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Cross-disciplinary system value overview towards value-oriented design

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Abstract
Systems design methods should aim for systems creating value. The decision-making processes in system engineering struggle to optimize this objective; however, even though the traditional concept of system value as a purely economic metric is recognized as deficient, a well-defined and standard conceptualization of comprehensive system value is still lacking. This study set out to facilitate different stakeholders, involved in developing systems, with a broad perspective on value. We define the system value as the system's holistic impact, encompassing the multi-domain effects on processes, environments, and stakeholders. This inclusive view, to be used by practitioners designing systems and policies, is expected to update existing practices and enhance resulting systems. This paper renders an extensive review of value references in multiple domains, both in system engineering and external, non-engineering, disciplines, and sets the foundation for a revised framing of value in systems engineering. To enable future applications for systems optimization, system value is thoroughly characterized, including its dependency on internal and external factors. This research lays the groundwork for problem formulation of a system value measure, its application in system engineering methods, and further analysis of the subject, both for engineered and non-technical systems.

Keywords Multidisciplinary value analysis · System evaluation · System value · Value characteristics · Value-oriented design · Value-oriented systems engineering

1 Introduction

Throughout the history of humanity, the quest for value influenced principal decisions both on global and individual levels. While highly desirable and frequently applied as a 'principle used for evaluation' (Keeney 1992), value is also an abstract concept with ambiguous interpretations compromising its reliability and validity as a measure (Sánchez-Fernández and Iniesta-Bonillo 2007; Gallarza et al. 2011; Grönroos and Voima 2013; Reber et al. 2021).

From a systems engineering (SE) perspective, we pursue to design the best system we can, whereas, intuitively, the best is associated with the most valuable. Traditionally, the SE point of view on system value includes mainly functionality, performance, and cost components. These are measurable and convertible, as functionality and performance costs can be estimated. Additional perspectives on value, which should be highly influential on many phases of the design process, to create a system embracing all stakeholders' needs, are currently neither well characterized, nor deeply embedded in SE practical methods. These value components are complicated to define and measure, and their evaluation scales vary, causing immense difficulties to employ them in SE processes.

While challenging to specify, value is a fundamental property of any system, either engineered or not (Andersson and Johannesson 2019). We ascribe it to the secondary category of system's properties, as in contrast to a primary objective feature, such as size or weight, value is relative to the evaluator (Francesco and Paoletti 2022). This is only one of the multiple complications associated with the system value definition.

It has been observed that a value-focused thinking approach to the design process enhances the creation of new alternatives, guides strategic planning, and facilitates

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multi-stakeholders' decisions (Keeney 1992). Hence, the concept of system value should be instrumental throughout the system lifecycle, starting at the need identification and requirements elicitation, and up to the maintenance schedule planning and retirement. The following examples illustrate potential applications: (1) selection of preferred system design alternative, whether by the SE team or the customer, employing system value as leading criterion; (2) requirements analysis identifying major influences on the system value, mapping the requirements to focus on the architecture conceptualization and the detailed design phases; (3) design optimization, with system value serving as an objective function; (4) sensitivity analysis of the system architecture as a function of the design variables; if a minor modification in a certain component or attribute of the design causes a major change in the system value, it might lead to system architecture modification to eliminate the excess design sensitivity; (5) system value monitoring throughout the design process, impacting detailed design decisions and bridging the gap between the top-down systems engineering and the bottom-up detailed design; and (6) system maintenance and upgrade plan, to preserve high system value throughout the lifecycle.

Publications related to system value are organized mostly around value-driven design (Brown et al. 2009; Collopy 2009; Bertoni et al. 2018) and value-based requirements engineering, the latter originating mainly in software systems design (Hujainah et al. 2018). While these methods typically strive to optimize economic value, a recognition of a need for a more inclusive perception starts to permeate the SE community. It is observed that the evaluated systems encompass dimensions outside the technical horizon and the set of stakeholders is wider than was acknowledged in standard SE methods (Bertoni et al. 2019). The original formulation of the value-driven design (VDD) approach does not directly cover the assessment of the qualitative part of value and is strongly oriented towards mathematical optimization, rather than focusing on enhancing engineers' awareness of the multidimensional aspects of value, facilitating decision-making (Bertoni 2013). In recent years, the VDD reference to value has evolved to include qualitative intangible factors (Bertoni et al. 2018) along with a more inclusive set of stakeholders (Bertoni et al. 2019). The World Economic Forum (2020) states that the system value, driving the decisions on solutions for economic growth acceleration and clean energy transition, can no longer be the levelized cost of energy (LCOE), and a more holistic view, evaluating economic, environmental, social, and technical perspectives, should be applied. The Design Council (2020) establishes that the value of design cannot solely be captured by quantitative methods; however, an appropriate framework for holistic assessment of design value is still to be specified. NASA, while defining the system value as the worth of the system to a stakeholder, considering system capabilities and the system's lifecycle costs, claims that 'the best method of forming system value models is still an open research question' (Watson et al. 2020). INCOSE (2021) establishes the importance of integrated system value in design decisions and acknowledges the need for research on system value foundations. Whilst the gap is acknowledged, few published studies have systematically analyzed the general notion of system value.

Our goal is to facilitate the stakeholders, including the system engineer, with a wider perspective of the measure frequently determining the success of a system. As we find little in SE, we employ case-based reasoning (Kolodner 1992) and trespass (Hirschman 1981) to domains less familiar to us as engineers, to survey what other disciplines have been proposing. We discover differing views, all siloed in their world, suggesting that there is a general lacuna in the concept of the value of a system. This study seeks to shed light on the problem as a preamble to its future elaboration and resolution.

The contributions of this paper include: a structured review of value both in SE and in domains external to engineering, such as economics, health systems, legal services, and others; analysis of possible applications of these extrinsic value definitions to SE; system value characteristics' description, essential for an extended understanding of this measure and its future utilization; proposal of future research areas regarding system value in SE. Hence, the paper is organized as follows. Section 2 describes the methodology employed to perform the analysis of the 'value' term definition in SE and other disciplines. Section 3 summarizes the literature survey and brings a multifaceted view of 'system value'. Section 4 elaborates on the observed features of system value, including examples. Section 5 discusses the potential utilization of holistic system value definition and future research directions. Section 6 is devoted to conclusions.

2 Methodology

The objective of this study is to map the research area, by surveying the definition of 'system value' employed in diverse domains, including SE, learning the deficiencies, and identifying the challenges if they exist. The systematic mapping study method was found the most appropriate for this purpose. The main concern of this method is to provide a comprehensive overview of a particular subject and structure a research area while discovering existing trends and identifying the gaps (Petersen et al. 2015). An integrated literature survey method, demonstrated in Fig. 1, employing the principles presented in Petersen et al. (2008), was applied to provide an extensive outline of the 'value' term characterization

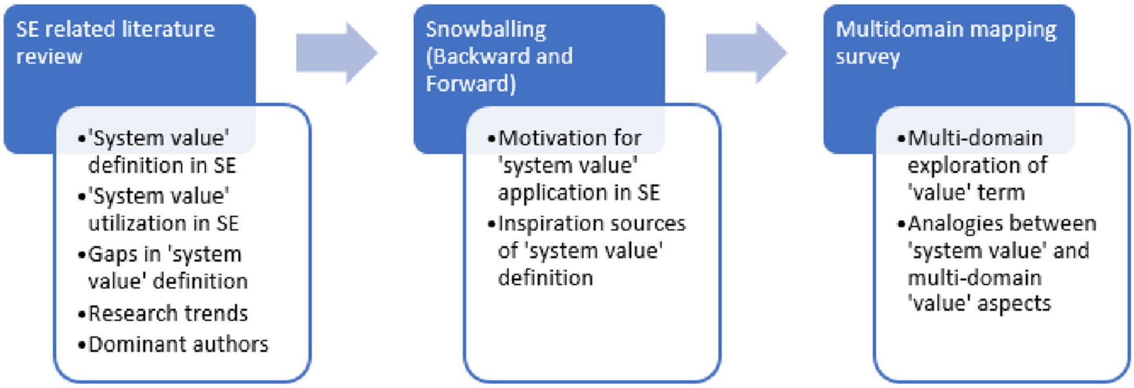

Fig. 1 Systematic mapping method interpretation employed in this study

and utilization in various areas. The results were later utilized to examine the possible analogies between the multidomain 'value' term and the 'system value' measure.

In the first phase of the mapping study, we conducted a literature review intended to gather evidence of the 'system value' measure application in SE. The review was performed by exploring various combinations of 'system' and 'value' keywords in systems engineering relevant literature. We performed an online search of electronic database resources, namely Google Scholar, IEEE Xplore, and SCOPUS, filtering the results relevant to systems engineering. Google Scholar delivered numerous results for "system value" and "system value definition" searches. Top relevant articles were chosen, leading mostly to Value Driven Design SE methods and specific energy systems design considerations. IEEE Xplore search concluded in 16 journal articles and 87 conference publications including reference to the "system value" term. At SCOPUS, we searched for the "system value" string in abstract, keywords, and title, returning 1499 results (the search was performed on September 2022). We then filtered only engineering and computer science relevant subjects, leaving us with 615 results. Applying filters, including the keywords "systems engineering" and "design", and English language articles, left us with 34 documents.

In the second phase, we performed a snowballing-based search, by inquiring about the references and the citations of the most relevant papers. Backward snowballing (Wohlin 2014), using the references, was performed to expand the knowledge base, to understand the motivation behind value measure utilization in SE techniques, and to learn about the inspiration sources of system value definitions in this field. Forward snowballing (Wohlin 2014) was employed to ensure the detection of the most recent publications on the subject.

The scarce results of these two phases led us to perform a mapping survey of additional domains, external or supplementary to SE. SE, being a socio-technical multi-disciplinary field, interfaces with many sciences, which provide a complementary view on the 'value' term. The third phase included a comprehensive search for value definitions in non-technological systems, such as health, education, and architecture, introducing new aspects of the value measure. Inspired by the ‘meta-analysis’ method, we also reviewed studies analyzing the perspective of specific or multiple domains on value. The purpose of this phase was to find analogies between the definition of value in external domains and the elusive 'system value' term.

The results of our survey are described in the following sections.

