General Examinations - Primary Area - Day 1

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1 Socio-environmental-technical Systems

The title of your Primary area is "Socio-environmental-technical Systems Design, Modeling, and Decision-Making." Using the literature in your reading list, define what you mean by "Socio-environmental-technical Systems." Consider what it means to use the terms to describe the phenomena occurring in the world versus using it to describe a software-based modeling developed by a human that seeks to capture some behaviors of phenomena.

The term Socio-environmental-technical Systems (SETSs) is a linguistically clumsy attempt at combining Sociotechnical systems (STSs) and Socio-environmental systems (SESs). By *sociotechnical sytems*, I mean generally that same thing as Maier and Rechtin: "Technical works involving significant social participation, interests, and concerns" [1]. This is to be contrasted with primarily technical systems, such as space launch systems or military aircraft, that the field of systems engineering is traditionally concerned with. A key point here is that many systems that engineers would traditionally have considered purely technical are now considered sociotechnical. A hydroelectric dam affects water rights and usage both upstream and downstream; a global communications system can impact public trust and the spread of disinformation; a national transportation system may reshape human settlement and migration. The term STS arose predominantly out of the field of systems engineering, which is still where it is most commonly used.

STSs can, to some degree, be characterized by four questions: Who benefits? Who pays? Who provides? Who loses? [1] Such questions go a long way towards remedying some of the professional arrogance historically found in the practices of systems engineers and are also can be considered to be the basis of stakeholder analysis, both of which are discussed further in Section 5.

SESs, on the other hand, refers to the complex phenomena that occurs due to the interactions of human and natural systems [2]. This can include such examples as near-urban renewable resource extraction, wildfires, and water management. This is a field that arose predominantly out of environmental sciences and economics, such as ecosystem services economics. Theories and methods developed out by SES researchers underly many aspects of the United Nations (UN) Sustainable Development Goals (SDGs).

Both STS and acses represent attempts to break out of disciplinary silos to addressing pressing issues and rectify methodological deficencies. The conceptualization of STS has led systems engineers to pull from fields such as economics (such as how to model value and utility [3], how to consider economic uncertainty in the design of systems [4], and how to consider impacts on different populations [5]) and psychology (such as the importance of perception over facts [1], how to resolve vaguness and ambiguity [6], and how to design interactive visualizations [7]). SES meanwhile draws weaves together strands of economics, urban development, and environmental scinces using a variety of methods including system dynamics, Bayesian networks, agent-based models, dynamic stochastic equilibrium models, statistical microsimulation models and hybrid approaches [8].

The term SETS can thus be viewed as another step along this path of integrating disparate fields. A key aspect here is that this term largely refers to a perspective that informs methodology selection, rather than the identification of some novel phenomena. That is, the connections between human behavior, environmental phenomena, and technical systems have long existed and are not themselves novel. Just as the hydroelectric dam mentioned earlier, which was once considered a purely technical system is now considered in terms of its social impacts on those downstream and upstream, so too it is now considered in terms of its environmental impacts. Traditionally, these connections have been neglected or assumed to be trivial due to a combination of ideology, ignorance, and the lack of sufficiently powerful tools. This is no longer acceptable due to both push and pull factors. The primary push factor is that these neglected interactions and feedbacks have accumulated, particularly over the past century, and can no longer be ignored without dire consequences. Furthermore, there has been a growing expansion of ethical concern in our society that makes it untenable to ignore other peoples and environments. The primary pull factors have been significant advancements in data collection, computing power, modeling methods, and scientific knowledge about each of the numerous individual disciplines involved. While our data and knowledge are by no means perfected, they are sufficient to at least make attempts and such attempts are necessary in the face of the rather dire push factors.

2 Glossary

"What terms do you find helpful, when rigorously defined, to describe the scope of your current research? Please start building a glossary of terms that you can continue to update throughout the exam. Please reference when you use terms from other scholars."

Collaborative Systems: A system that is not under central control, either in its conception, development, or operation. They tend to be assembled and operated through the voluntary choices of the participants, not through the dictates of an individual client [1].

Decision Support System (DSS): A technical system aimed at facilitating and improving decision-making. Functions can include visualization of data, analysis of past data, simulations of future outcomes, and comparisons of options.

geographic information system (GIS): Any digital system for storing, visualizing, and analyzing geospatial data, that is data that has some geographic component. The term can also be used to discuss specific systems, a method that uses such systems, a field of studying focusing on or involving such systems, or even the set of insitutions and social practices that make use of such a system [9].

Multidisciplinary Optimization: A methodology for the design of systems in which strong interaction between disciplines motivates designers to simultaneously manipulate variables in several disciplines [10].

Multi-Stakeholder Decision-Making: Any decision-making process in which more than one stakeholder must collaborate to reach a decision [5]. This can take a variety of forms, including cooperation, negotiation, voting, or consultation [11].

