Defining Sustainment for Engineered Systems – A Technology and Systems View

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Abstract: Sustainment and sustainability are concepts that have pervaded recent engineering culture. Although the popular media often associates sustainability with environmental and socio-ecological constructs, it is a widely used and understood concept with application to many technology, system and business areas that extend beyond a socio-ecological context. This paper discusses the usage of the term sustainment, proposes a general definition of sustainment that conflates ecological, social, political, economic and technological interests, and provides recommendations that broaden the perspective.

Keywords: sustainment, sustainability, resilient systems, triple bottom line, sustainment-dominated, technology

1 Introduction

Sustainability and its variants have captured the interest of engineering (and other disciplines) for several decades, with a variety of inferences. It is not uncommon for non-technical communities to exclusively associate "sustainment" and "sustainability" with environmental sustainability.[1] However, sustainment and sustainability are concepts that are much older and broader than the environmental context that the popular media most often relates them to. Even though sustainability and sustainment are sometimes used interchangeably, these words have unique connotations that depend on discipline in which they are used. Our objective for this paper is to define sustainment for engineered complex systems. Before we discuss a general definition, let's look at the most prevalent usages:

> *Environmental Sustainability* is "the ability of an ecosystem to maintain ecological processes and functions, biological diversity, and productivity over time" [2]. The objective of environmental sustainability is to increase energy and material efficiencies, preserve ecosystem integrity, and promote human health and happiness by merging design, economics, manufacturing and policy.
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> *Economic (Business or Corporate) Sustainability* refers to an increase in productivity (possibly accompanied by a reduction of consumed resources) without any reduction in quality or profitability. Business sustainability is often described as the triple bottom line (3BL) [3]: financial (profit), social (people) and environmental (planet). Closely related is "sustainable operations management", which integrates profit and efficiency with the company's stakeholders and the resulting environmental impacts [4].
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> *Social Sustainability* is the ability of a social system to indefinitely function at a defined level of social wellbeing [5]. Social sustainability has also been defined as "a process for creating sustainable, successful places that promote wellbeing, by understanding what people need from the places they live and work" [6]. Social sustainability is a combination of the physical design of

[1] Wikipedia provides an index of "sustainability articles" [1] with over 350 alphabetized topics all of which are in the socio-ecological sustainable development realm. Not a single topic included in the Wikipedia index addresses technology-oriented sustainability.

places that people occupy with the design of the social world, i.e., the infrastructure that supports social and cultural life.

Technology or System Sustainment refers to the activities undertaken to: a) maintain the operation of an existing system (ensure that it can successfully complete its intended purpose), b) continue to manufacture and field versions of the system that satisfy the original requirements, and c) manufacture and field revised versions of the system that satisfy evolving requirements [7]. The term "sustainment engineering" is sometimes applied to technology sustainment activities and is the process of assessing and improving a system's ability to be sustained by determining, selecting and implementing feasible and economically viable alternatives [8].

Of course many specialized uses of sustainability exist,[2] which overlap into one or more of the categories above, including: urban sustainability, sustainable living, sustainable food, sustainable capitalism, sustainable buildings, software sustainment, sustainable supply chains, and many others. Some attempts have been made to merge sustainability concepts into larger frameworks. For example, environmental sustainability is often folded into a larger socio-ecological sustainment construct usually referred to as sustainable development that is comprised of ecology, economics, culture/social and politics dimensions (sometimes referred to as "circles of sustainability" [10]). Of the four types of sustainability we have chosen to highlight above, all can be reasonably included under the sustainable development umbrella except for technology and system sustainment, which we will address in Section 3.

2 A General Sustainment Definition

Both sustainment and sustainability are nouns. Their common definitions are a bit different, sustainment is the act of sustaining something, i.e., determination and execution of the actions taken to improve or ensure a system's longevity or survivability; while sustainability is the ability to sustain something or a system's ability to be sustained. Setting the dictionary aside, what do we really mean?

The word *sustain* originates from the Latin word *sustenare*, which is defined as "to hold up" or "to support". Today, *sustain* is defined as keeping a product or system going or to extend its duration [11]. The most common modern synonym for *sustain* is *maintain*. S*ustain* and *maintain* may be used interchangeably, however, maintaining most often refers to actions taken to correct problems, while sustaining is a more general strategic term referring to the management of the evolution of a system.

The first use of the word sustainability in the context of man's future was in 1972 [12,13], and the term was first used in a United Nations report in 1978 [14]. For the history of the origin and development of socio-ecological sustainability see, [15] and [16].