3 Multifaceted interpretation of value

A. Systems engineering perspective

When evaluating an engineered system, a successful system is defined as a system achieving the intended objectives while complying with the stated requirements (INCOSE 2019). While widely adopted, this perspective tends to ignore the numerous implications projected by the system and its related processes on the surrounding ecosystem. The system's holistic impact, accounting for the multi-domain effects on processes, environments, and stakeholders, can be called the 'system value'. A genuinely successful system is one designed to and achieving, some sense of optimal value. Hence, the main goal of SE should be to design optimal value systems. Nonetheless, the 'value' term is absent from the INCOSE (2019) formulation of SE definition, outlining it as a "transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods". Classic SE methods, such as the V-model (Forsberg and Mooz 1998) and the systematic approach (Pahl et al. 2007), also do not explicitly refer to value. The apparent reason is that traditional SE is a requirements-centric process aiming to maximize the fulfillment of the system's requirements (Ring 1998). Whereas highly desirable, it is not enough for optimal system design and might result in a considerable loss of value (Hazelrigg 1998).

Several modern SE methods aspire to utilize value to guide through the complex decisions and processes of SE. Some of these methods try to concretize the 'value' measure for a specific system, while others merely cite the ambiguous term, leaving the interpretation to the subjective reader and the expectantly competent implementer. Most of these methods refer to the economic perspective, neglecting additional, utterly influential, factors. The following paragraphs concisely describe these methods.

The value engineering (VE) approach has evolved due to the lessons learned during World War II. It aspires to optimize the design processes and the resulting products, to attain a return on investment (ROI). In this method, value is perceived as the relationship between the worth or utility of an item, expressed in monetary terms, and its actual lifecycle costs (Mandelbaum and Reed 2006; SAVE International 2021). The value analysis method for product platform design presents a customer-centered view of value, tailoring the VE approach to include both functional and intangible benefits (Colombo et al. 2020).

Following a route similar to classic VE, the surplus-value theory (Collopy 1997), based on a profit calculation for an industrial product, defines the surplus value of a system as a sum of the net present value of the total profit of all business stakeholders and deploys it as the optimization objective during the design process. The value-driven design (VDD) refers to 'value' as an objective function employed to compare design concepts (Collopy 2009). As VDD originates in the von Neumann–Morgenstern (vN-M) expected utility theorem, the objective function must satisfy the vN-M axioms, one of which is the ability to order the options according to their 'value' (Hazelrigg 1998). As a result, the value measure in the original VDD framework is a combination of system attributes converted into a comparable scalar score (Collopy and Hollingsworth 2011), in most cases conveying the monetary value of a system. Efforts to extend the 'value' measure into a multi-dimensional function, such as the one performed by the Northrop Grumman Corporation during the F6 DARPA program, do not align with the method's requirement for comparison and ranking (Collopy 2009). Additional series of papers addressing the multi-attribute utility theory application in design (Brown et al. 2009; Malak et al. 2009; Abbas and Cadenbach 2018) suggest quantifying the value measure and turning it into a one-dimensional utility function, once again mainly representing monetary value. However, as multiple aspects of the system's lifecycle are difficult to convert to monetary terms, the value concept in VDD-related methods has evolved in recent years, providing expanded and case-specific value definitions. The EVOKE method (Bertoni et al. 2018) expands the performance and monetary perspectives of the design option selection process by stating the value creation strategy and setting the value drivers, including the *ilities* and intangible factors, before mapping them into engineering characteristics. To include sustainability implications in early design space exploration, VDD principles are combined with sustainable product development (SPD) (Bertoni et al. 2020). In research on the VDD derivative of value-based development (VBD) common ground of value concept is created for engineering and business stakeholders by including both development efficiency, testing, and integration ability aspects along with cost and revenue (Panarotto et al. 2022). However, while the importance of intangible elements of value and inclusion of the wider range of potential stakeholders are acknowledged, the combination of quantitative and qualitative metrics in a single notion of value is still recognized as problematic (Bertoni et al. 2019).

Value-based software engineering (VBSE) and the derived value-based theory of systems engineering (VBTSE) aspire to integrate value considerations into the full range of software-related practices relevant to the complete lifecycle of a software product (Boehm 2006; Boehm and Jain 2006). The success-critical stakeholders' win–win theory, central to VBSE, is intended to map the important values and assure their successful realization. The notion of value in the theory is generic, rather than formulated in detail. The interpretation of the theory application is case-specific, referring both to economic value and stakeholders' satisfaction.

Value-based requirements engineering (VBRE), applying VBSE guidelines for requirements analysis, includes principles and practices for identifying the system's success-critical stakeholders; eliciting their value propositions concerning the system; and reconciling these value propositions into a mutually satisfactory set of objectives for the system (Boehm 2006). Existing VBRE approaches, combining requirements engineering methods and value definitions (Karlsson and Ryan 1997; Gordijn and Akkermans 2003; Azar et al. 2007; Herrmann and Daneva 2008; Kukreja et al. 2012), are adapted mainly to software engineering. The value concept in these methods is employed to select the requirements providing the highest ROI, either in satisfying customer needs or in financial terms. The prevalent criteria for prioritizing the requirements are their cost and importance to identified stakeholders, usually the customers (Hujainah et al. 2018). However, as the stakeholders' views are seldom complete, the result, although improving projects' success rates, does not optimize system value.

Lean system engineering (LSE) is an application of lean thinking principles to SE practices aiming to deliver systems with the best lifecycle value and minimum waste (SEBoK 2021). While classic lean thinking assumes that value should be defined exclusively by the ultimate customer (Womack and Jones 1996), studies in product development note that lean should be viewed as maximizing the inclusive value of all stakeholders, including the enterprise, employees, shareholders, etc. (Browning 2000). Value in LSE is defined as the delivery of a complex system satisfying all stakeholders, which implies a flawless product or mission, delivered at minimum cost, in the shortest possible schedule during the complete lifecycle (Oppenheim et al. 2011). An extensive literature review of lean complex product development (Siyam et al. 2015) noted several gaps in existing references to value, such as multiple dimensions considerations.

Product-service systems (PSS) comprise integrated solutions of products and services to generate value. The nature of PSS, enforcing long and tightly coupled relationships with the customer, requires an extended and evolving perception of system value (McAloone 2011). In recent years several design methods have emerged proposing an inclusive value proposition of PSS. For example, the engineering value assessment (EVA) (Rondini et al. 2020) assesses PSS B2B (business to business) scenario concepts in early design phases. This method details diverse generic value drivers while considering both providers and customers. Another example is the business, environmental, and social screening tool (BESST) (Sarancic et al. 2022), adopting a provider's point of view to support decision-making in PSS design while considering sustainable value potential over the complete PSS lifecycle. The value proposition of PSS should address multiple stakeholders involved in different lifecycle phases; however, many methods include only a partial group (Fernandes et al. 2019), impacting the completeness of the value proposition. PSS is also labeled as a circular economy tool aiming toward resource efficiency (Tukker 2015). It is acknowledged that the value concepts of circular PSS should include additional stakeholders and their perceived value aspects, reflecting experience, economic, social, and environmental components (Kristensen and Remmen 2019; Fernandes et al. 2020).

Several SE methods, analyzing requirements exceeding obligatory system functionality, propose an additional interpretation of value. In a decision support model managing over-specifications in development projects (Shabi et al. 2021), value is defined as the customer satisfaction gained by implementing the design requirement in a product. The criterion of over-specification is a value-to-cost ratio, enforcing subjective value quantification. Alternatively, in a method assuming that adaptability for future requirements increases the overall product value (Engel et al. 2017), an architecture adaptability value (AAV) metric is defined, expressing the difference between the benefits of the architecture options and the costs of the interfaces supporting them.

Research (Reich 1995) proposing evaluation of the knowledge embedded in an intelligent system concludes that the value measures are context- and system-dependent, and the construction of the value measure, resulting in understanding the system, has equal importance to the actual measurement of the value.

Modern SE methods' focus includes *ilities* properties, such as quality, flexibility, reliability, and safety, which are not the primary functionality and performance of a system, but concern extended system impacts and stakeholders (De Weck et al. 2011). The shift from the concern for immediate functionality to a wider perspective was one of the first steps to a more holistic evaluation of systems. Several studies attempt to quantify some of the *ilities* of a system, using social network analysis (Enos et al. 2019), or other, disperse methods (Turner et al. 2017). However, an all-inclusive system value model is still to be developed.

Studies applying the multidisciplinary system design optimization (MSDO) generally employ quantifiable value metrics as objective functions, such as total system cost and system downtime costs (Sternberg et al. 2015), or combine engineering and financial design to express value through performance, cost, and revenue (Markish and Willcox 2003). Some researchers integrate the MSDO approach with VDD, representing value as a monetary measure (Kannan et al. 2020).

Efforts to build a taxonomy of value from an engineering viewpoint, enabling decision-makers to consider the immediate and long-term contributions to value, concluded, once again, in a purely economic view, including only knowledge as partial intellectual capital (Nishimura and Fukuda 2019).

The value-sensitive design (VSD) approach (Friedman et al. 2009) aims to design technology accounting for human values, such as privacy, freedom from bias, universal usability, etc. This approach refers to 'value' as the aspects important to people in their lives, focusing on ethics and morality. VSD application includes conceptual mapping of the stakeholders and the implicated values affected by the design, empirical research validating these values with the actual stakeholders, and adaptation of the deployed technology to support the involved human values. A parallel segment, residing in the requirements engineering discipline, refers to values as personal attitudes or long-term beliefs, which may influence stakeholder functional and non-functional requirements, proposing a method to examine these socio-political issues during the requirements analysis (Thew and Sutcliffe 2018). The IEEE organization has addressed ethical values concerns during system design at the IEEE-7000 standard (IEEE 2021). The standard establishes the processes enabling ethical values consideration during concept exploration and system design.

Several papers performed extensive literature reviews attempting to map design methods utilizing the value measure.

A literature review on value ideas in complex systems product development revealed that although frequently mentioning value, product development and SE literature consider value from discrete perspectives and lack a coherent theoretical foundation (Siyam et al. 2015). A more recent review of engineering design methods (Bertoni and Bertoni 2019), explicitly referring to value as a measure employed for assessing design concepts, concluded that the existing value models are poorly defined, while the cost-effectiveness of highly specific monetary objective functions in the early stages of system design is doubtful. Another study, mapping value interpretations in product development literature (Reber et al. 2021), established that the value term is ubiquitously defined as 'an outcome in return for an input (e.g., cost)'.

Table 1 summarizes the value-based systems engineering methods surveyed in this section. Collectively, these methods outline the critical role of value in SE, while leaving holistic and comprehensive system value definition open.

