Author 1	Author 2
First name: Joshua Last name: Sutherland	First name: Marc-Andre Last name: Chavy-Macdonald

Common details:
University affiliation: Department of Systems Innovation, Graduate School of Engineering, the University of Tokyo Supervisor: Prof. Kazuhiro Aoyama

1. Audience, Purpose and Summary

This document is written for the executive board of a large US automaker. It aims to offer guidance for navigating the next 15 years with regard to embracing new technology, engaging with the research community and thriving as world leader in the design and delivery of complex systems.

This paper is divided into three core sections. In Section 2 the scene is set regarding the concerns, fears and opportunities the industry faces, Section 3 describes *Vision 2030*, illustrating a successfully transformed enterprise in 2030 and Section 4 provides research directions which if taken and applied can contribute to the transformation into *Vision 2030*.

2. Current Concerns, Fears and Opportunities

Much of the mass media and industry publications are filled with descriptions of disruptive technologies and business models which being released or are predicted to be over the next 10 years. Including self-driving cars, virtual reality, artificial intelligence, electric cars, product sales being replaced with rental services and emerging countries upskilling industrial capacity.

While for some such news is exciting and holds promise for a future filled with abundance [1] it can be alarming for large enterprises highly optimized around a specific business model to see their entire business model challenged by new entrants - e.g. Silicon Valley vs. Detroit [2]. However these worries and threats can be reframed as excitement and opportunity.

Given it is recognised that the world is facing significant challenges, including becoming environmentally sustainable whilst simultaneously improving standards of living worldwide [3], large engineering design and manufacturing enterprises *can* be well positioned, given they have the experience, capital, knowledge and skills to proactively tackle these challenges, and in doing so provide: a valuable service to society, fulfillment to their employees and enrichment to their shareholders.

3. *Vision 2030* – A Leading Major Global Design and Manufacturing Automaker

3.1. Trends Since 2000

The past 15 years have been turbulent; they have witnessed terrible acts of terrorism, increasing alarm at environmental damage to our planet and a huge worldwide recession. However all the while humanity's ability to invent and innovate new complex systems has increased. We may note the increased penetration of high-speed internet, the rapid adoption of the smartphone, successful delivery and operation of an SUV-sized Mars rover and back on Earth, the increased safety and efficiency of our cars. Much of this has stemmed from the ever-increasing power of our computers and the speed at which they exchange data, which itself is enabling the design and manufacture of increasingly complex and complicated machines.

Within the field of Engineering and Systems Design, the past 15 years has seen many changes, many linked to ICT and dynamics in Software Engineering. For instance, we have the Agile manifesto in 2001, the increase in popularity of Integrated Product Development and Concurrent Engineering, the rise of Design for X, of Lean engineering, and many theories in Design such as Ulrich and Eppinger's product development process [3],[4],[5]. The backdrop is the rise of Model-Based Systems Engineering (MBSE), and attendant methods, a large field macro-trend transforming the profession. Also noteworthy are the rise of complexity-management techniques and models, and formalisms for linking a system design to its Enterprise or System-of-Systems context. Finally, we have seen the demonstration of the growing importance of Human-Machine interactions and social sciences in engineering with the triumph of Apple.

3.2. State of Engineering Design Now - In Theory and Practice

Today, Engineering Design and SE have advanced but are still immature or very different across industries - SE is accepted in aerospace and defence and gaining acceptance elsewhere [3], while Design (and indeed SE) research has entered a theoretical phase [5], [6]. SE is recently standards and handbook-based, but practices are variable and still based on heuristics [3]. Key challenges include integration across disciplines, project phases and systems, and creating an underlying theory. SE and Engineering Design are also perhaps converging, as SE focus is shifting from process to product [7]. Meanwhile, new cutting-edge practices are being introduced and widely adopted, including integrated platforms for real-time information sharing across teams, increased visualization, new "digital twins", and the increasing automation of routine design tasks.

