Risk Assessment Model for Congestive Heart Failure

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Abstract. Congestive heart failure is a common, chronic and debilitating condition with an extremely poor prognosis. This paper presents an approach to creation of risk assessment model for congestive heart failure. Two types of hierarchical multi-attribute models are developed and compared: qualitative and quantitative. The results for both models showed that the models can successfully assist and help the experts in their decision for estimation of the patient's risk. Also, the models analysis techniques can assist additionally by giving advices for future improvement of patient's health.

Keywords: Congestive heart failure, Risk assessment model, Decision support, Expert system.

1 Introduction

Congestive heart failure (CHF) is a common, chronic and debilitating condition. It is an issue when the heart cannot pump enough blood to the rest of the body. It is more common than most cancers, including breast, testicular, cervical and bowel cancers. Approximately 14 million people suffer from CHF in Europe [1].

The CHF issue is addressed in the CHIRON project [2]. The CHIRON is a European project whose final goal is the development of a reference architecture for personal elderly healthcare. One of the modules of the project is the creation of CHF Risk Assessment Model (RAM), which should assist the doctors in assessing the CHF risk of a patient. The aim of the RAM is to provide to the doctors the information needed to make clinical decisions regarding the patient's health.

In this paper we describe the development of a long-term RAM for CHF. Two approaches were used: qualitative and quantitative. Additionally, for both RAMs a
hierarchical attributes structure is created. The results showed that it is possible to create an accurate long-term RAM, and also to provide an explanation mechanism which assists the experts in their decision regarding the CHF risk factor.

2 Attributes and Alternatives

Attributes are an essential component in the development of RAMs. They represent relevant features that are used to model the risk. In our research, we first studied the literature and made a list of 70 relevant attributes. However, in this paper we focused only on a long-term risk. The idea of the long-term RAM is the modeling of a static risk. Therefore, only the attributes that are the most relevant for the long-term risk were used. This resulted in using 15 basic-information attributes that can be collected upon the patient's enrolment to the medical institution.

The first steps in creation of the model were: attribute understanding and grouping. The final hierarchy resulted in 4 layers, 15 basic and 11 aggregate attributes (shown in Figure 1). The different colors in Figure 1 show the importance of the attributes. Each attribute is labeled with an importance factor assigned by the medical expert (high importance – red, medium importance – yellow and low importance – green).

Alternatives are the options used for evaluation of the models. The alternatives analyzed by our models were: low, medium and high-risk patient. The data for these patients was provided by the medical expert in the CHIRON project. However, real-life data is expected in the later stage of the project.
3 Qualitative Hierarchical DEXi Model

The first model presented is the qualitative model. This model was developed using the DEXi software [3]. It is a hierarchical model that includes all of the previously described attributes and evaluates the data from the three alternatives.

One of the features in hierarchical modeling is the utility function. In qualitative models the utility function is a table of decision rules. This function maps all the combinations of the lower level attributes to the aggregate attribute. Furthermore, the importance of the attribute is encoded in the rules of the utility function.

Once the model was created, the next steps were the evaluation of the alternatives and model analysis. The model successfully evaluated each of the alternatives (Table 1). Further analysis was performed using two techniques: Plus-minus-1 and Selective explanation. Some of the results are presented in the following paragraphs.

The Plus-minus-1 analysis for the low-risk patient showed that, if the patient is less active in future, then s/he will be classified as a medium-risk patient. The same conclusion is for the smoking habit; if s/he decides to start smoking, the CHF risk increases significantly. The Selective explanation showed all the weak and strong attribute values that influence to a higher or lower risk. For the particular patient, the attribute values that influence towards a high risk are from the social-economic aspect: very old patient and low incomes; thus, they cannot be "improved".

The Plus-minus-1 analysis for the medium-risk patient showed that, if s/he changes his activity level from medium to high, then s/he will be in the low-risk category. On contrary, if s/he starts smoking, then the CHF risk is significantly increased. The Selective explanation showed that it is important that s/he is not smoking and also the diastolic blood pressure is one of the strong points. On the other hand, the mass related attributes are in the high-risk zone and they should be "improved".