B. Complementary perspectives external to SE

As value is an elusive concept in SE, we searched in other domains. Several publications performed a thorough survey of the value concept in the literature: presenting economics and philosophical references to value for marketing research purposes (Haase 2020), describing the evolution of value in economics (Mazzucato 2019), and outlining the influence of value on project management (Stewart and Stewart 2015). Surveying these, and other, field-specific, studies, this section presents a brief description of relevant references to value, possibly coinciding with system value characterization. We are aware that this is not an all-embracing review; however, it aims to be diverse and focused on domains with potential contributions to SE. The fields presented in this chapter are adjacent to SE or represent large-scale non-engineered systems, in which value definition is either widely adopted, such as in health or education systems, or still to be discussed, such as in legal services. As outsiders to these domains, we aspired to find reviews surveying the value definitions in the specific domain and supplying a general, rather than a case-specific, overview of the value term.

i. Economics

Economics, a social science analyzing the concept of value for hundreds of years, still debates the ultimate definition of value. David Ricardo, one of the most influential political economists, concluded two centuries ago that 'there is no such thing in nature as a perfect measure of value', meaning that there is no such thing as an invariable standard of value (Eatwell 2008). In his seminal work, 'The Wealth of Nations,' Smith (1776) defined value-in-use as the utility of a particular object, and value-in-exchange as the power of purchasing other goods, which the possession of the object conveys. Drawing an analogy to systems and SE, value-in-use can be interpreted as the value received by deploying the system, expressed either by the functionality, efficiency, and durability (Bos-De Vos, 2020) or by a financial profit for the operator. Value-in-use is subjective, therefore could be related to a perceived value-in-use and defined as the price the customer is willing to pay if there is a single source of supply (Bowman and Ambrosini 2002). This is relevant for systems aimed to be one of a kind or designed to serve a purpose defined by a specific customer, mainly System of Systems (SoS), such as a highway, a satellite, or smart city infrastructure. These systems are not designed to be traded in the market; hence, the features enhancing value-in-use of such systems should dominate their design process. By contrast, value-in-exchange represents what the system can be exchanged for, based on the price the person is willing to pay (Vargo et al. 2017). As the value-in-exchange is dependent on time and place, so is the financial value of the system. If the provided service is unique and essential, the system's financial value will increase, probably along with the profit.

Surplus-value represents the difference between the value of the product and the value of the elements consumed in the formation of that product (Marx 1887). The surplus value of a system is composed of the financial profit gained by all system's stakeholders through system's development and deployment, and the extra benefits evolving from system design or operation, serving goals external to the purpose of the specific system; for example, innovation, market share growth, or an unintended new capability facilitated by the system. The effort to increase the surplus-value of a system should be cautious, as every unessential feature adds either material, labor, or overhead, subsequently increasing costs, as well as potential undesired consequences. Value is lessened if the added cost does not improve the ability to perform the necessary functions (Stewart and Stewart 2015). Unproductive labor is a good illustration of value destruction when the resources are invested in creating features unvalued by customers, or in rework to fix features and repair the product at after-sale due to flawed design (Bowman and Ambrosini 2002).

The utility notion of value yielded from the subjective satisfaction derived from deploying the system (Bernoulli 1954), is the basis for cardinal and ordinal utility definitions. Cardinal utility is a quantitative approach, assuming utility can be measured numerically; while ordinal utility ranks preferences between choices, as the utility is claimed to be immeasurable (Hicks and Allen 1934). SE methods, based on value as an objective for design optimization, struggle with the need to quantify numerous aspects of value resulting either in neglect of abstract components or subjective quantization. Ordinal utility, enabling ranking of options, might be more suitable for SE decisions.

Table 1 Value-based design practices in SE

Method	Objective	Value definition
Value engineering (Miles 1972; Mandelbaum and Reed 2006)	Balance between performance and costs	Worth-to-cost ratio
Surplus value theory (Collopy 1997)	Maximizing profit for all stakeholders	Monetary value
Value driven design (VDD) (Hazelrigg 1998; Bertoni et al. 2020; Panarotto et al. 2022)	Design concepts comparison	Evolving from exclusive monetary value to a more inclusive model, encompassing evaluation of ilities and more intangible aspects
Value-based theory of system engineering (VBTSE)/ value-based software engineering (VBSE) (Boehm 2006; Boehm and Jain 2006)	General guidelines for reaching a Win–Win for all success-critical stakeholders at each step of the design process	Examples of specific and conflicting value propositions of the stakeholders
Value-based requirements engineering (VBRE) (Karlsson and Ryan 1997; Azar et al. 2007)	Selection of requirements for implementation	Current and future ROI (revenue vs. cost), monetary value
Lean system engineering (LSE) (Oppenheim et al. 2011)	Deliver systems with the best lifecycle value and minimum waste	Stakeholders' satisfaction during the complete lifecycle (system performance) vs. cost and schedule
Product service systems (Fernandes et al. 2020; Rondini et al. 2020; Sarancic et al. 2022)	Generate value by integrated solutions of products and services	The trade-off between benefits and penalties for provider and customer, evolving towards economic, social, and environmental aspects inclusion
Over specification management (Shabi et al. 2021)	Managing over specifications in system development	Value-to-cost ratio
Architecture adaptability value (AAV) Optimization (Engel et al. 2017)	Design for adaptability	The benefits of the architecture options vs. the costs of the interfaces, monetary value
Value sensitive design (VSD) (Friedman et al. 2009)	Design of technology that accounts for the human context	Human values (focus on ethics & morality)

Over the past few centuries, the definition of value evolved from an objective measure of the amount of labor required to produce a new object to a subjective value of useful goods and services, influenced by stakeholders' views and market forces (Mazzucato 2019). It keeps evolving, as a need for a 'paradigm shift' of economic analysis rises, requiring acknowledging the social, historical, political, and environmental context of economic behavior, and the feedback between individual decisions and societal dynamics (OECD 2020a). Value creation, in which different types of resources collaborate to produce new systems, depends on the quality of the system design and accompanying processes, on the deployment, including time and place, and on the interaction of constituent components generating functionality non-existent when operating separately.

ii. Business management

Similar to economics, value as a measure of business performance is no more a strictly financial term indicating profit (Drucker 2007, 2009). The value proposition of a business should include value for the customer, as well as value for the business itself, enabling, in its turn, sustainable creation of value for the customer (Osterwalder et al. 2014). Moreover, the modern perspective on business value in a digitally connected world, increasing the number of stakeholders for every system and gaining value opportunities, should be expanded to embrace the total, current and future, benefits for all partners in the ecosystem (Gassmann and Ferrandina 2021). These benefits include both tangible and intangible assets. Human, structural, and relational components of intellectual capital (IC) (Martín-de-Castro et al. 2011) are evident examples of intangible assets. Furthermore, positive environmental, social, and governance (ESG) propositions and reputation, while not always quantifiable, also have a positive effect on a company's overall value (Koller et al. 2020). While it is recognized that intangible assets are value drivers (Choong 2008), central to future value creation, and factors, such as employee know-how and reputation, contribute to business success (Hall 1992), the traditional accounting methods, employed to measure value, overlook its intangible aspects (Edvinsson 2013). To overcome this impediment, the value network analysis (VNA) methodology attempts to map the ways to transform the intangible assets of a business into a negotiable form of value, whilst acknowledging that in some cases, it is impossible or undesirable (Allee 2008). The value delivery modeling language (VDML), designed to provide a standard modeling language for analysis and design of an enterprise operation, specifically focuses on the creation and exchange of value (OMG 2018). It targets strategic planning through tangible and intangible value flow modeling. Nonetheless, although recognizing the intangible characteristics of certain value aspects, VDML still defines value as a measurable factor of benefit (OMG 2018).

Like SE, the business management community recognizes the need for a multi-dimensional representation of value, and while treating a system as a business unit, analogies can be drawn to include intangible factors into the system value.

iii. Innovation

OECD (2018) defines innovation as "a new or improved product or process (or a combination thereof) that differs significantly from the unit's previous products or processes, and that has been made available to potential users (product) or brought into use by the unit (process)", while value creation or preservation is the innovation's goal. The value of innovation lies in its impact on the market and underlying technologies, ranging from incremental innovation providing higher customer benefits per dollar to disruptive innovation introducing novel features to the customer or transforming markets (Edison et al. 2013).

From SE perspective, innovation is an instrument to create more value for the stakeholders, including individuals, institutions, entire economic sectors, and countries (OECD/Eurostat 2018).

iv. Axiology

Axiology, the philosophical study of the theory of value, examines the nature, types, and criteria of values (Merriam-Webster 2021). Commonly divided into the terminal, i.e., ultimate goals, and instrumental, i.e., means to reach the ultimate goals, these values are supposed to be ranked in order of importance and used as guiding principles in life (Rokeach 1973). The refined theory of basic human values (Schwartz et al. 2012) further extends the perspective on human values and identifies a comprehensive system of coherent values guiding the individual's attitude and behavior. The recognized values include: the freedom of thought and action, stimulation, hedonism, achievement, power dominance, power resources, public image, personal and societal security, tradition, compliance with rules, avoidance of harming others, humility, benevolence for others, dependability, and caring for equity, nature, and tolerance. As they drive the decisions making of individuals and groups, common views or apprehension of different perspectives are crucial for stakeholders of a system. Moreover, to perform efficiently, entire organizations must have aligned employees' values (Drucker 2009). Another aspect of values, guiding purchasing decisions of consumers, is thoroughly researched for marketing purposes. These values are classified into economic (extrinsic and self-oriented), social (extrinsic and other-oriented), hedonic (intrinsic and self-oriented), and altruistic (intrinsic and other-oriented) types (Holbrook 2006).

Observing a system, the instrumental values might be the means to create a system of optimal value, supplying the highest satisfaction to all stakeholders. The latter is the terminal goal. Moreover, we refer to the system value itself as an instrumental value leading the way to the ultimate goal of the system.

v. Construction

The “Vitruvian triad” of core architectural values are 'firmitas, utilitas, venustas', literally translated as structural integrity, utility, and beauty (Fisher 2016). The modern Design Quality Indicator (DQI), assessing the quality of construction projects, refers to these guidelines as build quality, functionality, and impact (Thomson et al. 2003). These can be further extended to six key areas of value: beauty, functionality, durability, suitability for the site and the community, sustainability as respect for the environment, and buildability (Emmitt 2006). It is acknowledged that value in construction should express outcomes relating to all areas, and consider all stakeholders, such as the society, construction industry, and more specifically, organizations, and projects (Devine-Wright et al. 2003). Data from several studies suggest that a good architectural design contributes substantially to economic and social value creation, e.g., productivity growth, recovery acceleration in hospitals, and crime rate reduction (Design Council 2002). Like other domains, construction relates to value as the relationship between the benefits that are obtained from an object to the sacrifices needed to achieve it (Thomson et al. 2003).