3.3. Trends for the Next 15 Years

Many global trends will continue for the next 15 years, including ever-more computing power, connectivity (and the Internet of Things), more available data and mining of it, the improvement of AI and Virtual and Augmented Reality (VR/AR). Against a backdrop of economic growth, other innovative technologies such as 3D printing and new energy sources together paint a picture of many possibilities for the practice of Engineering and System Design. However the challenges faced will also be grave: climate change and increased natural disasters, resource sustainability, population and urbanization growth.

3.4. Vision 2030

3.4.1. Design - A Creative Activity

In the company of 2030, design engineering will have shifted away from analysis and towards creative design and decision-making. While today he is more occupied with locating a solution space and determining if a given design meets requirements, the design engineer of 2030 will be focused on creatively generating designs, and making trade-offs with holistic criteria. Many analyses, of feasibility, performance, and cost will be largely automated in real-time inside the virtual design environment - the designer will rapidly create many feasible alternatives, and work on decision-making and optimising with respect to preference relations [7]. The design engineer will work more collaboratively, on multi-criteria group design decisions involving multiple engineering branches and specialties, as well as numerous stakeholders. To facilitate creative thinking, augmented and virtual reality will represent decisions real-time, with 3D printing of parts or shapes just a click away. Many more mundane tasks - designing routine components, like gearboxes - will be automated, saving valuable time. Knowledge of previous solutions to a design problem will be readily available in the model-based design environment for visualization - a strategic asset for the company. With immense sensor data from IoT automotive subsystems available, the designer will be more concerned with imagining and formulating his information request than fulfilling it. Design targets will be emotional reactions in the customer, with delight design and experience-based design [8], requiring increasing assistance from the social sciences, arts and humanities to continuously improve human-machine interfaces. The core capabilities of delight design in automotive will be the company's competitive advantage.

Design elegance will be another target [9]: other than meeting or exceeding customer expectations (1), an elegant design should be robust to changes in input and environment (2), be efficient, producing the desired result for lesser resource expenditure than alternatives (3), and have minimal unintended side effects and consequences (4). Such elegant cars and subsystems will be inexpensive to operate, being fuel- and maintenance-efficient, rugged and adaptable, forgiving of errors, eco-friendly and safe - all while delivering the driving experience and emotions customers expect.

3.4.2. Systems Engineering (SE) - External Interfaces and a Coordination Framework

Systems Engineering at the company of 2030 will be radically different - firstly there will be more of it, as product teams become more "top-heavy". Component design, progressively automated, will be replaced with more and better design coordination and integration, more interfacing with stakeholders for better setting and flow-down of design targets, more interdisciplinary thinking - in short more SE. More SE is will have high returns [10], especially by a more professionalized cadre, as specialized training will replace and complement seniority as the main job qualification. In fact all company engineers will have a broader skillset in 2030, including business literacy and better communications skills to suit their changing role [11].

Perhaps the most important change in company SE will be a shift from requirements to preference relations, which will be flown down, ensuring a top-down, correct design optimisation. These will allow multidisciplinary optimisation instead of sub-optimal requirement fulfillment [7], enabled by the use of an integrated modeling framework and virtual common platform for real-time concurrent cross-disciplinary work. To obtain these preference relations, system-level trades will be explored using visualizations, with many stakeholders - customers, top management, sales, marketing - will inspect "digital twin" 3D mock-ups from remote locations, and perhaps sit inside using AR and VR. The system-level design target will be simple: to maximise Net Present Value for the firm - with some corporate strategy considerations. Facilitating these NPV calculations, product line design is done simultaneously with economic calculation, via automatic costing in a CAE integrated software platform in real-time. Many reliability, availability and other -ilities calculations are also done, facilitating complex SE trades.

The effects on vehicle projects will also be positive: improved speed and agility will be possible, through more streamlined development and better understanding of solution spaces, with more concept generation. Effects of design decisions on project risk and cost will also be captured semi-automatically for Project Management use, allowing to see cost/benefit of using low TRL, hypothetical components in a car concept.

