Preparation2 Article: Systems Thinking

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The Need for Systems Thinkers in Engineering

As systems are becoming more interconnected and complex, demand for engineers who possess systems thinking is also increasing[1]. The US National Research Council[2] presented a framework for 21st century skills in science and engineering education—primary, secondary, and higher—which included systems thinking. Additionally, the ABET[3] 2025-2026 criterion 3 (student outcomes) for accrediting engineering programs mentions students must have the ability to produce engineering solutions while considering factors which require a systems perspective, namely global, cultural, social, environmental, and economic factors. Another testament of the need for system thinkers is that critically important skills for science, technology, engineering, and mathematics (STEM) disciplines, taken from the US Labor Department database[4], include systems analysis and systems evaluation.

What is a Technological (engineered) System?

While the definition of system is a subject of rich, ongoing academic debate[5], for the purposes of this class, we define a technological system, or system for short, as follows: a system is an entity composed of interacting parts. This entity delivers a predetermined function through its architecture, which is a combination of its structure and its behavior. The system's function is realized through interactions of the system parts, both internally and with the system's environment; these interactions can be explained by cause-and-effect relationships. Some whole-system properties vary from those of its individual parts. The purpose of a system is to deliver a predetermined benefit to specific group/s of humans—the system's beneficiaries. The system's purpose is achieved through its function[1,6-9].

What is Systems Thinking in Engineering?

Systems thinking is a higher-order thinking skill or set of skills which enable the identification, understanding, prediction, and improvement of every aspect of a technological system: purpose, function, structure, and behavior, and the way these aspects interrelate within the system[1,6-7].

The SAFO Framework: Systems Thinking for Technological Systems

The *system architecture-function-outcome* (SAFO) framework was designed for introducing first-year engineering students to systems thinking about technological systems in any domain. SAFO captures the definition of 'system' given above. Initial validations of the framework have been published in peer-reviewed works[10].

The framework uses distinct terms for the parts of a system (structure) and the relations & interactions between those parts (behavior). This allows for making clear distinctions between static and dynamic parts of a technological system[7].

SAFO also distinguishes between a system's *function* and its *outcome* (similar to *purpose*), both emergent aspects of technological systems. While *function* represents the interaction of the system (as a whole) with other entities or systems (technological or otherwise) in its immediate environment, *outcome* represents the effect of the system function on people. The system outcome in SAFO includes the problem being solved by the system's intended function as well as the group/s of people affected by it, thus explicitly including the human element in the description of a technological system.

SAFO's simplicity, coupled with its capturing of the essential aspects of technological systems, allows for the description and improvement of technological systems and for the assessment of conceptual understanding and of personal attitudes concerning these systems. It should be noted that as an introductory framework meant for first-year engineering students, the SAFO framework does not address attributes of system complexity[11].

Figure 1 shows the aspects and components which comprise the SAFO framework for technological systems.

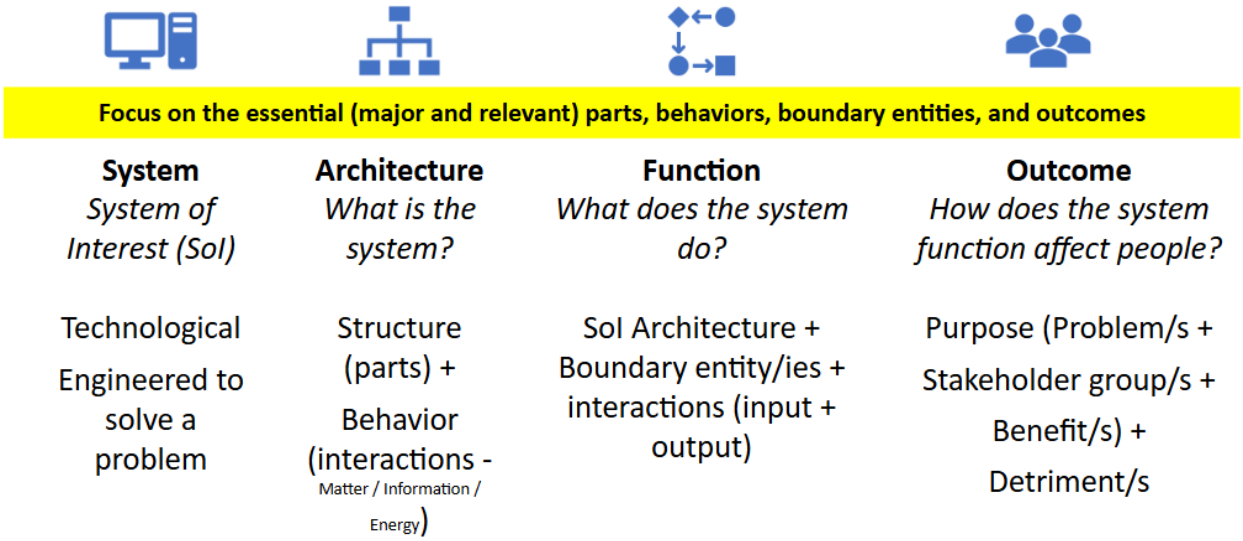

Figure 1. The *System Architecture-Function-Outcome* framework overview.

Figures 2 and 3 describe a bicycle using the SAFO framework.