Organizational Policy: Policy, decision-making, and politics within an organizational stakeholder. This includes decision-making policies, mechanisms of institutional learning and memory, capability development, etc. See Section 6 for further discussion.

participatory geographic information system (PGIS): A subset of GIS that seeks to directly involve the public and other stakeholders, including government officials, non-governmental organizations (NGOs), private corporations, etc [12]. It should be noted that these means involvement in both the production of data and in its application, not merely one or the other [13, 14].

Planning Support System (PSS): A type of DSS specifically designed to support urban or regional planning efforts. These often involve longer time scales and more general/strategic decisions than most DSSs.

Socio-environmental System: The complex phenomena that occurs due to the interactions of human and natural systems [2]. See Section 1 for further discussion.

Sociotechnical System: Technical works involving significant social participation, interests, and concerns [1]. See Section 1 for further discussion.

Socio-environmental-technical System: See Section 1

Stakeholder Analysis: Identifying, mapping, and analyzing the stakeholders in a system and their connections to one another in order to inform the design of the system. This involves both qualitative and quantitative tools, such as the Stakeholder Requirements Definition Process [15] and Stakeholder Value Network Analysis [16].

Systems Architecture/Architeting: The art and science of creating and building complex systems. That part of systems development most conerned with scoping, structuring, and certification [1]. This tends to refer to the high level form and function of a system, rather than detailed design.

Systems Engineering: An interdisciplinary approach and means to enable the realization of successful systems. It focuses on holistically and concurrently understanding stakeholder needs; exploring opportunities; documenting requirements; and synthesizing, verifying, validating, and evolving solutions while considering the complete problem, from system concept exploration through system disposal [17]. See Section 5 for further discussion.

Tradespace: The space spanned by the completely enumerated design variables, i.e. the set of possible design options [18].

Tradespace Exploration: A process by which various options with a tradespace may be examined and compared in the absence of a single utility function, such as when multiple stakeholders are involved or multiple contexts with no clear priority exist [18].

3 State of the art

"What is the current state of the art in "Socio-environmental-technical Systems Design, Modeling, and Decision-Making"? What are recent innovations in the space, who are some of the leading organizations and where do you see gaps that need to be filled?"

SETS design, modeling, and decision-making is part of a long history of multidisciplinary modeling, optimization, and analysis. Many technical systems have to balance multiple, sometimes competing requirements. A steam engine must maximize efficiency for a target power output, remain structurally sound, minimize cost, and fit into its intended space. Historically, these various concerns were treated largely separately in design, with engineers communicating and taking care to not step on each other's toes. This method became untenable when dealing with highly coupled behaviors or high performance systems, both of which require more explict considerations of linkages. This led to the fields of multidisciplinary modeling and multidisciplinary optimization. One of the primary fields in which this occured was aerospace engineering, where aerodynamics, structural statics and dynamics, thermal behaviorm and more are tightly coupled enough to require concurrent analysis. This requires exchanging large amounts of data, adjusting resolutions of multiple different disciplinary equations and models, making approximations where necessary, conducting sensitivity analyses to identify the more important factors, and clever computational efficiency tricks [10].

Beyond the computational power required to integrate models of multiple domains and scales, there exists real issues of integration and composability. Different domains rely on fundamentally different assumptions and concepts. Often, even within a single domain, different conceptions of the world exist at different scales. In crack growth, for example, the very point of a crack is best modeled using quantum mechanics, the area surrounding this by molecular dynamics, and the overall material using continuum mechanics. While it is possible to develop algorithms to effectively combine these different scales into one model [19], this is non-trivial, must be done for each such "handoff," and is epistemologically questionable [20].

Nonetheless, the appeal, even the necessity, of such multi-disciplinary models is undeniable. We need models to improve the design of our systems and we need forecasts to avoid harmful outcomes. For instance, in 1972 the Club of Rome created the World3 model to study interactions between food production, industry, population, non-renewable resources, and pollution in an effort to avoid global catastrophe [21]. Only a few years prior, Jay Forrestor had developed a similar, municipal-scale model called Urban Dynamics [22]. Neither of these were the first such models, but like most of the rest from their era, they were famously inaccurate and ultimately abandoned by the mid 1970s [23]. Multidisciplinary modeling largely retreated to linking closely related fields, such as the aforementioned aerospace applications or land-use + transportation planning, for the next few decades.

Ultimately the various push and pull factors discussed in Section 1 would cause the resurgence of multidisciplinary modeling and decision-making, however. Systems engineering would see advancements such as an improved understanding of complexity and dynamical chaos [24] and stakeholder analysis [25, 26]. Multidisciplinary optimization has likewise continued to advance. While there are still grounds for improvement in coupling and computing, the field has also turned towards incorporating new aspects that are more relevant for sociotechnical systems, including ongoing and future redesigns (i.e. that of a living system that is never complete); interactions with other, separately managed systems; and implementation of the system [27, 28].