Company vehicle product lines will be developed not as islands, but as interdependent systems-of-systems, with many sociotechnical interactions. Aided by a digital twin and AR/VR, the interfaces of a new car concept with many external systems will be assessed and simulated, early on: driving and fitting in garages, road handling and car "feel" in all weather, numbers of passengers and amount of cargo, breakdowns and crashes, experience in traffic, repair and servicing jobs... with a focus on Human Factors, so central to user experience.

3.4.3. Other Business Practices

In 2030, one of the most important differences in the company will be how its internal organization and communications is structured. The links between engineering design and other corporate functions will be completely different, and much greater. A description of each is given as follows:

- Marketing - data and expertise will be used in integrated modeling to determine preference relations and value functions, for delight design and emotion engineering.
- Operations management - day-to-day Big Data from sensor-filled vehicles on the road will be obtained, analyzed and mined, and interpreted by engineers. Analytics will be used to predict upcoming demand and need for spares, and this information used for the supply chain and manufacturing. Partnerships will be necessary with Big Data and analytics firms, as the company's volume of data will be immense (Tesla, with 70 000 data-gathering cars on the road, gathers a million miles in 10 hours [12]).
- Manufacturing - will be done on-demand, with made-to-order variant customization and increasing use of a marketplace of shared factories, with manufacturing as a commodified service in automotive.
- Sales - will be a key stakeholder for feedback to Systems Design, and ideal for preference articulation.
- Senior management - will increasingly formulate strategy concurrently with engineering product lines, utilizing fully-costed virtual twins.
- Accounting and finance - will have instant information visibility during design and throughout the product lifecycle - no more disconnect between written-off R&D costs and project performance - projects will be initiated based on the application of the rational and known NPV framework under uncertainty, and not instinct.
- HR & organizational behaviour - both engineers and non-engineers will be hired, fired, incentivized and trained based on "systems thinking" ability, and design engineers in particular instilled with basics in social sciences and psychology [7].
- R&D - will include more and better data visualization, further design automation, bringing in more social science, humanities and arts to Engineering Design, and better human-machine interfaces.

4. Delivering *Vision 2030* – Research Thrusts

The purpose of this section is to identify the gap between current business practice and *Vision 2030* and offer pathways for how the academic research community can enable *Vision 2030* to become *Reality 2030*.

4.1. Gap Identification

The Systems Engineering (SE) discipline aims to address many of the challenges around the design of complex systems, being defined by its industry body as "an interdisciplinary approach and means to enable the realization of successful systems" [13]. Its roots are in aerospace and defence where it has enabled the creation of some of the most high-performance, complex, complicated and expensive systems ever created by man. However even the industry body itself recognises that the current practices cannot keep up with the increasingly complicated systems needed to be developed [3]. With some [6] going far enough to say it is a "Field in crisis … Overruns, delays and cancellations are the most common outcome for development projects". With expenses rising to the point the systems being developed might be unattractive [7]. Specific criticism by the ex NASA Director [9] of Systems Engineering includes its process-heavy nature which is said to be: *Expensive*, *Inefficient*, *Unscalable*: often ineffective and focused on following process rather than thinking about the purpose and suitability of the systems design. Figure 1 is provided for illustration of the challenges faced by aerospace, here aerospace (blue) is shown to have increased in development time as the systems have become increasingly more complex. Figure 1 also shows automotive (green) has not experienced large increase in program length. Such a difference could be due to the high volumes and limited architecture variation that characterises automotive. Before 2030 automotive will experience complexity increases and architecture variations which if unchecked might result in similar increases in program length and cost. As such, to prevent the cost of cars increasing significantly as functionality and performance increases, researchers must contribute to the development of innovative, practical and effective solutions to the problems identified with Systems Engineering, and so enable the delivery of *Vision 2030*.