The best known socio-ecological definition of sustainability (attributed to the Brundtland Report [17]), is commonly paraphrased as "development that meets the needs of present generations without compromising the ability of future generations to meet their own needs." While the primary context for this definition is environmental (and social) sustainability, it has applicability to other types of sustainability. In the case of technology sustainment if the word "generations" is interpreted as the operators, maintainers, and users of the system, then the definition could be used to describe technology sustainment. Unfortunately, the concept of sustainability has been tailored by many groups to serve as a means-to-an-end in the service of special interests and marketing.[3]

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[2] There are also other common usages that are not particularly relevant to engineered systems, for example sustainment and sustainability are used as a general programmatic/practice metric; "sustainability" is a term used to refer to what happens after initial implementation efforts (or funding ends) where sustainability measures the extent, nature, or impact of adaptations to the interventions or programs once implemented, e.g., in health care [9].

[3] As aptly stated by one blogger: "The word 'sustainability' has been evacuated of any substantial meaning it may once have had. It's been appropriated by a ragbag of 'green-washing' market interests, opportunists and political

Going to the other end of the spectrum: The US Department of Defense defines sustainment in related but different ways. One definition is "the provision of logistics and personnel services necessary to maintain and prolong operations through mission accomplishment and redeployment of the force" [20].[4] In other words, sustainment provides the necessary support to operational military entities to enable them to perform their missions. The second, and perhaps more germane defense definition, is its use in the systems acquisition context. Once a system is developed and deployed the system operations and support phase consists of two major efforts "sustainment and disposal." How do these definitions relate to the design and production of systems? For many types of critical systems (systems that are used to insure the success of safety, mission, and infrastructure critical activities), sustainment must be part of the initial system design (making it an afterthought is a prescription for disaster – see Section 3).

In 1992, Kidd [15] concluded that "The roots of the term 'sustainability' are so deeply embedded in fundamentally different concepts, each of which has valid claims to validity, that a search for a single definition seems futile." Although Kidd was only focused on socio-ecological sustainability, his statement carries a kernel of truth across the entire scope of disciplines considered in this paper. Nonetheless, in an attempt to create a general definition of sustainment that would be universally applicable across all disciplines we developed the following. The best short definition of sustainment is the capacity of a system to endure. A potentially better, but longer, definition of sustainment was proposed by Sandborn [22]: "development, production, operation, management, and end-of-life of systems that maximizes the availability of goods and services while minimizing their footprint". The general applicability of this definition is embedded in the following terms:

- "footprint" represents any kind of impact that is relevant to the system's customers and/or stakeholders, e.g., cost (economics), resource consumption, energy, environmental, and human health;
- "availability" measures the fraction of time that a product or service is at the right place, supported by the appropriate resources, and in the right operational state when the customer requires it;
- "customer" is a group of people, i.e., individual, company, geographic region, or general population segment.

This definition is consistent with environmental, social, business, and technology/system sustainment concerns.

3 Technology and System Sustainment for Critical Systems

Critical systems perform safety-, mission-, and infrastructure-critical activities that create the transportation, communications, defense, financial, utilities and public health backbone of society. The cost of the sustainment of these systems can be staggering. For example the global maintenance, repair and overhaul (MRO) market for airlines is expected to exceed $100B per year by 2026 [23]. Amtrak has estimated its capital maintenance backlog (which includes physical infrastructure and electro-mechanical systems) in the US Northeast Corridor, alone, at around $21 billion [24]. The annual cost to operate and maintain the Department of Defense vast sustainment enterprise was over $170B in 2011 [25].

The critical-systems world defines sustainment-dominated systems as a system for which the lifetime support footprint significantly exceeds the footprint associated with producing it [7]. Where "footprint" has the same definition as in Section 2. For technological systems, "sustainment-dominated" creates a

hacks." [18]. Another source points out that corporate interests latched onto the word sustainable because they felt that it resonated with people, and as a result is has little real meaning now, [19].

[4] In the same reference [20], sustainment is carefully distinguished from logistics, which is "supply, maintenance operations, deployment and distribution, health service support (HSS), logistic services, engineering, and operational contract support". In this context, engineering supports the military commander with "the ability to execute and integrate combat, general, and geospatial engineering to meet national and Joint Force Command (JFC) requirements to assure mobility, provide infrastructure to position, project, protect, and sustain the joint force." [21]

distinction between high-volume, low-cost consumer products like cell phones, and complex, high-cost systems such as trains, airplanes, infrastructure, and military systems. Non-sustainment-dominated technological products, which tend to be high-volume, inexpensive products, have short manufacturing and operational lives – and therefore little investment in sustainment. Low-volume, long-life sustainment-dominated products, which are very expensive, have high sustainment costs.

The US Department of Defense (DoD), as a developer and user of many complex systems, has a detailed process for planning and implementation of system sustainment, that can serve as an exemplar. DoD uses a five step process for the development and production of hardware intensive systems [26]. These are: 1) Materiel Solution Analysis, 2) Technology Maturation & Risk Reduction, 3) Engineering & Manufacturing Development, 4) Production & Deployment, and 5) Operations & Support. This last phase Operations and Support has two major applicable efforts, Sustainment and Disposal. As part of the development process, the system's program manager prepares a life-cycle sustainment plan; this plan is the basis for of all of the activities conducted to support the system's sustainment. Within this context, sustainment is used synonymously with product support. Sustainment, then is comprised of activities that fall within 12 broad-in-scope, multi-disciplinary Integrated Product Support Elements. These elements include [27]: "Product Support Management; Design Interface, Sustaining Engineering; Supply Support, Support Equipment; Packaging, Handling, Storage, and Transportation; Computer Resources; Manpower and Personnel; Maintenance Planning and Management; Training and Training Support; Facilities and Infrastructure; and Technical Data Management."

