user mobility is modeled and simulated using MATLAB.

As in previous work, in [18], the authors use MATLAB to develop the simulation model and to evaluate the handoff process between WLAN and cellular networks using two algorithms:

- The first algorithm is based on the algorithm developed by Zahran [23] with a few modifications. This algorithm used averaged RSS (Received Signal Strength) and lifetime estimation as the criteria to start vertical handoff.
- The second algorithm is based on the conventional algorithm. This algorithm used the average signal strength as the criteria to start the handoff process.

In this research, the performance of the handoff algorithms was evaluated according to few analyses. The analyses were based on the number of handoff and handoff delay.

Considering the simulation using software as an alternative, an interesting model was published in [17], which allows evaluating the behavior of the network selection process in converged wireless network scenarios. The authors proposed an evaluation methodology (Ubique middleware) that considers three key factors to decide to change the network connection, such as applications, user and operator. Additionally, they used the CanuMobiSim simulator [24] to generate realistic mobility.
patterns, which is one of the factors that are taking a great importance as critical element in the new VHA.

The main advantage of using simulation tools for this type of practice is that we can simulate VHA evaluation models and determine their benefits, advantages and disadvantages, facilitating the implementation and analysis of communication systems that are increasingly more complex. However, is required an appropriate software tool to simulate scenarios and sufficient computing resources to carry out the simulation tests.

### 2.1.4 Solutions based on mathematical and statistical models

#### 2.1.4.1 Mathematical models

The authors of the doctoral thesis published in [19] present a framework for performance evaluation of a variety of algorithms for different types of networks. The core of the framework is defining a realistic scenario for performance evaluation using mathematical analysis and computer simulation. This scenario identifies the wireless network type and topology, defines the location of wireless connection points, and specifies a path for the mobile terminal in which it experiences a handoff.

This dissertation divides wireless networks into three categories according to their topology and wireless service application: traditional cellular phone networks, heterogeneous wireless data networks, and rate adaptive wireless data networks. For each category of wireless networks, the authors define a performance evaluation scenario and using Monte Carlo simulations, Monte Carlo calculations, and direct mathematical analysis to analyze the effects of different handoff decision algorithms.

#### 2.1.4.2 Statistical models

In [21], the authors proposed and developed a comprehensive methodology for evaluating and comparing the inter-technologies handoff algorithms. They proposed the definition of a common metric, namely the Standard Deviation from Optimum Interface based on the well-known standard deviation (i.e., which calculates the deviation from an average value) for evaluation of VHA. This optimal interface is actually an ideal interface.

In tests, the authors defined the standard deviation from optimum for a particular decision parameter (e.g. bandwidth), but they state that the same procedure can be used with all decision parameters involved in a vertical handover decision algorithm.

The proposal presented by the authors of this paper combines statistical concepts with the computing capacity to automate calculations for analyzing the handoff process. However, this method can be complex to more than one criterion (multivariable optimization problem).

In general, mathematical and statistical models help to predict optimal solutions and they are much easier to understand than other analytical models. Although is possible to gain experience at a lower cost and quickly, these models include formulas and complex algorithms that use a lot of computer resources to perform the analysis.

### 2.2 Underlying Concepts to Generate the New Evaluation Model

#### 2.2.1 Concept of criticality

Criticality Analysis (CA) is a methodology to establish a hierarchy or priorities of processes, systems and machines, creating a structure that facilitates effective decision making, directing the effort and resources in areas where it is most important and/or need to improve operational reliability, based on the current situation [25].

The term “critical” and definition of criticality can have different interpretations and depends on the objective that is trying to prioritize. The criticality analysis generates a weighted list from the most critical to least critical of the whole analyzed set, differentiating three classification zones: high, medium and low criticality. After identifying these, it is much easier to design a strategy for studies or projects that improve operational reliability, starting the applications on the set of processes that are part of the high criticality zone.

The criteria for criticality analysis are associated mainly with safety, production, operation costs, failure rate and repair time.

These criteria are related through a mathematical equation that generates a score for each item evaluated. It is common to find studies that use a criticality matrix, in which are located the criteria of importance and for each zone is defined concepts that allow measuring the degree of impact on operational reliability if a machine fails during their service.

#### 2.2.2 Multicriteria evaluation

Multi-Criteria Evaluation (MCE) is an effective technique used in multidimensional decision and evaluation models within the field of decision making [26]. Its main objective is to help the decision makers to evaluate, prioritize, select or reject objects based on an evaluation by scores and according to several criteria [27].