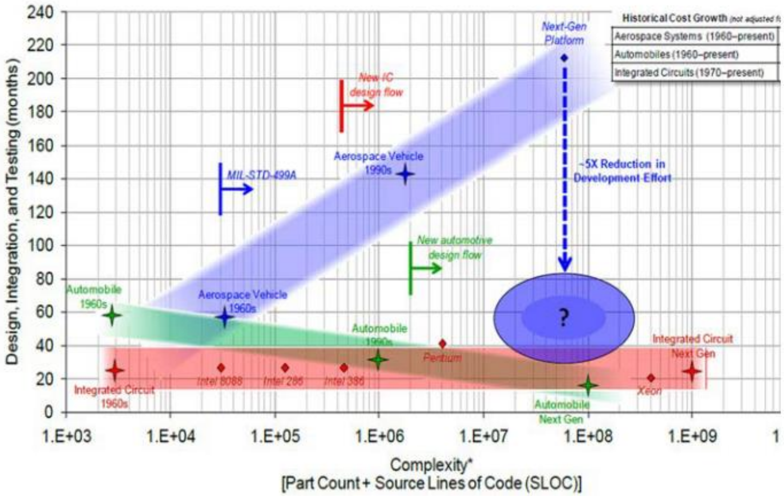

Figure 1 (from [14]). Historical Schedule Trends with Complexity

4.2. Research & Development Approach

Only 14 years are available to deliver *Vision 2030* (given the pressing need of industry), thus a clear research approach whose output can be readily adopted by industry is required. This presents some unique challenges that are listed as questions and expanded as follows:

- How to assess the efficacy of proposed solutions to development challenges? Given that success and failure in complex system design is dependent on multiple time-varying factors (none of which can be individually isolated) it is impossible to prepare repeatable experiments as in classical physics.
- How to ensure adoption? The company being a large corporation, substantial inertia to adoption of even proven solutions will exist as a result of legacy products, legacy processes and employees trained in them. Further risk aversion associated with possibly degrading *current* development performance hinders experimentation. This leads to an additional question of how to avoid a disconnect developing between the state of the art in academia and what is practiced by industry. Given academia's focus on small-scale demonstrations it is possible for the rate of innovation to be faster than what industry can adopt.
- How to integrate the expertise of multiple experts? Complex system design and development is inherently a multi-disciplinary activity. Thus research to contribute to it must often also be multi-disciplinary, but traditional university departments are formed around single disciplines with students and laboratories learning and interacting within (e.g. mechanical engineering vs. social science vs. operations research).

To address these challenges we advocate the usage of modular, collaborative and multi-disciplinary research firmly nested in the problem domain of the company. Explanation of each feature of the research approach and its purpose is described as follows:

- Modularity indicates a single piece of research has a very clear functional focus that can be created, assessed and adopted in isolation. It is a necessity due to the large scale of the development programs and potential risk associated with adopting monolithic changes to the development process. With modularity new best practices can be adopted selectively based on the business needs at a particular time. An example of how the modularity approach can be applied to SE research is provided in [15].
- Collaborative denotes that the research is planned and conducted with the company. As per [9] it enables academia to get involved with actual complex system design and allows industry to adopt the latest best practice and give feedback for future improvements, so that the company can shape the research to solve their highest-priority items and achieve *Vision 2030*.
- Multi-disciplinarity is required to utilize the skills and knowledge of different research domains. This has been shown to be productive in existing research projects including that described in [14].

There has been much criticism of the conduct of Engineering Design and Systems Engineering research, [16], [17]. However work has started on developing best practices [17], further work is required to be undertaken as indicated by its inclusion in the recent call for research proposals on Systems Science for National Science Foundation funding [18]. Further a large amount of effort is required to develop Systems Engineering research and development roadmaps, which typically involve multiple authors and multi-day workshops e.g. [14], [15]; to clarify the research topics into tangible research projects in the field is difficult. This is further demonstrated by the SE industry body's 2025 vision statement [3] which announced an upcoming research roadmap. This was in 2014; none can be found as of this writing.

