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EDITORIAL

Digital twins for dynamic sustainable decision making: a research need in the study of engineering sustainability

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Engineering sustainability has continuously increased in salience in industry, as it has evidently shown that companies making sustainability as a goal have clearly achieved competitive advantages. This was further emphasized in a recent report, titled "National Strategy for Advanced Manufacturing," by the U.S. National Science and Technology Council (2022), where sustainable manufacturing is listed as the first objective for achieving the goal—development and implementation of advanced manufacturing technologies. Engineering sustainability is commonly referred to a process of catalyzing, planning, and delivering changes necessary to meet a sustainable development goal through a transformation path (Rosen 2012). Engineering sustainability needs to be pursued in three main recursive steps: sustainability assessment, short-to-long-term strategy development, and implementation and effectiveness evaluation. Significant progress in engineering sustainability research has been made over the past decade or so, but there still exist various fundamental challenges, and thus new research directions are being explored.

It is known that the rapid development of digital technologies has led to a variety of opportunities for companies to access numerous types of real-time data at a relatively low cost. Industries are successfully applying digital twin (DT) technology, utilizing those data intelligently, to design more efficient processes, streamline and optimize operations, improve product design and innovate new types, manage for more robust supply chains, etc. Recently, Kaplan indicated that DT technology should be also used to improve the sustainability performance of industrial systems (Kaplan 2023). As DTs are operated using real-time data, a system's sustainability status can be investigated in the dynamic domain. Huang discussed a number of research needs for the realization of dynamic sustainability assessment in the digital age, for which DTs could play a unit role for comprehensive and predictive sustainability assessment (Huang 2022). The other research need should be the development of methodologies and tools for conducting dynamic sustainable decision making supported by DTs.

Sustainable decision making is one of the most critical tasks in the pursuance of engineering sustainability, as it aims to generate optimal solution(s) for sustainability performance improvement and goal achievement. As sustainability is triple-bottom-lines based, sustainable decision making problems should be approached from a multi-objective optimization (MOO) perspective. There are two major types of MOO methods (Marler and Arora 2004): the lexicographic methods and the weighted sum methods. In the former type, objective functions are ranked by importance and solved individually in cascade. Caution must be taken when there exist many intertwined factors. In the later type, objective functions are combined into a single function using weighting factors that model decision-makers' preferences. There exist many scientific or empirical methods to determine the ratios of weighting factors reflecting the relative importance of the terms in the objective function.

It is important to note that the majority of the known methodologies for sustainable decision making are incapable of catching dynamic sustainability behavior of an industrial system and providing solutions based on the prediction of the system's future behavior. This could make decision makers to lose opportunities of identifying critical sustainability issues in time and taking prompt actions; as a consequence, sustainability problems could be more difficult to solve when they may appear in the (near) future. Therefore, it becomes imperative to investigate how to conduct dynamic sustainable decision making. In investigation, one important issue is about how to address uncertainty issues effectively. In various stages of the sustainability assessment and decision making process, uncertainty is pervasive. Diwekar et al. analyzed all major types of uncertainty, discussed decision

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making under deep uncertainty from clear enough futures to true surprises, and shared experience in developing and using a variety of methods for handling uncertainties in the study of sustainability science and engineering problems (Diwekar et al. 2021).

In the formulation of a dynamic sustainable decision making model, a dynamic sustainability assessment model, system's DTs, and uncertainty models must be incorporated. The dynamic decision making problem could be defined as one of the following types: (1) a maximum sustainability problem (i.e., to achieve the most significant sustainability performance improvement), (2) a minimum cost problem (i.e., to achieve the preset goal at the lowest cost), (3) a minimum time problem (i.e., to identify a technical solution for achieving the preset goal in the fastest way), and (4) a maximum efficiency problem (i.e., to identify the most cost-efficient way to achieve the most significant performance improvement). However, the known methodologies are essentially for static sustainability decision making (Moradi Aliabadi and Huang 2018). For dynamic sustainable decision making, new methodologies should fully utilize time-variant sustainability status data including those about future states predicted by the DTs. This will ensure that the derived solutions be robust for the achievement of the short-to-long term sustainability goal.

Dynamic sustainable decision making supported by DTs is a very challenging task in sustainability science and engineering in the digital era. Successful methodological and tool development must contribute very positively to the pursuance of engineering sustainability. We are looking forward to publications in this area in our journal.

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Data availability Enquiries about data availability should be directed to the authors.

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