Almost all MCE techniques consist of a first stage, which consists in designing a matrix with defined criteria. The next stage is the addition of scores to the criteria, with the use of a specific aggregation procedure (any MCE technique), taking into account the expressed preference of decision makers in terms of weights, which assigned to different criteria. This procedure or technique allows the decision maker to compare the different alternatives based on the weights assigned.

The central problem of the EMC is:

- Select the best alternative(s);
- Accept the good alternatives and reject those that are bad; and
• Generate a ranking of the considered alternatives (from best to worst).

It is important to note that the MCE does not consider the possibility of finding an optimal solution.

2.2.2.1 Multicriteria evaluation techniques

Multicriteria techniques are characterized by methodological variety and can be grouped into three main groups of techniques:

• Order or hierarchy: These techniques require of comparisons between pair alternatives and are not practical when the number of alternatives is large.

• Multicriteria utility: These techniques are based on simple multiplicative models or addictive to group simple criteria and therefore are not suitable to analyze complex systems.

• Mathematical programming: These techniques are used in a continuous context to identify solutions very close to the ideal solution introducing the measure of distance in metric units.

These techniques are developed in the linear programming approach (operations research).

3. PROPOSED EVALUATION MODEL

The design of the model is based on multicriteria evaluation methodology, which is usually used to evaluate alternatives when several criteria exist, and also uses the concept of criticality analysis, which is taken from the operational reliability strategies.

3.1 The Structure of the Evaluation Model

The main objective of the evaluation model is to evaluate the performance of VHA from a number of defined parameters. The new evaluation model for VHA is defined by the following steps.

3.1.1 Definition of evaluation parameters

The evaluation parameters are indicators that significantly affect the performance of VHAs. These parameters allow evaluating each algorithm, according to the assigned weights and that reflect the importance (priority) of each parameter.

The number of parameters that can be defined for the evaluation model is flexible, but for its validation and implementation through software, this value has been bound in a range from 3 (minimum) to 5 (maximum).

3.1.2 Definition of the criticality matrix

The criticality matrix that is shown in Table 1 is used for evaluating the algorithms. Each evaluation parameter is spread over four levels rated from 1 to 9.

These levels are required in order to minimize subjective assessments and specific indicators are used to evaluate the algorithms easily.

<table>
<thead>
<tr>
<th>Evaluation parameter</th>
<th>Valuation of performance levels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low=1</td>
</tr>
<tr>
<td></td>
<td>Medium=5</td>
</tr>
<tr>
<td></td>
<td>High=7</td>
</tr>
<tr>
<td></td>
<td>Very high=9</td>
</tr>
<tr>
<td>x &gt; 90% of the max.</td>
<td>60% &lt; x &lt; 90% of the max. value</td>
</tr>
<tr>
<td>value</td>
<td>40% &lt; x &lt; 60% of the max. value</td>
</tr>
<tr>
<td>x &lt; 40% of the max.</td>
<td></td>
</tr>
<tr>
<td>value</td>
<td></td>
</tr>
</tbody>
</table>

3.1.3 Evaluation matrix

The evaluation matrix is a decision matrix that summarizes the evaluation of each algorithm (rows) under to each parameter (columns). Each position of the matrix must be filled with the results obtained from simulation of the algorithms.

If there are several simulation results for each evaluation parameter, the following procedure must be applied: assuming the data are normally distributed, we use the criterion of two times the standard deviation from the average to ensure that a large percentage of the data is around the average.

The data that are outside of this range will be ignored and treated as erroneous. Then, the average of the new set of data must be calculated, and this value will be entered into the evaluation matrix.

3.1.4 Calculating the weight of evaluation parameters

After completing the evaluation matrix is necessary to determine the weight of each parameter in the final evaluation i.e., the relative importance given to each parameter in the global set of parameters.

Since the performance measures of these parameters are in different units, we proposed a method that normalizes the matrix \( D \) and turns into \( D_0 \), so that \( d_{0i} \in [0,1] \). In this way, is controlled the magnitude of the attributes, and also it prevents that some of the attributes can dominate others due to their units.

3.1.5 Comparison of algorithms using the criticality matrix

After obtaining the weights for each parameter is necessary to compare each one of the algorithms with the criticality matrix that is shown in Table 1, valuing each parameter according to the defined valuation scale. For this, we should identify the highest result of simulation for each evaluation parameter and then every element of the column (parameter) is divided by this result.