4.3. Specific Research Thrusts

Some specific research thrusts are identified, which if completed will contribute to enabling *Vision 2030*. To ease comparison with existing research programs these are grouped under the National Science Foundation’s research proposal categories of Systems Science [18] and Engineering and Systems Design [19]. With the former focusing on fundamental research leading to a clearer theoretical foundation [18] and the later to then operationalize the theoretical foundation for specific contexts [19].

4.3.1. Systems Science and Theory

While there are plenty of topics worthy of investigation in this category it is important to focus the approach such that the core research outcome can be delivered. This should follow an approach similar to the natural sciences. As described in [18] this should be the form of “explanatory models, derived from the underlying theoretical foundations will lead to a testable hypotheses. Based on collected evidence supporting or falsifying the hypotheses, new insights are gained allowing the explanatory models to be refined or updated”.

To facilitate research into areas of particular importance [6] provides seven research thrusts with (1) Verification and Validation, (2) Requirements, (3) Conveying Design Guidance through Contracting and (4) Risk Management considered in dire need of theoretical underpinnings for the purposes of Systems Engineering. Also, (5) Abstraction and Elaboration, (6) Organization Design and (7) Guidance in Model-Based Systems Engineering are suggested as lower-priority candidates for investigation.

4.3.2. Engineering and Systems Design

As stated previously the aim of this research type is to operationalize the theoretical foundation for specific contexts [19]; when coupled with the modular, collaborative and multi-disciplinary research approach advocated previously, it has potential to directly contribute to the realization of *Vision 2030*.

a. From a Process Focus to a Value Focus

As described previously in this paper in the Gap Identification, Systems Engineering has been criticised for being more focused on the processes to design and deliver a system than the value created for stakeholders by the system. As such a critical research thrust must be to address this. Under the broad title of Value-Driven Design [7] or Design for X [19] one can produce two sub-fields, Delight Design and Elegant Design. Delight Design [4] is somewhat consumer product driven, encouraging the engineer to focus on the functionality and attributes which make a product delightful rather than simply delivering the primary required functionality and improving the performance from there. Elegant Design focuses on core system attributes that are appreciated even in large-scale systems deployments, with [9] defining an elegant design being one which: 1) Actually works, 2) Is robust, 3) Is efficient and 4) Has few unintended consequences. In both these cases they ultimately require research into the characterization, measurement and modeling of something that is somewhat intangible but evokes significant emotion from stakeholders and then synthesizing new designs that are more delightful and elegant. As such the initial research thrust must be to characterize why some designs are currently delightful and/or elegant. Further implementation of the more broad Value-Driven Design approach will likely require the movement away from fixed hard requirements to the optimization cost and reward functions, which likely requires further requires legal innovation around procurement contracts in aerospace [9]. Indicating this research thrust requires significant investigation into the ramifications for all stakeholders across the lifecycle, such that they are willing to adopt the change in business and engineering practices [20].

b. Modeling, Simulation, Prediction and Decision Making

One could say sustained technological development in the computing industry has and will continue to enable this research thrust to progress with little direct involvement from those who simply use the technology. However this would be naive as access to increased computing and networking resources does not alone enable "better" model-based development. The research community must proactively embrace and utilize this technology to enable *Vision 2030*. This involves identifying technology trends outside of the immediate field and hypothesising and subsequently investigating their utilization for complex system development (e.g. does immersive VR improve the capture of customer preference for a particular design set, does social network style collaboration tools increase the efficiency and effectiveness of a design team, does more simulation result in a higher quality end product design). Further areas of research study are described below.

b.1. Development of Representative Models

Increased computing abundance increases a design team's capacity to simulate. This is however dependent on the development of representative models. Currently models used tend to be deterministic. Representing and simulating the uncertainty associated with the system of interest is likely a fruitful direction. However in all cases appropriate characterisation of the model when compared to reality so that the model is "good enough" is critical for the simulation results to drive improvements in complex systems design. As such, model validation and verification is a critical area of research.