Inspired by architectural values in construction engineering, additional attributes of value in SE to be considered are the elegance of the system, feasibility, and applicability. The elegance of the system is subjective and might always be included in customers' satisfaction. The feasibility attribute is relevant in the requirements analysis phase, as it expresses the potential feasibility of the system's implementation and operation. Applicability is an imperative parameter of system value, stating whether the designed system could be applied to reach the declared system goals.

vi. Health systems

In recent years value-based frameworks play a key role in healthcare (Marzorati and Pravettoni 2017), later moving toward the concept of value-based health systems. In a competitive environment, and often from a provider's point of view, value is defined as the health outcomes achieved per dollar spent (Porter 2010), as long as the outcomes are not compromised by lower costs (Porter 2011). A different, and more recent, approach defines value as the contribution of the health system to collective or personal wellbeing (WHO 2020). Therefore, a unifying concept of health system value should align the perspectives of all actors participating in the healthcare process, e.g., patients, doctors, suppliers, and others (WHO 2020). Moreover, similar to the design and business management communities' perspectives, the customers' (patients) active involvement in the process increases the health system value (WHO 2021). A holistic view on healthcare value includes four pillars: technical—achieving best possible outcomes with available resources; allocative—equitable distribution of resources across all patient groups; personal—appropriate care to achieve each patient’s personal goals; and societal—contribution of health care to social participation and connectedness (EXPH 2019). An adjunctive definition of value in health systems includes the following dimensions: health improvement, responsiveness, financial protection, efficiency, and equity (WHO 2020).

The health system value is directly connected to efficiency, whether technical or allocative. Similarly, while designing a system, the effectiveness of features and requirements should be questioned concerning their contribution to overall holistic system value, and resources should be allocated to the ones contributing most to the system value. Two systems with an identical amount of resources may reach an immensely different level of value, depending on the issues the resources were invested in, analogously to the health systems.

vii. Legal services

Although the need for evaluation of legal services, as a tool for quality and efficiency improvement, is acknowledged (Carlson 1976), the legal industry still does not rigorously estimate their value (Linna Jr. 2021). The difficulty of value measurement (Chisholm 2018; Semple 2018) slows down the shift from the traditional time-based billing indicating the internal efforts of the law firm, to value-based pricing methods, reflecting the external value provided (Baker 2012). A recently presented value model for measuring legal services includes four main elements: effectiveness, affordability, client experience, and third-party effects (Semple 2018). Three metric types can express each: output, internal, and input. Output metrics measure the actual outcomes coinciding clients' satisfaction and the work products; internal metrics express the firm's processes, practices, and structure, dominating the prospect for high-value services delivery; and input metrics focus on the education and capabilities of the staff providing the legal services (Semple 2018). Additional references to the value of legal services emphasize the following elements: quality of work, cost-effectiveness, responsiveness and timeliness, results, alignment to business goals, service delivery, and diversity (Linna Jr. 2021). The "contract quality model" demonstrates the value of a product of legal services: speed and cost of contracting, evaluating the direct and indirect costs; financial and reputational risks; the current and future commercial impact of the contract; and overall alignment between parties predicting the probability of execution (Linna Jr. 2021).

Parallels to technological system's value could be drawn: the importance of expectations matching, the efficiency of the design process, the applicability and the performance of the resulting system, the system's effect on the society, and most important is the comprehension that only combination of these various aspects truly expresses system value.

viii. Educational systems

Evaluation frameworks are essential tools in designing educational systems and policies. Many studies have been conducted on educational system evaluation, including specific attributes and benchmarks on students' performance. To serve our goal of conceptual understanding of multi-domain evaluation processes, we choose to survey the principles of the generalized educational systems assessment method. The value of a specific policy is usually analyzed in three perspectives: educational attainment reflecting the human capital, equity and efficiency in the performance of the educational system itself, and externalities expressing the impact of the educational system on future aspects (Vos 1996). Each of the perspectives is analyzed using the following metric types: (i) input: measuring the invested resources, such as costs per student, or the pedagogical content; (ii) access: determining the accessibility of the services, such as distance to the educational facilities, or the ability to pay; (iii) output: measuring to what extent the immediate objectives of the educational system are achieved, such as achievement scores and completion rates; and (iv) outcome and impact: expressing the long term development goals, such as productivity and income of graduates (Vos 1996; OECD 2021). The quantitative measures are completed by contextualized qualitative analysis providing valuable information for system evaluation (OECD 2012).

The complexity of educational systems evaluation lies in the emergent character of their results, appearing in the distant future and influenced by multiple factors; hence, difficult to assess in the early stages of design. Both the technological and educational systems should be adapted to deal with present circumstances, while designed to face future challenges.

ix. Digitization

No modern review of value is complete without a reference to digitization and digital assets. Digitization and digitalization create more intangible assets, new sources of value (OECD 2020b), and potential for improved value capture. The industry 4.0 vision is a vivid example of digitalization creating value, making more for less, endorsing the ephemeralization principle (Buckminster Fuller 1963). Digital form assets, both tangible and intangible, can be defined as assets whose compromise will cause economic loss to its owning entity (Keyun 2019). Digital asset valuation models include: intrinsic value—consisting of the production costs and the direct conversion of the financial value of the non-digital equivalent of the asset; extrinsic value—expressed by the market price in a competitive market or usage value of a digital asset (how much the asset is shared or downloaded expanding the users' basis); subjective value—determined by the importance an entity places on the asset, and the price it is willing to pay; and opportunity value—expressed by the value of using the digital asset, compared to using the non-digital or nonexistent alternative (Keyun 2019).

Information, or data, can be considered as a category of digital assets (Keyun 2019). Data value has several attributes: intrinsic value—information's quality (accuracy, completeness, exclusivity); business value—the relevance of the data to a specific purpose; performance value—data impact on key business drivers; cost value—the implications of losing the data; market value—the exchange value of the data; and economic value—the contribution of the data to the economic value of the business (Gartner 2015).

Systems collect data. It could be a by-product of the system's operation or the whole purpose of the system. Whether it is fault tracing, usage patterns, production rates, or data recording during operation, data have value contributing to the overall system's value. This should be accounted for in evaluating system value, accompanied by the consequences of fulfilling this requirement. As always, every feature has costs and should be included only if its long-term value transcends them.

x. Summary

The bounded review described in this section establishes that multiple domains recognize the need for a conceptual shift from quantifiable, tangible, and mainly monetary measure of value to a more holistic and inclusive one. The journey is just in the beginning and there is a lack of well-defined and widely accepted models of value. Exploring domains external to SE uncovered new aspects of system value, and demonstrated the challenges present in holistic value definition. Table 2 summarizes the diverse interpretations of value among different domains.

4 System value characteristics

Although abstract and challenging to measure, system value can and should be characterized to enable future analysis and application. Since we classify value as a complex property of a system, it is in fact analyzable, owning structure and properties (Francesco and Paoletti 2022). Understanding the dependency of system value on external and internal factors will enable its adaptation, leading to system optimization.

Table 2 Concise summary of value concepts external to SE

Domain	Objective of value	Value definition and dimensions	System engineering implications
Economics	Analyzing worth and utility of goods and services	Value in use Value in exchange Surplus value	System value creation is a result of diverse resources collaboration. Unproductive labor invested in unnecessary features or faults repairs lessen system value
Business management	Measuring business performance	Financial capital Intellectual capital: Human Structural Relationship	A system has tangible and intangible aspects driving its value
Innovation	Assessing the contribution of innovation to social and economic goals	Customer benefits per dollar Novel features Transforming markets	Innovation is an instrument to create more value to the system's stakeholders
Axiology	Guiding principles of attitude and behavior	Ultimate goals Instrumental goals	System value relies on the instrumental values of the resources creating it. Value might even be created as a side effect of the design process leading to the ultimate system
Construction	Expressing outcomes relating to all areas and considering all stakeholders	Beauty Functionality Durability Suitability for the site and the community Sustainability Buildability	Applicability, feasibility, and elegance of a system should be included in system value attributes
Health systems	Aligning the perspectives of all participants	Health improvement OR Technical Responsiveness Allocative Financial protection Personal Equity Societal Efficiency	Efficient resources allocation results in technical efficiency
Legal services	Improving quality and efficiency	Effectiveness Affordability Client experience Third-party effects	Design process efficiency, system performance, system effect on the environment, and the society, all affect the system value
Educational systems	Designing educational policies	Educational attainment Equity Efficiency Externalities	System design performed at present circumstances should be adapted to future challenges
Digital asset	Evaluating digital assets	Intrinsic—production costs Extrinsic—market price Subjective—importance to a specific entity Opportunity—relative to analog version or non-existence	System value depends on alternative solutions to the problem the system is solving; therefore, it is context-dependent
Information asset	Evaluating information value	Data quality Business value Performance value Cost value Market value	Collected data adds value to a system

Throughout this section we present the features of system value, demonstrating their appearance in existing systems. This is a summary of value measure characteristics identified during the literature survey, combined with the ones derived from the authors' own experience.

(1) Context-dependent

System value is dependent on the context in which it is evaluated (Thomson et al. 2003, Vargo and Akaka 2012, Andersson and Johannesson 2019), specifically on the following aspects:

(a) *Time:* The value the system provides depends on the time it was designed and deployed; hence, it may be subject to change during its lifetime (van de Poel 2021). The technologies and the competencies available at the time the system is designed, and the intensity of the need at the time the system is deployed, have vast influence on the system value. An extreme example of time-variant value is of a system whose development lasts so long that it is no longer relevant. It could happen either if a competitor has released a product with equivalent properties, or if the feature is no longer required, such as a low-performance analog camera in a digital world. A possible application of time-based value measure is dynamic tasks scheduling, allocating more resources to the task providing the highest value at a specific point in time, e.g., during real-time system operation (Aldarmi and Burns 1999). The variable character of system value challenges its model definition and application. Nevertheless, the system designer should attempt to define the system value similarly to the system itself, to the best of his current knowledge and robust to future modifications.

(b) *Place:* The locations of the system's design, manufacturing, and deployment highly influence the resulting system value. Regulations, natural and human resources availability, and cultural attitudes endure substantial effects:

  (1) While the digitally connected world enables the global recruitment of experts, cultural diversity might influence the design process.
  (2) Using local raw materials in the manufacturing process eliminates the need for transfer, and increases system value by reducing systems costs and donating to sustainability.
  (3) Local ESG regulations might affect the financial value of the system along with its environmental effect.
  (4) Deployment location influences system value through workforce and materials resources required for system operation, the demand at the specific location, such as an irrigation system in the desert, the performance of the system at the specific environment, and the adaptivity of the system to its environment, e.g., the platform it is installed on.

(c) *Ownership:* system ownership can deliver financial or social value. Either it is the ensuing social status, the financial profit from providing the system services, or the organizational reputation in the eyes of potential employees and consumers. Consequently, the owner of the system affects system value. Whether it is the operational or business skills of the owner, his environmental awareness, or the stakeholders' trust in the owner's ability to deploy the specific system.