3.1.6 Calculating the criticality index

The criticality level of the algorithms can be represented by the criticality index, \( I_c \), applying (1):
\[ I_C = 100 \frac{\sum_{i=1}^{n} (n_i, p_i)}{n \sum_{i=1}^{n} p_i} \]  

(1)

Where,

- \( n \) = Number of parameters
- \( p_i \) = Weight of each parameter
- \( n_i \) = Assigned valuation level to each parameter
- \( n \) = Maximum valuation level of all parameters

3.1.7 Priority algorithms

We have two ways of evaluation: the first one is based on the criticality index and the second one is based on the valuation of a specific parameter.

In the first way, the algorithms are prioritized or ordered according to their criticality. While in the second way each algorithm is analyzed according to the measure of a particular parameter.

3.2 VHA Evaluation Process

The evaluation process using the proposed model can be summarized as follows: VHAs generate results from its simulated execution in a simulation tool. These results are taken as the evaluation parameters and are the input for the new evaluation model, which can be implemented using software application, because it is based on two fundamental concepts, criticality analysis and multicriteria evaluation, which are computable.

Figure 1 illustrates the evaluation process and it shows the three phases of the process: the simulation of the algorithms (previous phase), the execution of the evaluation model and the generation of results in a simple format (graphics and files) for its analysis.

The implementation of the evaluation model using software application automates the evaluation process of the VHA, and the researchers can analyze the obtained results.

4. CASE STUDY

In this section, we present the results of the performance evaluation of two VHA, namely: algorithm based on user preferences [4] and algorithm based on application requirements [5].

The first algorithm (Alg. 1 - Based on user preferences) involves a cost function designed to test the VHA in the decision stage. Parameters used in the cost function are bandwidth (bit rate), battery consumption, monetary connection cost and mobility speed, multiplied by the weight that the user had assigned to each parameter. Two additional elements: dwell timer and hysteresis margin, are used to stabilize the handoff process and ensure that always the best network is chosen.

The second algorithm (Alg. 2 - Based on application requirements) uses the bandwidth, the latency and the percentage of packet loss rate as decision parameters. To make the handoff decision, the mobile node creates a profile (maximum and minimum values of parameters) considering the characteristics of applications running on the mobile node, and compares it with the network conditions which it could be associated. If the values of these parameters accomplish the requirements of the applications profile, the handoff is executed.

These algorithms were simulated in NCTUns tool [28] and tested in simulation scenarios with WiFi and WiMAX wireless network technologies.

4.1 Procedure

4.1.1 Define the evaluation parameters

For this case study were defined three evaluation parameters:

- Number of handoffs: It is the number of network handoffs that mobile node have realized for a given time period.
- Handoff delay: It is the time between the initiation and completion of the handoff process.
- Computational complexity: It is a measure of computational resources that an algorithm requires for its execution, being the amount of memory and time of execution, key resources. The computational complexity calculation is made based on the size of the input of the algorithm (i.e., the number of data) [29].

4.1.2 Definition of the criticality matrix

Based on the algorithmic complexity theory, the efficiency of an algorithm can be quantified with the measure of the order of
complexity. The notation $O$ is used for the parameter computational complexity, that generalizes the notion of cost regardless of equipment used [29].

Table 2 shows the criticality matrix that was used to compare the evaluated algorithms based on computational complexity.

<table>
<thead>
<tr>
<th>Evaluation parameters</th>
<th>Low=1</th>
<th>Medium=5</th>
<th>High=7</th>
<th>Very high=9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computational complexity</td>
<td>$O(a^n)$, where $a&gt;2$</td>
<td>$O(n^{a})$, where $a&gt;2$</td>
<td>$O(n) \leq O(n \log n)$</td>
<td>$O(\log n)$</td>
</tr>
</tbody>
</table>

Taking into account the review of methods to calculate the order of complexity of an algorithm, the computational cost of the two simulated VHA is $O(n)$.

4.1.3 Constructing the evaluation matrix

We used the criterion of two times the standard deviation from the average of the data set of the parameters number of handoffs and handoff delay.

Table 3 shows the measured values of these evaluation parameters.

<table>
<thead>
<tr>
<th>Simulation</th>
<th>Number of handoffs (units/s)</th>
<th>Handoff delay (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>8</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>9</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>10</td>
<td>7</td>
<td>13</td>
</tr>
</tbody>
</table>

Total simulation time: 400s

In this case no data was discarded because all of them are within the range, which means that the initial average value will be entered in the evaluation matrix.

Table 4 shows the evaluation of each algorithm under each parameter.