b.2. Enterprise Systems and System of Systems

As per [21] the development of very large-scale systems, so called Enterprise Systems and System of Systems will become increasingly important and so need modeling and simulation. However such modeling includes socio-technical aspects and evolving systems, not simply the following of deterministic physical laws as many engineers are familiar with. Based on this a worthy research pathway would be to develop models of existing large-scale systems and characterize based on reality. Subsequently the approach could be applied to the design and analysis of new large-scale systems.

b.3. Translating Data Between the Models and Users

Currently the Systems Engineering industry body is moving towards an architecture of models of a single model repository which can be viewed in different ways depending on the desired outcome of the engineer [3]. Such an approach requires technology, methods and standards (common ways to interface between the data sources and consumers). To accelerate the adoption of new research it is critical that academia embrace existing industrial standards to interface between data sets and model views. Development of custom tools and methods for every PhD thesis is slow and does not create a product suitable for industry.

b.4. Decision Making

The purpose of the simulation results of any model is to inform the decision maker so that a decision can be made. Given the proliferation of models and simulation results of increasingly complex systems without a subsequent increase in human cognitive capacity, appropriate ways to filter, consolidate and reduce data are needed to present the decision maker with manageable knowledge to make a decision. As such this requires research on consolidation of simulation results into meaningful performance metrics and the enabling of multi-disciplinary optimization.

c. Psychology, Social Science and Training

As stated previously human interactions (for a range of stakeholders) over the lifecycle of the system are critically important in successful complex system development, something that differentiates this discipline from more traditional engineering disciplines. Given that humans on an individual level and in groups are systems themselves that are highly complicated it is important for the research community to provide insight into them such that the design of complex systems can best incorporate the complicated nature of humans. This leads to two research strands: the study of how humans interact with the system, and how to teach humans to successfully develop complex systems. These are explained as follows.

c.1. Sociology, Psychology, and Economics [7]

Given researchers of engineering background likely do not have the skills, tools or knowledge to successfully and efficiently carry out such research in social science, it is important for the complex system design community to proactively engage with disciplines more suited to conducting it for guidance and collaboration. Under such collaborative research the following areas should be investigated: how different stakeholders interact when creating new complex systems, how the resilience of a system can be improved by placing human actors in key locations for when a system fails and how to trade-off value allocated to different stakeholders who have competing requirements.

c.2. Human Capital Development [21]

Additionally the development of the individuals who maintain current complex systems and will build the next generation is arguably the most important field as these individuals will feedback ideas and insights into the research process which will shape subsequent generations of systems for the better. Of this a key research topic must be the acceleration of acquiring experience. Given that many large-scale systems will last longer than the careers of the individuals who work on them, interactive simulation must be provided for training at various lifecycle stages. It is too late to wait for when the decision must be made on a real system.

d. Trusted Systems

The ability to develop Trusted Systems which work is recognised as a key research area [21]. Trusted systems are described as safe, secure, dependable and survivable, which aligns well with the definition of Elegant Systems mentioned previously. Such research topics should include Systemic Security and Systemic Assurance to help ensure the system being developed will inherently perform desirably with non-functional requirements.

5. Conclusions

This paper has provided, with *Vision 2030*, a target for a large US automaker to be transformed into a leading global design and manufacturing entity. The embracing of new technology and business model trends enable it to thrive rather than struggle.

To reach *Vision 2030* several research thrusts are identified, which the company must prioritize for engagement with academia such that appropriate tools, methodologies and theoretical understandings are available. These research thrusts were grouped as:

- Systems Science and Theory
- Engineering and Systems Design:
    - From a Process Focus to a Value Focus
    - Modeling, Simulation, Prediction and Decision Making
    - Psychology, Social Science and Training
    - Trusted Systems

References

[1] P. H. Diamandis and S. Kotler, *Abundance: The Future Is Better Than You Think*, Reprint edition. New York: Free Press, 2014.