During the Operations & Support phase, the Program Manager will also measure, assess, and report system readiness using the approved "sustainment metrics, and implement corrective actions for trends diverging from the required performance outcomes" [26]. Finally, with changes to operational needs and fiscal constraints, technology advances, evolving threats, and process improvements, changes to the life-cycle sustainment plan are evaluated, and changes are made, to continue to provide the best value to the system's users.

A significant body of literature has been dedicated to the optimization of sustainment, i.e., identifying policies, methodologies, and application-specific actions that minimize the life-cycle cost, required resources and/or time required to support systems. A detailed discussion of these works is out of the scope of this paper, but it is important to note that these works vary in life-cycle scope (the portion of the life cycle of a system they focus on), the system scope (the portion of the system they focus on), and context scope (the context that the system is used within).

4 Going Forward

Sustainability is a "holistic" concept that demands that decisions by policy makers, programs/businesses and individuals are made in such a way as to ensure that the stakeholder's present needs are met while not placing the future wellbeing of the stakeholders at risk. Socio-ecological sustainability adds to this a shared responsibility of all parties to work together and to assess actions against their consequences for all stakeholders and the entirety of society.

Sustainment goes hand-in-hand with providing the framework for assuring the financial, security, and mission-success welfare of the enterprise, where the enterprise could be a population, company, or nation.

A pervasive problem faced by an increasing number of systems is that today, sustainment is usually only recognized as an organizational goal by the top layers of management after it has already impacted the bottom-line and/or mission success of the organization, which is too late. With the advent of increasingly complex systems that are embedded in everyone's daily lives, how do we change the sustainment culture so that it is part of system design and planning? Here are several actions that should be considered:

1) Sustainment isn't only an engineering problem. Engineering, public policy and business must come together in order to appropriately balance risk aversion with innovation and system evolution. In

the defense world this could be called “sustainment reform” (borrowing from the DoD’s “acquisition reform” coined in the 1980s).

2) Design for sustainability. In particular for sustainment-dominated systems, sustainment, and its impact on life-cycle costs, must be designed into systems from the beginning of the system’s development. Developing sustainment requirements and metrics, such as system availability, early enough so that the system design can be impacted, is as critical to a program's success as identifying requirements for cost, schedule, and performance; but, often does not receive the requisite attention.
3) Educate earlier and more broadly. Generally, universities are good at preparing students to design and create *shiny* new things, but the majority of students (even engineers) receive minimal exposure to the challenges of keeping systems going or the role that government policies often play in regulating sustainment.
    a. We need to educate students (engineering, public policy, and business) to contribute to the sustainment workforce.
    b. We need to “socialize” everyone – even socializing the students that will not enter the sustainment workforce helps because all of them will become customers or stakeholders at some level (tax payers, policy influencers, decision makers, etc.). The public has to be willing to resource the sustainment of critical systems.[5]
4) The broader concept of sustainment needs to be leveraged to create more resilient systems – resilience is more than just reliable hardware and fault tolerant software. Resilience is the intrinsic ability of a system to resist disruptions, i.e., it is the ability to provide its required capability in the face of adversity, including adversity from non-technological aging issues. Resilient design seeks to manage the uncertainties that constrain current design practices. From an engineered systems point of view, system resilience requires all of the following:
    - reliable hardware and fault tolerant software;
    - resilient logistics (which includes managing changes that may occur in the supply chain and the workforce);
    - resilient legislation or governance (rules, laws, policy);
    - a resilient contract structure; and
    - a resilient business model;

    while not causing harm or placing an undue burden upon the social and ecological footprint left by the system.

The world is full of complex systems (communications, transportation, energy delivery, financial management, defense, etc.). Because these systems are expensive to replace, they often become “legacy” systems.[6] At some point the amount of money and resources being spent on sustaining the legacy system hinders the ability invest in new systems, creating a vicious cycle in which old systems do not get replaced until they become completely unsustainable or lead to a catastrophic outcome.

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[5] One need look no further than the Washington DC Metrorail system, which is currently undergoing an expensive and painful overhaul due to many years of neglected maintenance caused by failure to implement a strategic sustainment plan (due, in large part, to a lack of effective governance, leading to the inability to make a useful business case to the supporting organizations and customers to fund its sustainment) [28].

[6] A legacy system is a system that is based on, or composed of, methodologies, processes, architectures, technologies, parts, and/or software that is out-of-date.

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