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Multi Criteria Importance Measure For Identifying Critical Components Of Electro-Hydrogen Generator

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Importance measures are valuable tools for raking components or group of components of complex engineering systems. In the literature, many importance measures have been developed for different purposes. For example, (Xie and Bergman, 1991) investigated a universal importance measure of system components, determined by ranking the reduction in expected yield resulting from variations in the lifetime distribution of these components. (Do et al., 2008) estimated the importance measures for Markovian systems using perturbation analysis. (Si et al., 2010) developed an integrated importance measure that accounts for the reliability, structure, and causality characteristics of components. (Do and Bérenguer, 2020) evaluated the impact of information and economic dependencies between components on system reliability and proposed a condition-based importance measure for multi-component systems. (Wu and Coolen, 2013) proposed a cost-based importance measure that incorporates the cost associated with maintaining a system and its components over a specified time horizon. (Dui et al., 2017) proposed an innovative importance measure that assesses the influence of external factors on system performance. The literature review discusses various methods to calculate the importance of components in a system. However, there is no standardized and widely adopted approach for prioritizing critical components in predictive maintenance, especially when considering multiple criteria and their correlation. Therefore, the main objective of this work is to propose a methodology for identifying critical components using a multi-criteria decision process while considering the correlation between criteria. For this purpose, we propose a methodology based on the Dui's work (Dui et al., 2023), tailored to suit the distinctive characteristics of the GeH2 system. This adaptation involves refining techniques such as data normalization and employing absolute values for criteria correlation coefficients. These adjustments ensure the relevance and applicability of the approach to the intricate complexities inherent in GeH2 system.

We consider a system consisting of a set of components $X = \{x_1, x_2, \dots, x_i, \dots, x_n\}$ and a set of criteria $C = \{C_1, C_2, \dots, C_j, \dots, C_m\}$. The attribute of the system under criterion C_j is denoted by $y_j(X)$. The attribute of component x_i under criterion C_j is denoted by $y_j(x_i)$. Additionally, $\mathrm{Y} = \{y_j(x_i) \mid i = 1, \dots, n;\ j = 1, \dots, m\}$ denotes the set of attributes of each component under each criterion. Considering the correlation between criteria, the goal is to rank the components x_i based on the multi-criteria C. The proposed methodology contains the following main steps:

- normalize the attributes using the Max-Min method.
- calculate the sensitivity of each component under all criteria to get a Jacobian matrix J of size $n \times m$.
- according to the type of criteria (benefit or cost), normalize the matrix J using the Max-Min method to get a normalized Matrix R.
- split the matrix R into rows to obtain the attribute characteristics vector $\Phi(x_i)$ for each component x_i.
- determine the criteria weights based on the criteria correlation.

- calculate the multi-criteria importance measure, denoted by MCIM, as the L2-distance between the vector $B = [1 \quad 1 \quad \cdots \quad 1]^T$ of size m as an ideal component and the attribute characteristic $\Phi(x_i)$.
- based on MCIM, establish a ranking for the components within the GeH2 system.

The above methodology is then applied to a real case study of a zero-emission electro-hydrogen generator system (GeH2) developed by the Energy Observer Development (EODev) group.

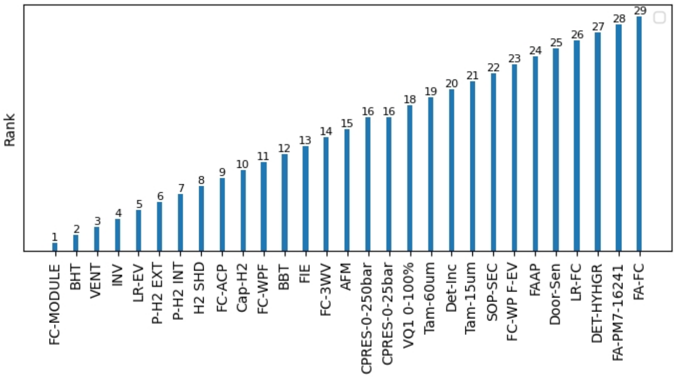

Fig. 1. Ranking of GeH2 components according to the multi-criteria importance measure.

To ensure the practical relevance of the proposed methodology, we collaborated with GeH2 maintenance experts to identify the main criteria related to predictive maintenance. The selected criteria are maintenance frequency, maintenance duration, training requirements, difficulty of inspection, component lifespan, and component cost.

The results obtained, presented in Figure 1, highlight the most significance of certain components, such as the FC-MODULE, BHT, and VENT, as they consistently demonstrate the highest importance measures. This coherence is in line with expectations, given that these three components collectively serve as the foundational core of the GeH2 system, emphasizing their pivotal role and justifying their elevated priority. Despite their significant contributions to the GeH2 system, certain components such as the FC-ACP, FC-WPF, FC-3WV and FC-WP F-EV have a lower rank. This nuanced ranking is a direct consequence of considering the correlation between criteria. The expected consistency in this ranking arises from the understanding that these components function as subordinate sub-components of the main component, the FC-MODULE, which remains the most critical component even when accounting for criteria correlation, underscoring its central and indispensable role within the GeH2 component hierarchy. On the other hand, filters and sensors within the GeH2 consistently receive lower importance rankings. This observation aligns with expert opinions, confirming the reliability of rankings obtained when considering criteria correlation. The emphasis on incorporating correlation insights into the assessment, particularly for components with intricate interdependencies within the system hierarchy, becomes increasingly evident. This approach ensures a comprehensive understanding of the relative importance of each component and its role within the broader context of the GeH2 system.

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