[2] “Silicon Valley vs. Detroit: The Battle For The Car Of The Future - Forbes.” [Online]. Available: http://www.forbes.com/sites/joannmuller/2013/05/08/silicon-valley-vs-detroit-the-battle-for-the-car-of-the-future/#1e5a711d375d. [Accessed: 02-Jun-2016].

[3] INCOSE, “A world in motion: Systems Engineering Vision 2025,” INCOSE, Jun. 2014.

[4] JSME - The Japan Society of Mechanical Engineers, “Roadmap of design engineering technology,” *JSME News*, vol. 18, no. 2, Dec-2007.

[5] A. Chakrabarti and L. Blessing, “A Review of Theories and Models of Design,” *J. Indian Inst. Sci.*, vol. 95, no. 4, pp. 325–340, Jan. 2016.

[6] P. D. Collopy, "Systems engineering theory: What needs to be done," in *Systems Conference (SysCon), 2015 9th Annual IEEE International*, 2015, pp. 536–541.

[7] P. Collopy, "A Research Agenda for the Coming Renaissance in Systems Engineering," 2012.

[8] JSME - The Japan Society of Mechanical Engineers, "Roadmap of design engineering technology," *JSME News*, vol. 18, no. 2, Dec-2007.

[9] M. D. Griffin, "How do we fix System Engineering?," presented at the 61st Annual International Congress, Prague, Czech Republic, 2010, vol. 27.

[10] J. P. Elm and D. Goldenson, "The Business Case for Systems Engineering Study: Results of the Systems Engineering Effectiveness Survey," Software Engineering Institute, CMU/SEI-2012-SR-009, Nov. 2012.

[11] Institute for Alternative Futures, "2028 Vision for Mechanical Engineering: A Report of the Global Summit on the Future of Mechanical Engineering.," ASME, Jul. 2008.

[12] N. Hines, "Google's Got Less Self-Driving Data Than Tesla, but It's Better," *Inverse*, 25-May-2015. [Online]. Available: https://www.inverse.com/article/16139-google-s-got-less-self-driving-data-than-tesla-but-it-s-better. [Accessed: 01-Jun-2016].

[13] INCOSE, "INCOSE - What is System Engineering?," 14-Jun-2004. [Online]. Available: http://www.incose.org/practice/whatissystemseng.aspx. [Accessed: 07-Dec-2014].

[14] "NSF/NASA Workshop on the Design of Large-Scale Complex Engineered Systems - From Research to Product Realization," 2012.

[15] J. Wade, A. Madni, C. Neill, R. Cloutier, R. Turner, P. Korfiatis, A. Carrigy, B. Boehm, and S. Tarchalski, "Development of 3-year roadmap to transform the discipline of systems engineering," DTIC Document, 2010.

[16] S. F. Brown, "Naivety in systems engineering research: Are we putting the methodological cart before the philosophical horse?," in *7th Annual Conference on Systems Engineering Research (CSER 2009)*, 2009.

[17] L. T. M. Blessing and A. Chakrabarti, *DRM, a Design Research Methodology*, 2009 edition. Dordrecht ; London: Springer, 2009.

[18] NSF - National Science Foundation, "Systems Science | NSF - National Science Foundation." [Online]. Available: https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=504788&org=NSF. [Accessed: 01-Jun-2016].

[19] NSF - National Science Foundation, "Engineering and Systems Design | Program Guidelines." [Online]. Available: https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=13340. [Accessed: 01-Jun-2016].

[20] A. Salado and R. Nilchiani, "Elegant space systems: How do we get there?," presented at the Aerospace Conference, 2013 IEEE, 2013, pp. 1–12.

[21] Systems Engineering Research Center (SERC), "Research Programs and Projects | Systems Engineering Research Center." [Online]. Available: http://www.sercuarc.org/research/research-programs-and-projects/. [Accessed: 01-Jun-2016].