4.1.4 Calculate the weight of the evaluation parameters

The method for calculating the weights of the parameters consist in adding the values of each column of the evaluation matrix and calculate the inverse values of these sums. Then these results are normalized, dividing each result by the total sum of the inverse values and multiplying by 100. The resultant vector represents the priorities of each parameter.

Taking into account that is required quantitative valuation to calculate the weight of the parameters in the final evaluation, we assign a numerical value to each order of complexity.

The most common algorithmic complexity functions ordered from highest to lowest efficiency are shown in Table 5. And its valuation scale is shown in the third column of the Table 5.

<table>
<thead>
<tr>
<th>Notation</th>
<th>Name</th>
<th>Numerical value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$O(1)$</td>
<td>Constant order</td>
<td>10</td>
</tr>
<tr>
<td>$O(\log n)$</td>
<td>Logarithmic order</td>
<td>20</td>
</tr>
<tr>
<td>$O(n)$</td>
<td>Linear order</td>
<td>15</td>
</tr>
<tr>
<td>$O(n \log n)$</td>
<td>Linear-logarithmic order</td>
<td>15</td>
</tr>
<tr>
<td>$O(n^2)$</td>
<td>Quadratic order</td>
<td>10</td>
</tr>
<tr>
<td>$O(n^3)$</td>
<td>Cubic order</td>
<td>10</td>
</tr>
<tr>
<td>$O(n^n)$</td>
<td>Polynomial order</td>
<td>10</td>
</tr>
<tr>
<td>$O(2^n)$</td>
<td>Exponential order</td>
<td>5</td>
</tr>
<tr>
<td>$O(n!)$</td>
<td>Factorial order</td>
<td>5</td>
</tr>
</tbody>
</table>

The two algorithms analyzed have a linear-order computational complexity, for that reason we used a value of 15 to calculate the weight of this parameter.

4.1.5 Comparing the algorithm with criticality matrix

Table 6 presents the results of the comparison between the evaluation matrix and the criticality matrix that were obtained previously.
Table 6. Valuation matrix

<table>
<thead>
<tr>
<th>VHA</th>
<th>Number of handoffs</th>
<th>Handoff delay</th>
<th>Computational complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alg. 1</td>
<td>5</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Alg. 2</td>
<td>1</td>
<td>1</td>
<td>7</td>
</tr>
</tbody>
</table>

4.1.6 Prioritize the algorithms

Table 7 shows the scores; criticality indices and priority of the algorithms analyzed in this case study.

Table 7. Evaluation and prioritization of VHA

<table>
<thead>
<tr>
<th>Weights</th>
<th>Number of handoffs</th>
<th>Handoff delay</th>
<th>Computational complexity</th>
<th>Criticality index $I_c$</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>60.2 %</td>
<td>0.083 %</td>
<td>39.7 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alg. 1</td>
<td>5</td>
<td>5</td>
<td>7</td>
<td>82.76</td>
<td>1</td>
</tr>
<tr>
<td>Alg. 2</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>48.31</td>
<td>2</td>
</tr>
</tbody>
</table>

4.2 Results

The results of criticality analysis show that the algorithm based on user preferences (Alg. 1) has the highest score, which means that this algorithm has the “best” performance. The algorithm based on application requirements (Alg. 2) has the lowest score and therefore is considered that its performance is lower than the first one.

If we evaluate the algorithms under a particular parameter, e.g. handoff delay, we can say that the first algorithm (Based on user preferences) is “better” than the second one (Based on application requirements) because it has a higher valuation. The measure of this parameter is within level 'regular' of criticality matrix and therefore was assigned a score of 5, whereas the second algorithm has a score of 1, given that its measure is within level “bad”. This is the same situation for the parameter of number of handoffs, so it means that first algorithm is better than second one.

5. CONCLUSIONS

The interest in the vertical handoff (VH) has generated a number of algorithms. Some are purely academic solutions, but others already have been implemented in physical prototypes. Given this variety of VHA of different complexity, researchers have begun to generate some evaluation models to analyze the performance, efficiency, or simply compare the algorithms. However, the proposed evaluation models usually are not flexible in defining the parameters to evaluate and are complex to apply in algorithms evaluation exercises.

The proposed evaluation model is flexible in terms of the number of parameters to evaluate and facilitates the analysis of studied VHA for researchers. The design of the new evaluation model is based on multicriteria evaluation methodology and criticality analysis, which allows that the model can be implemented using a software application, resulting in an automated evaluation process of VHA.

6. REFERENCES