(d) *Intensity of the need:* whether temporary or permanent, local or global, emotional or physical, the intensity of the need for a system solving a specific problem extremely affects this system's value.

(e) *Ecosystem:* the surrounding ecosystem profoundly influences the system's value. The ecosystem embraces competing organizations, alliances, alternative solutions to the same problem, the state of the economy, availability of qualified operating personnel, society priorities, ESG requirements, etc. Ecosystem is an integrative term that might also include the aspects specifically mentioned before, such as time and place. However, the combined perspective of the comprehensive ecosystem along with the distinct focus on its components enables top-down and bottom-up integrative analysis of the context impact on system value.

(f) *Scenario:* just as system performance, so does its value depend on the operation scenario. A scenario differs from the aspects mentioned before, as it describes a specific state, including time, place, operators, users, and ecosystem situation. Scenario-based value can be perceived as a singular point in the context-based multidimensional value function. During the design process, the system value should be evaluated across various scenarios, including: several performance levels, variable functionality, diverse stakeholders' viewpoints, ecosystem states, and different phases in the system's lifecycle.

One of the major challenges in SE is to optimize the designed system value for each scenario and to adapt the system for its operating context. System engineers, designing long-lifecycle systems, should be aware of the expected context changes and aspire to design a system capable of evolving to maintain its value. The system's robustness only partially covers this capability, and value-focused SE is expected to provide new insights to system design.

A complementary perspective is system value optimization by adapting the context to the system. Sometimes, to increase a system's value, adjustments should be performed to the system's environment, ecosystem, or application,

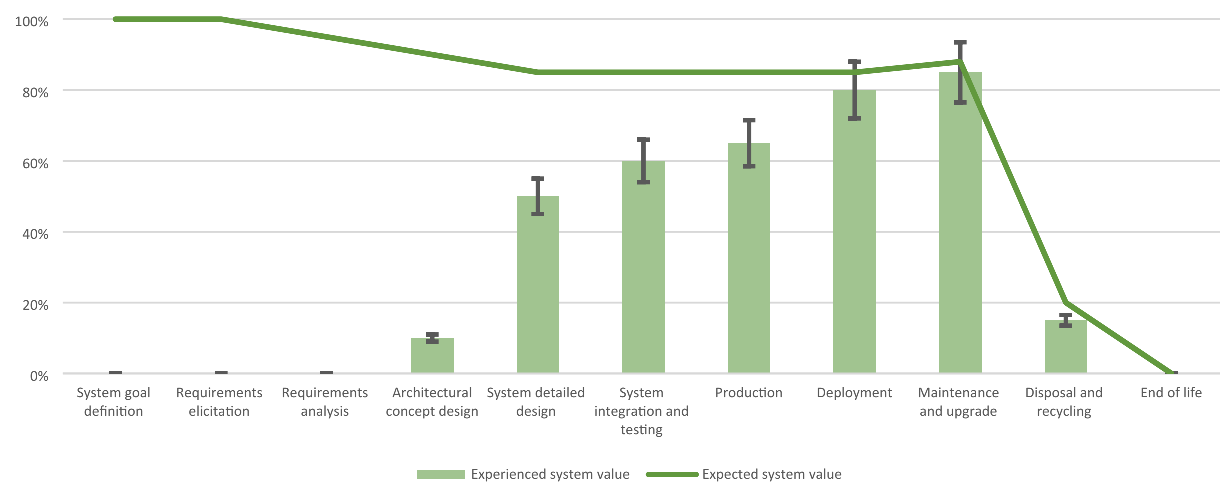

Fig. 2 Variability of system value lifecycle for an engineered product

rather than to the system itself (Williams 2019). This is an important viewpoint, as occasionally it is more cost-effective and valuable to modify the surroundings, rather than the system itself. The COVID-19 vaccination is a contemporary example. The vaccine ecosystem includes, among others: scientific research, development funding, FDA approval, massive infrastructure for rapid distribution, healthcare services, governmental policy, and public opinion. When first presented, COVID-19 vaccines required stringent environmental conditions, limiting their handling and distribution. Consequently, the difficulty to make the vaccines widely available weakened their value. The ecosystem adaptation, supplying suitable transport and storage facilities, and outlining allocation schemes to healthcare centers increased the vaccines' value. This practice demonstrates that optimal system value is the result of a balance between system design and ecosystem adjustment. To maintain optimal value, this collaboration should persist throughout the system lifecycle. In the COVID-19 vaccine case, research advancement enabled alleviating the vaccine storage conditions. FDA authorized undiluted thawed Pfizer-BioNTech COVID-19 vaccine vials to be stored in the refrigerator for up to one month, extending the previous five days restriction (FDA 2021). The ecosystem adjusted again, reducing vaccination costs, and enabling wider distribution, increasing the vaccine value.

Analyzing value in context is specifically significant for SoS, due to their protracted lifecycle. The users, the operators, and the constituent systems might vary, but the system must maintain its value through these environmental and contextual changes.

(2) Expected vs. Experienced

System value is both the goal we design for and the value the resulting system provides. Kahneman and Tversky (1984) distinguished between the 'decision value', perceived at the time the decision is made, and the 'experienced value', resulting from the actual outcome of the decision. In this paper, we use the terms 'expected' and 'experienced' system value. System engineers aspire for the maximal similarity between the two, interfered by uncertainty factors and risks, realized during the system lifecycle.

Based on our experience, Fig. 2 illustrates an example of the presumed variation of expected and experienced system values during the lifecycle of an engineered product, such as a motor vehicle. The expected ultimate system value is the target set at the goal definition and requirements elicitations phases. It starts to decline during the requirements analysis, as the constraints emerge, and information accumulates. The trend persists through conceptual and detailed design phases, as real-life difficulties arise. The manufacturing phase by itself should not affect the expected system value, as the scenarios, the difficulties, and the uncertainties should be considered and managed at previous phases; nevertheless, unexpected events could change this, for example, consider contemporary shortage in processors or various materials influencing production. The same applies to system deployment. Upgrade and maintenance of the system are expected to increase system value by adding new features, fixing design faults, and incorporating new technologies. After end-of-life disposal, the system value is annulled, or turned negative, for example, due to toxic waste. Oppositely, the experienced system value escalates with the design process progress, once fragments of the system materialize, such as source code or COTS sub-systems. The peak of system value is reached during the deployment or upgrade phases. The experienced value is anticipated to be lower than the expected value. However, occasionally, the experienced system value can overshoot the expected one. It can occur if the system's deployment is wider and more diversified than planned; the system's performance exceeds theoretical or simulated models; an upgrade based on new disruptive technology is introduced; or the eco-system alters, improving system value. The experienced value depends on multiple factors, such as operating personnel skills or updated governmental regulations, modifying its ratio to the expected value. This variability is illustrated by error lines on the bars representing experienced system value in Fig. 2.

The circular economy approach to products aspires to increase both the expected and experienced values of a system at the disposal and recycling phase aiming to maintain close to 100% value of the system or its components.

It could be argued that for some systems, such as the pharmaceutical industry products, a major part of system value prevails at the ideation phase resulting in a patent. This point of view is partially justified, as the patent has a value of its own, and when expired, other enterprises in the industry can manufacture the product, reducing the prices and making it more accessible, increasing the overall value of the product. Yet, from the product's perspective, this occurs at the production, deployment, or upgrade phases, so the value lifecycle variability demonstrated in Fig. 2 is valid also for this scenario, and the patent's value is the expected system value. If an idea or a patent are not realized, resulting in a product or a foundation for additional ideas, the system value will be low throughout the complete lifecycle.

(3) Emergent

System value emerges as a result of the external system-ecosystem interaction (Vargo et al. 2017), and the internal collaboration of systems components. In both cases, value is co-created by a collection of elements, either artificial, natural, or human. This is evident in the case of SoS in which emergent behavior (Maier 1998) implies emergent value. While each constituent system has a value of its own, the value of SoS is emergent, consequently sometimes difficult to determine. The constantly evolving Internet is a classic example of a system presenting value not anticipated by its initial designers, and nonexistent while separately analyzing the constituent systems and applications. The emergent characteristic of value can be further exemplified by open-source software whose value emerges through spontaneous collaborative development and adoption. In contrast to desired, even though unexpected, value, a contingent negative side effect of the system may substantially diminish its value. Revisiting the Internet example, illegal activity, such as cyber-attacks and fraud, abusing the capabilities of existing infrastructure co-creates negative emergent system value.

(4) Biased

System value evaluation is a matter of perception, therefore subjectively biased. The origin of bias and its effects have been extensively studied and are supported by well-established theories. The framing effect described in prospect theory (Kahneman and Tversky 1979) proves that the information presentation form influences decisions, creating bias. The expectation disconfirmation theory (Oliver 1980) determines that expectations set before performance have a major influence on satisfaction evaluation. Hence, the judgment of value is comparative to the evaluators' expectations, i.e., expectations create bias. In this respect, the perceived value depends on the perceived benefits of service versus the sacrifices made to use it (Boksberger and Melsen 2011). Furthermore, the value depends on the initial position of an asset, serving as the reference point, and on the magnitude of change in the benefits, such as wealth or welfare (Kahneman and Tversky 1979). The initial position depends on personal beliefs, experiences, expectations, and affinity to the issue at hand. These fluctuate between people, time, and situations, also causing biased evaluation of value. The following conclusion can be drawn from this paragraph: the value evaluation process should be profoundly designed, including evaluators selection, framing outline, and expectations matching.

(5) Qualitative and quantitative

The diverse aspects of system value cannot be captured by exclusively quantitative methods. Qualitatively analyzed values, such as vision alignment or knowledge development, should be recognized along with the more standard quantitative aspects, such as financial profit. Hence, a holistic assessment of value should comprise a combination of qualitative and quantitative techniques (Design Council 2020). Furthermore, as it could be difficult, up to impossible, to measure the value of a system directly, it is rather a relational property (den Ouden 2012). This approach supports Hicks and Allen's (1934) ordinal utility notion of value. Conversely, others claim that to provide holistic complementary perceptions for guiding decisions and creating design alternatives, the qualitative perspective should be employed when stating the system objectives, while the system value itself should be represented quantitatively (Keeney 1992). Summarizing the opposing opinions, system value has qualitative and quantitative complementary aspects. To enable value applications to optimize, compare, or rank methods, the holistic value representation should be conceptualized.

(6) Multidimensional

Previously described characteristics of value, such as qualitative and quantitative aspects, and its context-dependence, assuredly lead to concluding that value is a multi-dimensional measure. The dimensions of value may deviate to correspond to the specific issue at hand. Examples of such are presented in the previous section and summarized in

Table 2. As noted by the VDD pioneers, this characteristic of value obstructs ranking, frequently required for alternatives comparison (Collopy 2009). Although system value has multiple applications beyond ranking, value analysis frameworks should acknowledge its multidimensionality, and outline appropriate methods.

