Journal of Industrial Engineering & Management Editorial: Special Issue on Decision Support for Sustainability Management

This special issue brings together research articles to address the timely topic of decision support for sustainability management. Relative to other life cycle properties, (e.g. quality, safety, and reliability), sustainability is relatively new to the academic literature. However, its importance and prominence as measured by the number of academic publications on the topic has grown by a factor of approximately 10x per decade since the 1970's[1]. The motivations behind this increasing level of attention are multiple:

- Seminal works like *The Limits to Growth*[2] have warned of the potential for over-utilization of the planet's resources. Thus, sustainable development is often taken to mean: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[3]. This definition brought about the later recognition that sustainability addresses not just environmental but also social and economic impacts[4]. No longer could technological advancement be viewed as greater efforts for quality and reliability nor could economic development be viewed as greater profit margins.
- Another reason for this tremendous research effort has been the unprecedented degree of intertwined complexity found in sustainability problems and the shortage of tools required for the holistic thinking of their solutions. Limited product-centric paradigms had to evolve towards *engineering systems* – "classes of systems characterized by a high degree of technical complexity, social intricacy, and elaborate processes, aimed at fulfilling important functions in society"[1]. The three aspects of sustainability: environmental, social, and economic would have to be holistically applied to the all of the processes of an engineering system's life cycle. This often meant interdisciplinary work on multiple time, length, and energy scales. Unsurprisingly, the study of sustainability and its management remains a developing science.
- Finally, sustainability principles, when applied to engineering systems do not have "one size fits all" solutions. Rather sustainability management solutions take on new form when applied to systems as varied as energy, industrial production, transportation, healthcare, agriculture, water, finance, education and communication. Seen from another lens, many of the 21st century Grand Challenges for Engineering recently identified by the National Academy of Engineering are intimately linked to improving the sustainability of engineering systems[5].

Given this broad scope of application for sustainability management, this special issue addresses the tremendous open potential for improved decision support tools and methods. Such tools may be classified along three complementary axes. First, the drivers for sustainability, be they economic, social, or environmental, ultimately apply to three types of decision variables: engineered equipment, people, and financial costs/revenues. Next, the decisions may be viewed to have a degree of organizational scope: from small product design teams, to full organizations, to sectors that represent full value chains. These entities must address the decisions on the decision variables over which they have responsibility and assess the impacts on the external context in which they exist. Finally, the decisions can occur within any process along an engineering system's life cycle. Some of the challenges encountered in strategy, planning, and operations phases are highlighted to motivate this special issue.

Strategy: Strategic decisions in sustainability management can often bring about radical new paradigms of operation within an engineering system. For example, in the early years, sustainability was often limited to reactive quality-driven thinking on how to best achieve regulatory compliance with new environmental regulations. As time went on, organizations looked beyond compliance to weave cost reduction strategies with reductions in resource utilization. The most recent advances in corporate social responsibility advocate strategies where sustainability management brings about new value-driven business models and their subsequent revenue streams[6]. On a social level, human resources management evolved from project and cost driven strategies to long-term strategies of competence management, development and retention for the knowledge-based economy.

Planning: Planning decisions are often characterized by large-scale changes to the system architecture. Here, the 80/20 rule is often used as a salient heuristic: 80% of the sustainability impact is determined within the first 20% of a system's planning, engineering and construction. One important class of sustainability planning decisions has been those that favored process-integrated sustainability solutions over retrofitted or add-on solutions. For example, thermal power generation used end-of-pipe technologies such as selective catalytic reduction for NOx reduction and carbon capture and sequestration for CO_2 reduction. Later on, integrated process-centric solutions such as low NOx burners and oxy-combustion gained prominence for their cost as well as environmental efficiency. Another class of sustainability planning decisions is that which decides between centralization and distribution. In energy, centralized power generation often brings about economies of scale but the growing prominence of distributed generation not just favors renewable energy technologies but also reduces electrical losses by bringing generation closer to demand centers. Similar trends around these two classes of planning decisions continue to emerge in the other engineering systems mentioned previously. Despite computational challenges, the operations research community has often been able to formulate these decisions as multi-objective optimization problems and bring rigorous quantitative methods to their solution. Additionally, the environmental management community has evolved to include research themes in sustainability impact assessment and design for sustainability[7][8]. Increasingly, these works assume sustainability to be a ubiquitous responsibility within an organization rather than that of a single environmental management department.

Operations: Challenges in sustainability decisions at the operational time scale are driven by the need for timeliness and efficacy despite great complexity. Historically, energy and environment managers within enterprises have implemented closed-loop management systems based upon plan-do-check-act loops. However, as the need for sustainability grows, the number of decision criteria must also grow such that this closed loop must cycle increasingly fast. Additionally, the required measurement and monitoring becomes increasingly burdensome. Once acquired, this "Big Data" requires greater analytical effort for intelligent decision-making. To this effect, many enterprises are tending towards integrated control, automation and IT structures that support automated or semi-automated decision making. Most recently, sustainability resources planning (SRP) software has emerged from the familiar enterprises resource planning developed a decade ago. In the coming years, as these SRP solutions strive towards continual sustainability improvement, they will gain greater sophistication as they include methods from the operations research, artificial intelligence and data mining fields.

Conclusions: In summary, this issue on decision support in sustainability management addresses the continuing need for interdisciplinary research in sustainability. While many volumes are yet to be written on the topic, the issue does gather papers from three relevant research axes: types of decisions of variables, scope of organizational entity and life cycle phase. These axes loosely map on to the fields stated in the original call for papers:

- Sustainable development
- Sustainable operations management and research
- Social development for knowledge based economy
- Quality management and control for sustainable operations
- Environmental management
- Industrial ecology

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