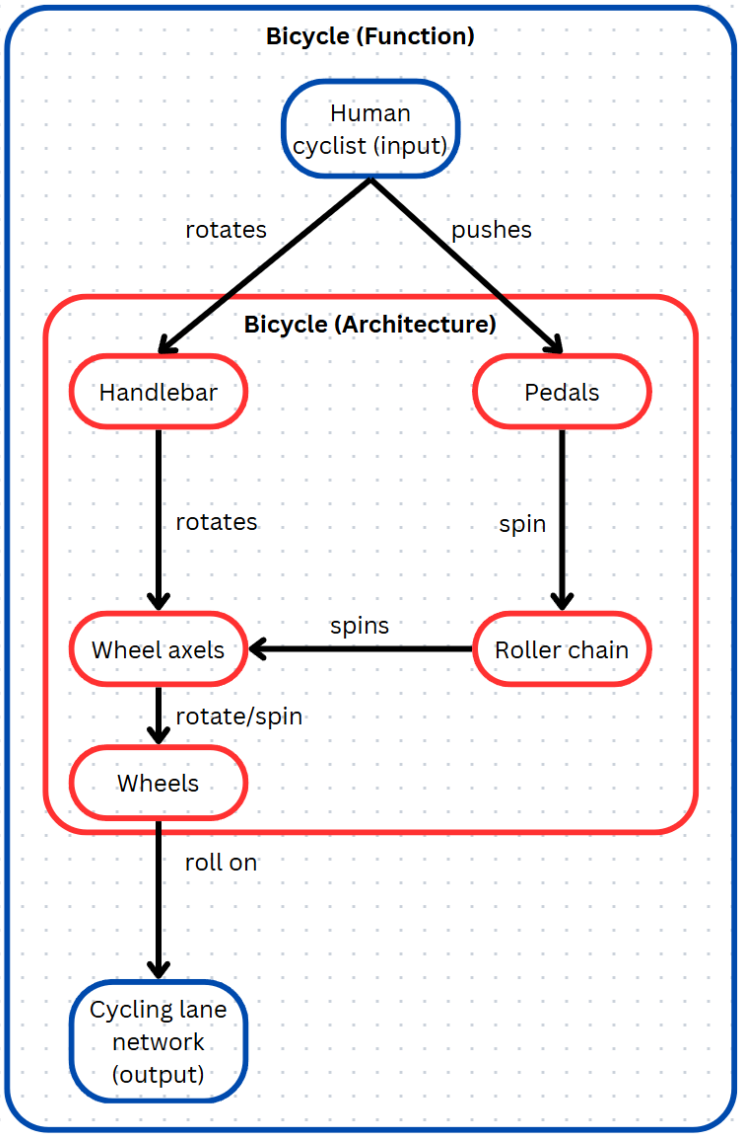

Figure 2. The *System Architecture-Function-Outcome* framework applied to a bicycle, showing the system's architecture and function. Red borders: system of interest. Blue borders: boundary system.

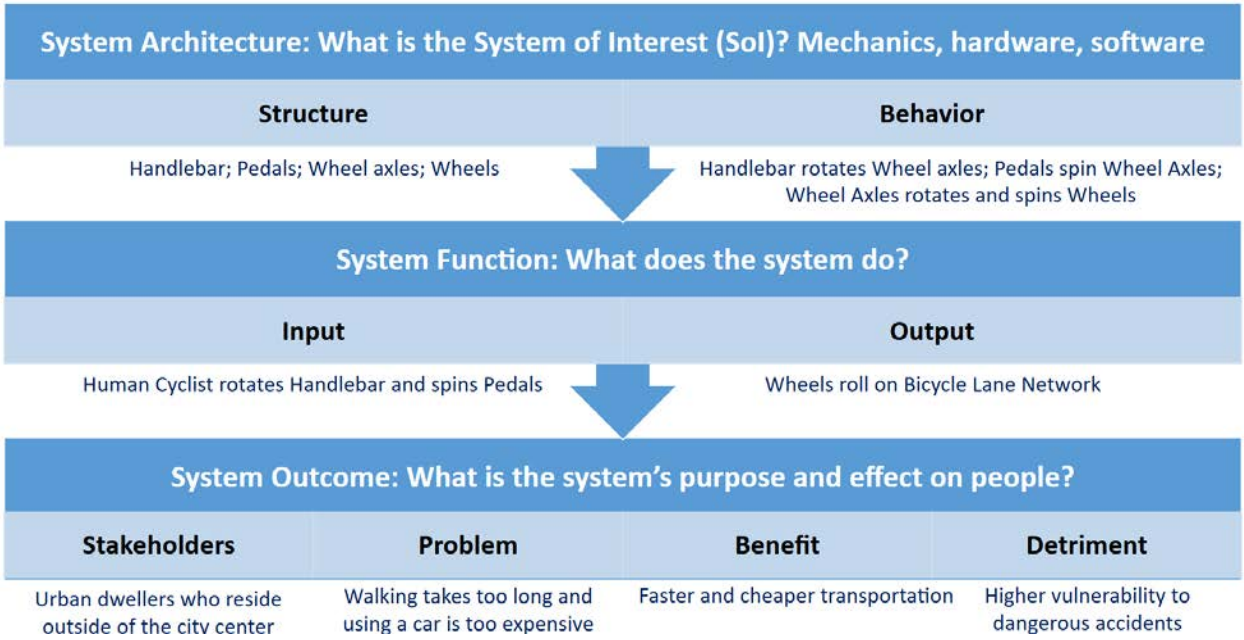

Figure 3. The *System Architecture-Function-Outcome* framework template applied to a bicycle. Red font: system of interest. Blue font: boundary system.

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