The analysis results showed that the qualitative model can definitely assist the experts in their risk decision, but also for future healthy advices for the patient. For instance, suggesting more activity, not smoking, losing weight are some of the advices that were revealed by this analysis. These advices overlap with the real-world advices which are usually given from a doctor to a patient.
4 Quantitative Hierarchical Model

The quantitative model was created by using the same attribute hierarchy. The differences with the qualitative model are in the attribute values and utility functions. In contrast to the quantitative symbolic values, the quantitative model uses numerical values. Additionally, the utility function for the quantitative model is a mathematical formula – weighted normalized sum of risks:

\[
\text{risk} = \frac{1}{\sum_{i=1}^{N} w(p_i)} \sum_{i=1}^{N} w(p_i) \text{risk}(p_i)
\]  

(1)

\(N\) is the number of attributes, and each attribute is associated with a weight, i.e. \(w(p)\). The weights of the attributes were chosen with accordance to the importance of the attribute, i.e. low = 0.5, medium = 1, high = 1.5. The risk of each attribute, \(\text{risk}(p)\), is the normalized risk value of the attribute (0 – low, 1 – very high risk).

The same alternatives were evaluated with this model, as well. The results showed that each patient is correctly evaluated (Table 1). For further analysis, the same Plus-minus-1 "advice"s from the DEXi model were applied. Similar behavior for the quantitative model was noted, e.g. if the low-risk patient is less active, the risk factor is significantly increased (from 0.27 to 0.31). The changes in the other attribute values were not so significant. Therefore, one can conclude that both models have similar sensitivity to the changes of the important attributes values.

5 Qualitative vs. Quantitative models

Even though both models evaluated the alternatives correctly (Table 1), they differ on a very basic level. The qualitative model uses discrete values and the quantitative uses numerical values. Each of the models has its advantages and disadvantages.

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Low-risk Patient</th>
<th>Medium-risk Patient</th>
<th>High-risk Patient</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEXi model evaluation</td>
<td>Low Risk</td>
<td>Medium Risk</td>
<td>High Risk</td>
</tr>
<tr>
<td>Quantitative model evaluation (0 - low; 1 - high)</td>
<td>0.27</td>
<td>0.44</td>
<td>0.69</td>
</tr>
</tbody>
</table>

In the qualitative model, the utility function is a table of decision rules. Most of these rules should be manually created and this can be exhaustive for the expert who is building the model. Therefore, qualitative models have a natural limitation in the number of attributes and their values. On the other hand, in the quantitative
models the utility function is a mathematical function. Thus, there is no limitation with the number of attributes and their values. However, the definition of this function is a problem by itself.

The analysis techniques for the qualitative model are more informative and understandable. Usually users of such RAMs are people that do not want to look and play with numbers, but they want simple rules that explain the model.

Finally, the concept of *weights* in the quantitative model is straightforward; it is a number representing the importance of the attribute. On the other side, the qualitative functions have to encode the importance into the utility functions.

### 6 Conclusion

We presented an approach for creation of multi-attribute RAM for CHF. Two types of models were developed: qualitative and quantitative. The results for both models showed that it is possible to evaluate the patients with the correct long-term risk factor. Moreover, we showed that using a hierarchical structure of the attributes significantly improves the understandability and interpretation of the models. The results showed that the model can successfully assist and help the experts in their decision. Furthermore, the analysis techniques can assist with giving future advices for improving the life of the patients. For instance, suggesting to the patient to be more active, not to smoke or lose some weight, are only some of the healthy advices that were produced by these models.

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### References:

2. CHIRON project JU ARTEMIS Grant Agreement # 2009-1-100228. http://www.chiron-project.eu/
Congestive heart failure (CHF) is a common and chronic condition with an extremely poor prognosis. It is an issue when the heart cannot pump enough blood to the rest of the body. It is more common than most cancers, including breast, testicular, cervical and bowel cancers. Approximately 14 million people suffer from CHF in Europe.

In this paper we presented models that can predict the CHF risk of a patient. We were focused on predicting the long-term, static, risk that can be assessed upon patient's enrolment in the medical institution. The aim of the model was to predict the CHF risk, but also to provide additional explanation for the decision: the reason why the predicted risk is such as it is (low, medium or high).

To achieve this goal, we developed two types of hierarchical models: qualitative and quantitative. The first one is more user-friendly because it is using symbolic values for the data, e.g. low activity, high blood pressure, medium risk, etc. The other one is more mathematical and is using numbers instead of symbolic values.

We tested these models on a data created by a medical expert. First, the data is used as input to the models. Then, the models analyze the data and make the final decision (prognosis) for the risk. Additionally, both models have visualization mechanism, which shows the attributes that are extremes: the most and the least risky. Finally, the analysis techniques reveal healthy advices for the patient, such as: suggesting being more active, not to smoke and lose weight.

The results showed that the models successfully predict the correct risk factor, and also provide explanation mechanism which could assist the experts in their decision regarding the CHF risk factor.