(7) Intrinsic and extrinsic

System value may originate from the system itself, intrinsic value, or from the system's interaction with external factors, extrinsic value. Existing research literature suggests alternative interpretations. Intrinsic value is what the system possesses in its own right as a goal, for example, aesthetics or elegance. Extrinsic value is instrumental, i.e., the means to reach some goal for a distinct beneficiary. Following this interpretation, exemplar extrinsic values are financial profit, efficiency, or training during the design process of a system. Some researchers claim that only an experience can have intrinsic value, the object, being the means to such an experience, having solely extrinsic value (Holbrook 1999).

While defining system value, following our definition of intrinsic and extrinsic, we categorize its components into the next intersecting categories: intrinsic value enablers, which are the system's qualities, such as performance, aesthetics, architectural elegance, or resilience; extrinsic value enablers, which include the ecosystem elements in general, such as the system's beneficiaries, market's supply and demand rates, organizational alliances, system designers, or operators. Both intrinsic and extrinsic value enablers could produce either product or process-related value. For example, process-related value could be engineers' qualifications for new technology deployment during system design, or customer engagement during the requirements elicitation phase. Product-related value could be fulfilling customer needs, efficiency, or reliability of the system. Some components of value can be ascribed to more than one category, e.g., the financial value of system deployment is enabled both by the system's internal qualities (intrinsic enablers) and by the consumers' willingness to purchase the system or its services (extrinsic enablers).

(8) Tangible and intangible

System value includes both tangible and intangible factors. Like business value, described in Sect. 3, the intangible drivers, although challenging to measure, are substantial contributors to overall system value. An example of intangible value could be a contribution to organizational reputation or culture, as a result of either the design process or ownership of the system. Tangible value components are typically physical or measurable, such as an efficiency boost or monetary profit.

The chord diagram presented in Fig. 3 summarizes the system value characteristics detailed in this section and their inter-relations. It is demonstrated that system characteristics are interdependent. The relations' mapping donates to the comprehension of system value and assists in applying value-oriented SE methods. For example, the relation between biased, expected/experienced, context dependent, and intrinsic/extrinsic characterizations of value implies that to minimize the gap between the expected and experienced system value, the requirements elicitation should be performed in controlled environment, including a diverse group of stakeholders, composed of agents representing intrinsic and extrinsic value enablers, presented with achievable performance of the system and the required sacrifices. Another example is the inter-dependency between multidimensional, tangible/intangible, and qualitative/quantitative characteristics, indicating that to compare design alternatives employing system value measure, a method either enabling quantification of an integrated measure of value or ranking each dimension separately should be proposed.

5 Discussion

This study set out to survey and characterize the 'value' term interpretation in diverse areas, intending to facilitate the SE community with a wider perspective of the term. One of the strengths of this study is that it represents a cross-disciplinary examination of references to value. The findings, described in previous sections, show that multiple domains acknowledge the superiority of value over other measures. Marketing experts urge businesses to move to value-based selling (Harri et al. 2012), modern economists movement argues for a novel holistic definition of value over purely financial worth (Mazzucato 2019), and even the conservative legal services industry strives for a pertinent value measure to replace the time-based billing (Baker 2012; Semple 2018). Similar to other domains, SE methods should support system design creating holistic value. This direction is recognized by the SE community and various methods, such as VDD-related approaches, gradually expand the stakeholders' views and the dimensions included in system value notion. The value lies in the foundation of evaluation processes; therefore, its definition should precede a system, a decision, or a design evaluation. Defining the expected value of a system answers the pivotal 'why' query, paving the way for further SE decisions answering the 'how' and 'what' questions. This sequence of thinking is also endorsed by the 'golden circle' theory (Sinek 2009).

The results of this study indicate that the SE discipline, while comprehending the critical role of value in SE

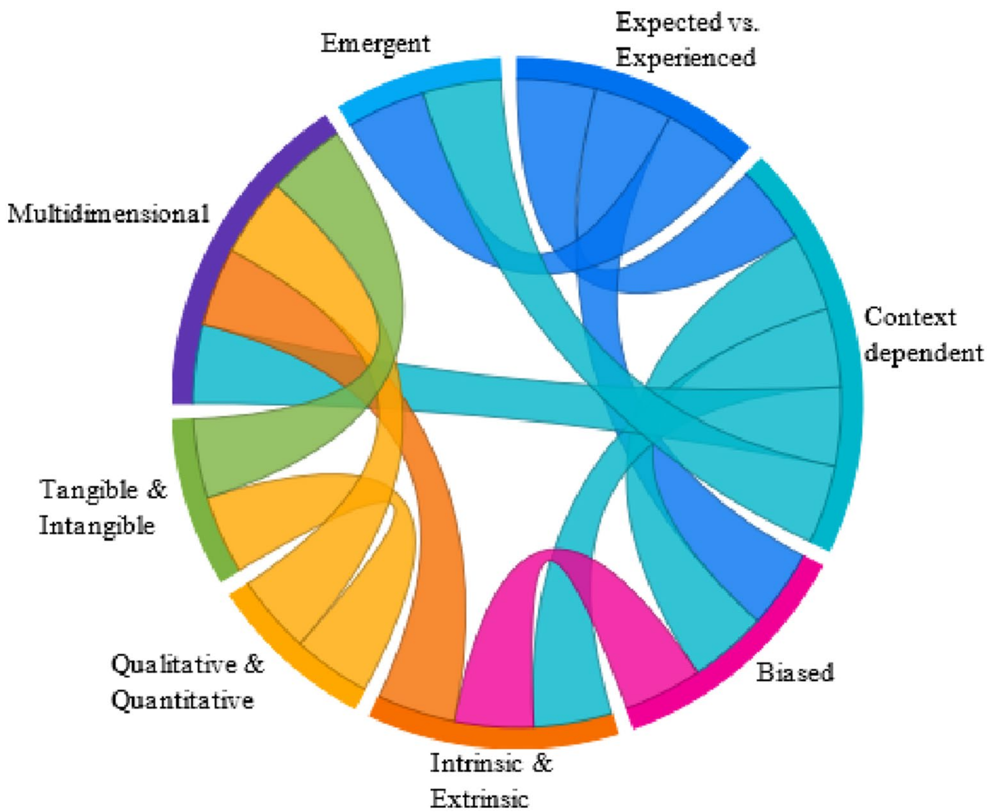

Fig. 3 System value characteristics relations

decisions and processes, still did not embrace a common holistic definition of system value. Concluding the literature survey performed in this research, we found several emerging value-based design methods agreeing on the imperative expansion of system value, defining either similar or complementary system value dimensions. However, in the scope of this literature survey we did not detect a general, rather than case-specific, system value model employed in multiple SE practices. Till now, the most common definition of value is the benefits received for the resources invested (Buckminster Fuller 1963; Thomson et al. 2003; Porter 2010; Reber et al. 2021). Furthermore, while resources are usually recognized as monetary costs, the benefits are either partial, subjective, or in dispute. Many domains confuse the partial representation of value, such as quality, financial worth, effectiveness, or customer satisfaction, with the complete notion of value (EXPH 2019; Teisberg et al. 2020; Linna Jr. 2021). As evaluations should not be focused solely on the outcomes, but also on the processes, structure, objectives, and unintended consequences (Stufflebeam and Coryn 2014), so should the system value reference these elements.

SE, being a socio-technical discipline, is highly influenced by political, cultural, and social trends. As the paradigm shift in value definition pervades multiple domains, starting to include aspects such as sustainability, personnel development, and others, the SE is obliged to follow by expanding the value scope beyond functionality, performance, and financial revenue. As a result, SE processes are inclined to change, involving a larger and more diverse group of stakeholders, and altering the decision-making by optimizing towards an inclusive value measure.

The SE discipline that normally strives for complete and unique definitions to plan an optimal system, struggles to provide a comprehensive system value characterization. A possible explanation for this might be that evaluating the value of a system can be classified as a 'wicked problem' (Rittel and Webber 1973; Conklin 2006). The value is subjective, since biased and differently evaluated by stakeholders; framing and context deeply impact system value; the criteria, constraints, and tools for system value evaluation are bound to change over time; there is no 'right' or 'wrong' value, and each system has a unique value; hence the evaluation problem is also exclusive. It can thus be suggested that the solution should start with a "mess formulation" describing the problem (Britton and McCallion 1994). It would include a systemic and synthesized view of system value. While the problem cannot be decomposed hierarchically, the overlaps enable to perform a triangulation of thought, verifying that no aspect is neglected, and revealing incoherencies if they exist. For example, analysis of value per ecosystem, references also the time and the place; or the emergency attribute of value might be included in the context-based feature.

The insights gained from this study may help to better understand the nature of system value and have a few important implications for future practice. It is recommended that further research be undertaken in the following areas:

(1) *System value model taxonomy:* as system value cannot be universally defined, and we assume there is a unique value proposition for each system in a particular context, further studies are needed to develop standard comprehensive taxonomy for system value models. Once defined, this taxonomy may serve as a foundation for outlining a specific and case-dependent system value model.

(2) *System value definition framework:* the roadmap to system value construction is vague. Inspired by the CMMI maturity models (ISACA 2021), we suggest creating a framework guiding system value definition. This framework could be used for processes and best practices development, enabling the definition of the system value model aligned with stakeholders' desires, capabilities, and the relevant context. This process-level framework is expected to improve both organizational capabilities and the resulting system value.

(3) *SE methods utilizing system value:* the main aim of system value is optimizing SE processes leading to high-value systems. A natural progression of current research is a retrospective analysis of existing SE methods and a proposal of revised, system value considering, procedures. One of the examples is a value-oriented requirements analysis method assorting requirements according to their impact on the holistic system value, as jointly defined by the stakeholders. Such method can be used to detect architecturally significant requirements substantially influencing the system value, avoid overspecifications (Shabi et al. 2021), and minimize negative value caused by excessive work.

(4) *System value accessibility for practitioners:* for evaluation to make a positive difference, in addition to being competently made, decision-makers ought to be value-oriented (Stufflebeam and Coryn 2014). To support this, the value model should be usable. Hence, we conclude that for practical applications, the system value measure would have to be quantified, including its qualitative aspects. 'Ordinal value', inspired by 'ordinal utility' (Hicks and Allen 1934), should be formed, at least for alternatives comparison purposes. Further research should be carried out to establish the quantification scheme and the resulting system value validation process.

(5) *Value-embedded model-based systems engineering (MBSE):* provision of system value support in MBSE could assist in constructing the system value model itself, and modeling the system value flow through SE processes; consequently, enhancing absorption of value in SE. Further studies are required to investigate this issue and develop relevant tools.

(6) *Generalizability of system value to domains external to SE:* Coming from the SE domain, we pursue to define value for technological systems and SE processes. Nonetheless, a holistic system value definition could be beneficial for additional disciplines. The generalizability of the findings of this study should be explored by experts in these fields.

6 Conclusions

The purpose of each decision and action is to create value either for the decision-maker or for the surrounding ecosystem. It is acknowledged that value-oriented thinking, in any domain, focuses the efforts, and contributes to better outcomes. Optimizing decisions, processes, and structures, when value serves as the objective function is bound to improve results. However, the definition of the value objective function is a major challenge.

The traditional concept of value as a purely economic measure, expressing the gains versus the costs, is outdated. While many disciplines strive to generate a domain-related definition, a holistic, generally applicable, and widely accepted, value model still does not exist. This applies and is further emphasized, for systems engineering. The system's holistic impact, accounting for the multi-domain effects on processes, environments, and stakeholders, can be called the 'system value'. A genuinely successful system is one designed to and achieving, some sense of optimal value.

The main contributions of this study are to highlight the significance of value definition in system design, present a cross-disciplinary review of the multifaceted perspectives on the value both of SE and non-engineering domains, describe the features of the system value measure, and lay the background for formulating system value definition. As has been demonstrated, it is a 'wicked problem', hence lacking a single correct formulation or a universal definition of value. We outline the complexity of the issue and lay the groundwork for further research on this subject, both for engineered and non-technical systems.

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References

Abbas AE, Cadenbach AH (2018) On the use of utility theory in engineering design. IEEE Syst J 12(2):1129–1138

Aldarmi SA, Burns A (1999). Dynamic value-density for scheduling real-time systems. In: 11th Euromicro Conference on real-time systems, York, UK, pp 270–277

Allee V (2008) Value network analysis and value conversion of tangible and intangible assets. J Intellect Cap 9(1):5–24

Andersson B, Johannesson P (2019) Ascribing exchange value. In: 13th International Workshop on Value Modeling and Business Ontologies, Stockholm, Sweden

Azar J, Smith RK, Cordes D (2007) Value-oriented requirements prioritization in a small development organization. IEEE Softw 24(1):32–37

Baker R (2012) Putting a price on the value of legal services. Lawyers Wkly 429:24–26

Bernoulli D (1954) Exposition of a new theory on the measurement of risk. Econometrica 22(1):23–36

Bertoni A (2013) Value driven design: a methodology for value-oriented decision making in preliminary design. Luleå University of Technology, Luleå, pp 1–32.

Bertoni M, Bertoni A (2019) Iterative value models generation in the engineering design process. Des Sci 5(e18), pp 1–22

Bertoni M, Bertoni A, Isaksson O (2018) EVOKE: A value-driven concept selection method for early system design. J Syst Sci Syst Eng 27(1):46–77

Bertoni M, Bertoni A, Murat Hakki E (2019) Value driven design revisited: Emerging modelling concepts and applications. In: ICED19, Delft, The Netherlands

Bertoni A, Hallstedt SI, Dasari SK, Andersson P (2020) Integration of value and sustainability assessment in design space exploration by machine learning: an aerospace application. Des Sci 6, pp 1–32

Boehm B (2006) Value-based software engineering: overview and agenda. In: Biffl S et al (eds) Value-based software engineering. Springer, Berlin, pp 3–11

Boehm B, Jain A (2006) A value-based theory of systems engineering. In: INCOSE, Orlando, FL, pp. 840–854

Boksberger PE, Melsen L (2011) Perceived value: A critical examination of definitions, concepts and measures for the service industry. J Serv Mark 25(3):229–240

Bos-De Vos M (2020) A framework for designing for divergent values. In: DSRS2020, Brisbaine, Australia, pp 39–53

Bowman C, Ambrosini V (2002) Value creation versus value capture: towards a coherent definition of value in strategy. Br J Manag 11(1):1–15

Britton GA, McCallion H (1994) An overview of the Singer/Churchman/Ackoff school of thought. Syst Pract 7(5):487–521

Brown OC, Eremenko P, Collopy PD (2009) Value-centric design methodologies for fractionated spacecraft: progress summary from phase 1 of the DARPA system F6 program. In: AIAA Space 2009 Conference & Exposition, Pasadena, CA

Browning TR (2000) Value-based product development: Refocusing lean. In: IEEE, Albuquerque, NM, USA, pp 168–172

Buckminster Fuller R (1963) Nine chains to the moon. Southern Illinois University Press, Carbondale

Carlson RJ (1976) Measuring the quality of legal services: an idea whose time has not come. Law Soc Rev 11(2):287–318

Chisholm J (2018) Remaking law firms. [Online] https://remakinglawfirms.com/why-and-how-to-switch-to-value-pricing/. Accessed 9 Oct 2021

Choong KK (2008) Intellectual capital: definitions, categorization and reporting models. J Intellect Cap 9(4):609–638

Collopy P (1997) Surplus value in propulsion system design optimization. In: 33rd Joint Propulsion Conference, AIAA, Seattle, WA, USA

Collopy PD (2009) Aerospace system value models: a survey and observations. In: AIAA Space, Pasadena, CA

Collopy PD, Hollingsworth PM (2011) Value-driven design. J Aircr 48(3):749–759

Colombo EF et al (2020) Value analysis for customizable modular product platforms: theory and case study. Res Eng Design 31:123–140

Conklin J (2006) Dialogue mapping: building shared understanding of wicked problems, 1st edn. Wiley Publishing, Chichester

De Weck OL, Roos D, Magee CL (2011) Engineering systems: meeting human needs in a complex technological world, 1st edn. MIT Press

den Ouden E (2012) Value from different perspectives. In: Innovation design: creating value for people, organizations and Society. Springer, London, pp 21-60

Design Council (2002) The value of good design. CABE, London

Design Council (2020) Moving beyond financial value. Design Council

Devine-Wright H, Thomson D, Austin S (2003) Matching values and value in construction and design. Aberdeen, UK, Robert Gordon University, pp 42–51

Drucker PF (2007) The practice of management. Taylor & Francis Group, London

Drucker PF (2009) Management challenges for the 21st century, E-Book. HarperCollins Publishers

Eatwell J (2008) Absolute and exchangeable value. In: Durlauf SN, Blume LE (eds) The new palgrave dictionary of economics, 2nd edn. Palgrave Macmillan, London

Edison H, bin Ali N, Torkar R (2013) Towards innovation measurement in the software industry. J Syst Softw 86(5):1390–1407

Edvinsson L (2013) IC 21: Reflections from 21 years of IC practice and theory. J Intellect Cap 14(1):163–172

Emmitt S (2006) Researching a value-based approach to design and construction. In: Proceedings of 3rd International Salford Centre for Research and Innovation (SCRI) Symposium, Delft, Netherlands, pp 65–77

Engel A, Browning TR, Reich Y (2017) Designing products for adaptability: Insights from four industrial cases. Decis Sci 48(5):875–917

Enos JR, Farr JK, Nilchiani RR (2019) Identifying and quantifying critical ilities in the acquisition of DoD systems. Defense A R J 26(1):18–43

EXPH (2019) Defining value in "value-based healthcare." European Commission, Brussels

FDA (2021) FDA in brief: FDA authorizes longer time for refrigerator storage of thawed Pfizer-BioNTech COVID-19 vaccine prior to dilution, making vaccine more widely available. [Online] https://www.fda.gov/news-events/press-announcements/fda-brief-fda-authorizes-longer-time-refrigerator-storage-thawed-pfizer-biontech-covid-19-vaccine. Accessed 8 Nov 2021

Fernandes SC, Martins LD, Rozenfeld H (2019) Who are the stakeholders mentioned in cases of Product-Service System (PSS) design? The Netherlands, Cambridge University Press, Delft, pp 3131–3140
Fernandes S, Pigosso DC, McAloone TC, Rozenfeld H (2020) Towards product-service system oriented to circular economy: a systematic review of value proposition design approaches. J Clean Prod 257:1–16
Fisher S (2016) Philosophy of architecture. In: Zalta EN (ed) The Stanford encyclopedia of philosophy, Winter 2016. Metaphysics Research Lab, Stanford University, Stanford
Forsberg K, Mooz H (1998) System engineering for faster, cheaper, better. INCOSE, Vancouver, pp 917–927
Francesco O, Paoletti MP (2022) Properties. In: Zalta EN (ed) The Stanford Encyclopedia of Philosophy, Spring 2022. Metaphysics Research Lab, Stanford University
Friedman B, Kahn PHJ, Borning A (2009) Value sensitive design and information systems. In: Himma KE, Tavani HT (eds) The handbook of information and computer ethics, 1st edn. Wiley, Hoboken, pp 69–101
Gallarza MG, Gil-Saura I, Holbrook MB (2011) The value of value: Further excursions on the meaning and role of customer value. J Consum Behav 10(4):179–191
Gartner (2015) Why and how to value your information as an asset. [Online] https://www.gartner.com/smarterwithgartner/why-and-how-to-value-your-information-as-an-asset. Accessed 15 Oct 2021
Gassmann O, Ferrandina F (2021) Connected business: create value in a networked economy. Springer, Cham
Gordijn J, Akkermans J (2003) Value-based requirements engineering: Exploring innovative e-commerce idea. Requir Eng 8(2):114–134
Grönroos C, Voima P (2013) Critical service logic: Making sense of value creation and co-creation. J Acad Mark Sci 41(2):133–150
Haase M (2020) Considering value-related concepts in service-oriented approaches to marketing studies in light of philosophical and economic value theories. J Serv Manag Res 4(2–3):133–144
Hall R (1992) The strategic analysis of intangible resources. Strateg Manag J 13(2):135–144
Harri T, Haas A, Eggert A, Ulaga W (2012) 'It's almost like taking the sales out of selling'—towards a conceptualization of value-based selling in business markets. Ind Mark Manag 41(1):174–185
Hazelrigg GA (1998) A framework for decision-based engineering design. J Mech Des 120:653–658
Herrmann A, Daneva M (2008) Requirements prioritization based on benefit and cost prediction: an agenda for future research. In: 16th IEEE International Requirements Engineering Conference, Barcelona, Spain, pp 125–134
Hicks JR, Allen RGD (1934) A reconsideration of the theory of value. Economica 1(1):52–76
Hirschman AO (1981) Essays in trespassing: economics to politics and beyond. Cambridge University Press
Holbrook MB (1999) Introduction to consumer value. In: Holbrook MB (ed) Consumer value a framework for analysis and research. Taylor & Francis Group, London, p 10
Holbrook MB (2006) Consumption experience, customer value, and subjective personal introspection: an illustrative photographic essay. J Bus Res 59(6):714–725
Hujainah F, Bakar RBA, Abdulgabber MA, Zamli KZ (2018) Software requirements prioritisation: A systematic literature review on significance, stakeholders, techniques and challenges. IEEE Access 6:71497–71523
IEEE (2021) IEEE Std 7000™-2021. IEEE Standards Association, New York
INCOSE (2019) Systems engineering and system definitions. INCOSE Publications Office, San Diego
INCOSE (2021) Systems engineering vision 2035. INCOSE, San Diego
ISACA (2021) CMMI Institute. [Online] Available at: https://cmmiinstitute.com/. Accessed 1 Dec 2021
Kahneman D, Tversky A (1979) Prospect theory: An analysis of decision under risk. Econometrica 47(2):263–292
Kahneman D, Tversky A (1984) Choices, values, and frames. Am Psychol 39(4):341–350
Kannan H, Mesmer BL, Bloebaum CL (2020) Incorporation of risk preferences in a value-based systems engineering framework. Syst Eng 23(2):237–257
Karlsson J, Ryan KT (1997) A cost-value approach for prioritizing requirements. IEEE Softw 14(5):67–74
Keeney RL (1992) Value-focused thinking: a path to creative decision making. Harvard University Press, Cambridge
Keyun R (2019) Digital asset valuation and cyber risk measurement, 1st edn. Elsevier Science & Technology, Saint Louis
Koller T, Goedhart MH, Wessels D (2020) Valuation: measuring and managing the value of companies, 7th edn. Wiley, Hoboken
Kolodner JL (1992) An introduction to case-based reasoning. Artif Intell Rev 6(1):3–34
Kristensen HS, Remmen A (2019) A framework for sustainable value propositions in product-service systems. J Clean Prod 223:25–35
Kukreja N, Payyavula SS, Boehm B, Padmanabhuni S (2012) Selecting an appropriate framework for value-based requirements prioritization. In: 20th IEEE International Requirements Engineering Conference, Chicago, Illinois, USA, pp 303–308
Linna DW Jr (2021) Evaluating legal services: The need for a quality movement and standard measures of quality and value. In: Vogl R (ed) Research handbook on big data law. Edward Elgar Publishing Limited, Cheltenham, pp 404–431
Maier MW (1998) Architecting principles for systems-of-systems. Syst Eng 1(4):267–284
Malak RJ, Aughenbaugh JM, Paredis CJJ (2009) Multi-attribute utility analysis in set-based conceptual design. CAD Comput Aided Des 41(3):214–227
Mandelbaum J, Reed DL (2006) Value engineering handbook. Institute for Defense Analysis, Alexandria
Markish J, Willcox K (2003) Value-based multidisciplinary techniques for commercial aircraft system design. AIAA J 41(10):2004–2212
Martín-de-Castro G, Delgado-Verde M, López-Sáez P, Navas-López JE (2011) Towards "An intellectual capital-based view of the firm": Origins and nature. J Bus Ethics 98(4):649–662
Marx K (1887) Constant capital and variable capital. In: Engels F (ed) The Capital, 1st English ed. Progress Publishers, Moscow
Marzorati C, Pravettoni G (2017) Value as the key concept in the health care system: how it has influenced medical practice and clinical decision-making processes. J Multidiscip Healthc 10:101–106
Mazzucato M (2019) The value of everything: making and taking in the global economy, 2nd edn. Penguin
McAloone TC (2011) Boundary conditions for a new type of design task: understanding product/service-systems. In: Birkhofer H (ed) The future of design methodology. Springer, London, pp 113–124
Merriam-Webster (2021) axiology. [Online] https://www.merriam-webster.com/dictionary/axiology. Accessed 2 Aug 2021
Miles LD (1972) Techniques of Value Analysis and Engineering, 2nd edn. McGraw Hill, New York
Nishimura S, Fukuda K (2019) Prototyping a taxonomy of value types. In: Graz, Austria, CEUR Workshop Proceedings
OECD (2012) Education system evaluation. In: OECD reviews of evaluation and assessment in education: Portugal 2012. OECD Publishing, Paris

OECD (2020a) Beyond growth: towards a new economic approach. OECD Publishing, Paris
OECD (2020b) Roadmap toward a common framework for measuring the digital economy, Saudi Arabia: Report for the G20 Digital
OECD (2021) Education at a glance 2021: OECD indicators. OECD Publishing, Paris
OECD, Eurostat, (2018) Oslo Manual 2018: Guidelines for collecting, reporting and using data on innovation. OECD Publishing, Paris
Oliver RL (1980) A cognitive model of the antecedents and consequences of satisfaction decisions. J Mark Res 17(4):460–469
OMG (2018) Value delivery modeling language (VDML). [Online] https://www.omg.org/spec/VDML/. Accessed 5 Mar 2021
Oppenheim BW, Murman EM, Secor DA (2011) Lean enablers for systems engineering. Syst Eng 14(1):29–55
Osterwalder A, Pigneur Y, Bernarda G, Smith A (2014) Value proposition design, 1st edn. Wiley, Hoboken
Pahl G, Beitz W, Feldhusen J, Grote KH (2007) Engineering design: a systematic approach, 3rd edn. Springer, London
Panarotto M, Isaksson O, Habbassi I, Cornu N (2022) Value-based development connecting engineering and business: a case on electric space propulsion. IEEE Trans Eng Manag 69(4):1650–1663
Petersen K, Feldt R, Mujtaba S, Mattsson M (2008) Systematic mapping studies in software engineering. GBR, BCS Learning & Development Ltd., Swindon, pp 68–77
Petersen K, Vakkalanka S, Kuzniarz L (2015) Guidelines for conducting systematic mapping studies in software engineering: an update. Inf Softw Technol 64:1–18
Porter ME (2010) What is value in health care? N Engl J Med 363(26):2477–2481
Porter ME (2011) What is value in health care? N Engl J Med 364(13):e26 (author reply)
Reber M, Duffy AH, Hay L, Whitfield RI (2021) ValueD: a model of cognitive value determination in design. J Eng Des 32(9):1–29
Reich Y (1995) Measuring the value of knowledge. Int J Hum Comput Stud 42(1):3–30
Ring J (1998) A value-seeking approach to the engineering of systems. In: IEEE International Conference on Systems, Man, and Cybernetics, San Diego, CA, USA, pp 2704–2708
Rittel HWJ, Webber MM (1973) Dilemmas in a general theory of planning. Policy Sci 4(2):155–169
Rokeach M (1973) The nature of human values. Free Press, New York
Rondini A, Bertoni M, Pezzotta G (2020) At the origins of product service systems: supporting the concept assessment with the engineering value assessment method. CIRP J Manuf Sci Technol 29:157–175
Sánchez-Fernández R, Iniesta-Bonillo MA (2007) The concept of perceived value: a systematic review of the research. Mark Theory 7(4):427–451
Sarancic D, Pigosso DC, Colli M, McAloone TC (2022) Towards a novel Business, Environmental and Social Screening Tool for Product-Service Systems (BESST PSS) design. Sustain Prod Consumption 33:454–465
SAVE International (2021) About the value methodology. [Online] https://www.value-eng.org/page/AboutVM. Accessed 3 July 2021
Schwartz SH, Cieciuch J, Vecchione M, Davidov E, Fischer R, Beierlein C, Ramos A, Verkasalo M, Lönnqvist JE, Demirutku K, Dirilen-Gumus O, Konty M (2012) Refining the theory of basic individual values. J Pers Soc Psychol 103(4):663–688
SEBoK (2021) Lean engineering-SEBok. [Online]. https://www.sebokwiki.org/wiki/Lean_Engineering. Accessed 18 Sep 2022
Semple N (2018) Measuring legal service value. Univ Br Columbia Law Rev 52(3):943–1006
Shabi J, Reich Y, Robinzon R, Mirer T (2021) A decision support model to manage overspecification in system development projects. J Eng Des 32(7):323–345
Sinek S (2009) Start with why, 1st edn. Portfolio/Penguin, New York
Siyam GI, Wynn DC, Clarkson PJ (2015) Review of value and lean in complex product development. Syst Eng 18(2):192–207
Smith A (1776) The wealth of nations, 2nd edn. Harriman House LTD, Petersfield
Sternberg D, Chodas M, Jewison C, Jones M, De Weck O (2015) Multidisciplinary system design optimization of on orbit satellite assembly architectures. In: Big Sky, Montana, USA, IEEE, pp 1–14
Stewart RB, Stewart RBJ (2015) Value optimization for project and performance management, 1st edn. Wiley, Hoboken
Stufflebeam DL, Coryn CL (2014) Evaluation theory, models, and applications, 2nd edn. Wiley
Teisberg E, Wallace S, O'hara S (2020) Defining and implementing value-based health care: a strategic framework. Acad Med 95(5):682–685
Thew S, Sutcliffe A (2018) Value-based requirements engineering: method and experience. Requir Eng 23(4):443–464
Thomson DS, Austin SA, Devine-Wright H, Mills GR (2003) Managing value and quality in design. Build Res Inform 31(5):334–345
Tukker A (2015) Product services for a resource-efficient and circular economy—a review. J Clean Prod 97:76–91
Turner AJ, Monahan W, Cotter M (2017) Quantifying the ilities: a literature review of robustness, interoperability, and agility. In: Madny AM, Boehm B, Ghanem RG, Erwin D, Wheaton MJ (eds) Disciplinary convergence in systems engineering research. Springer International Publishing, Cham, pp 1035–1049
van de Poel I (2021) Design for value change. Ethics Inf Technol 23:27–31
Vargo SL, Akaka MA (2012) Value cocreation and service systems (re)formation: a service ecosystems view. Serv Sci 4(3):207–217
Vargo SL, Akaka MA, Vaughan C (2017) Conceptualizing value: a service-ecosystem view. J Creat Value 3(2):1–8
Vos R (1996) Educational indicators: what's to be measured? IDB, Washington DC
Watson MD, Mesmer B, Farrington PA (2020) Engineering elegant systems: postulates, principles, and hypotheses of systems engineering, Huntsville, Alabama, USA
WHO (2020) Building on value-based healthcare. World Health Organization, Copenhagen
WHO (2021) From value for money to value-based health services: a twenty-first century shift. World Health Organization
Williams T (2019) Product ecosystems. Queensland University of Technology, Queensland
Wohlin C (2014) Guidelines for snowballing in systematic literature studies and a replication in software engineering. In: Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering, London, UK, pp 1–10
Womack J, Jones D (1996) Lean thinking : banish waste and create wealth in your corporation. Second Edition, 2003rd edn. Free Press, Simon & Schuster Inc., New York
World Economic Forum (2020) System value. [Online]. https://www.weforum.org/projects/system-value. Accessed 1 July 2021