Over this period, SES modeling and decision support started incorporating new tools and methods. This included a shift to combining spatial and non-spatial analysis components [29], such as the use of cellular automata with systems dynamics to capture both spatial dynamics and macroscale demand-supply dynamics in order to simulate residential development [30]. Shahumyan and Moeckel even ArcGIS Model Builder to link disciplinary models for transportation, land use, mobile emissions, building emissions, and land cover [31]. While this implementation had only limited feedbacks, their approach could be extended to more fully address the needs of SETS. All of this has led to optimism about the future of integrated urban models, even within the urban planning field [32].

Furthermore, the past few decades have seen the rise of the concept of sustainable development, which is often defined as the integration of three separate fields: economic development, social development and environmental protection [33]. These fields are alternately described as "as interdependent and mutually reinforcing pillars" [33, 34], and as 'conflicting' [35], as shown in Figure 1. This three-part model of sustainable development has become so powerful that it forms the theoretical foundation of the UN SDGs, one of the motivating factors for advacning SETS design, modeling, and decision-making.

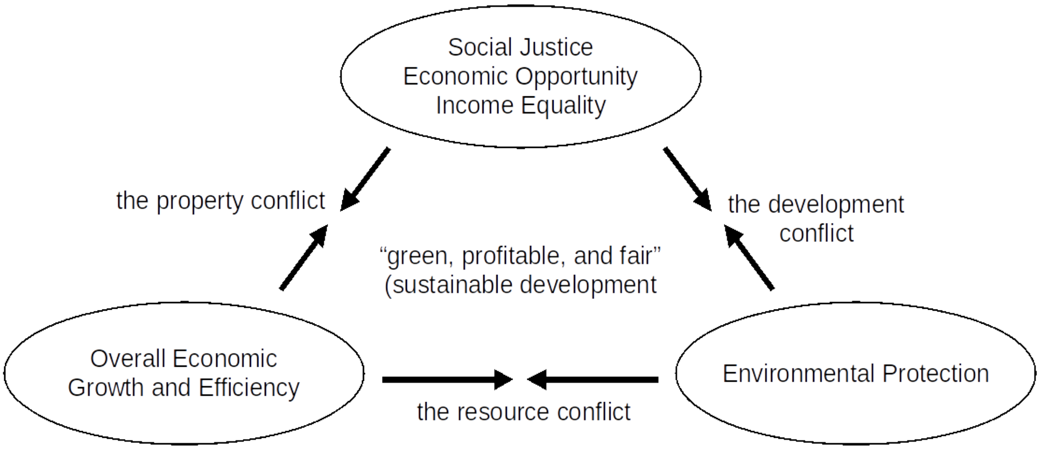

Figure 1: The triangle of conflicting goals of sustainable development. Adapted from [35]

We are far from the first to argue that such integration is necessary, nor to recognize that it is easier said than done [31].

There have been many land use and transportation models. The open source UrbanSim, for example, combines land use, transportation, and certain environmental factors in a dynamic, area-based simulation system that, similar to Environment, Vulerability, Decision-Making, Technology (EVDT), is a collection multiple models [36].

The agent-based Integrated Land Use, Transportation, Environment (ILUTE) model simulated the urban spatial form, demographics, travel behavior, and environmental impacts for the Toronto area [37].

Now that we are in an era that is starting to recognize the importance of SETS, what challenges exist? SETS has inherited some of the challenges found in multidisciplinary optimization and SES. For instance, SETS most cope with the difficulties of integrating different disciplinary epistemologies, developed ways of coping with modeling uncertainty, handle disciplinary models that address multiple different spatial and temporal scales, and integrate implementation challenges into [27, 2]. That said, due to the relative novelty of the field and the high levels of uncertainty involved with human and environmental systems, we are still quite some distance from performing rigorous optimizations. Instead SETS is focused on improving understanding and examining different potential scenarios. This means that SETS is not as burdened by some of the priorities of multidisciplinary optimization, such as computational power limitations and the ability to handle large numbers of slightly, different, competing designs. SETS does, however, have to deal with some of the challenges more specific to SES, including combining both qualitative and quantitative data sources, seeking to model human decision-making processes, and understanding the relevancy of novel datasets [2].

4 EVDT

In our work, we propose EVDT to include information about the Environment, Human Vulnerability or Benefits, Decision Making and Technology Design. Building from the readings you have curated for the Primary Area of your General Exam, please write an argument evaluating whether EVD&T (Environment, Human Vulnerability or Benefits, Decision Making and Technology Design) are appropriate concepts to select as the core of a customizable modeling framework.

While the specific EVDT framework is new, the previous sections have made it clear that integrated, multidisciplinary modeling involving the relevant fields has a long tradition. EVDT is a framework for considering and modeling SETSs, which themselves are the combination of STSs and SESs, as seen in Figure 2. It is natural that just as we would want to expand our consideration of technical systems to sociotechnical systems and of social systems to socio-environmental systems, so too would we want to consider all three components together.

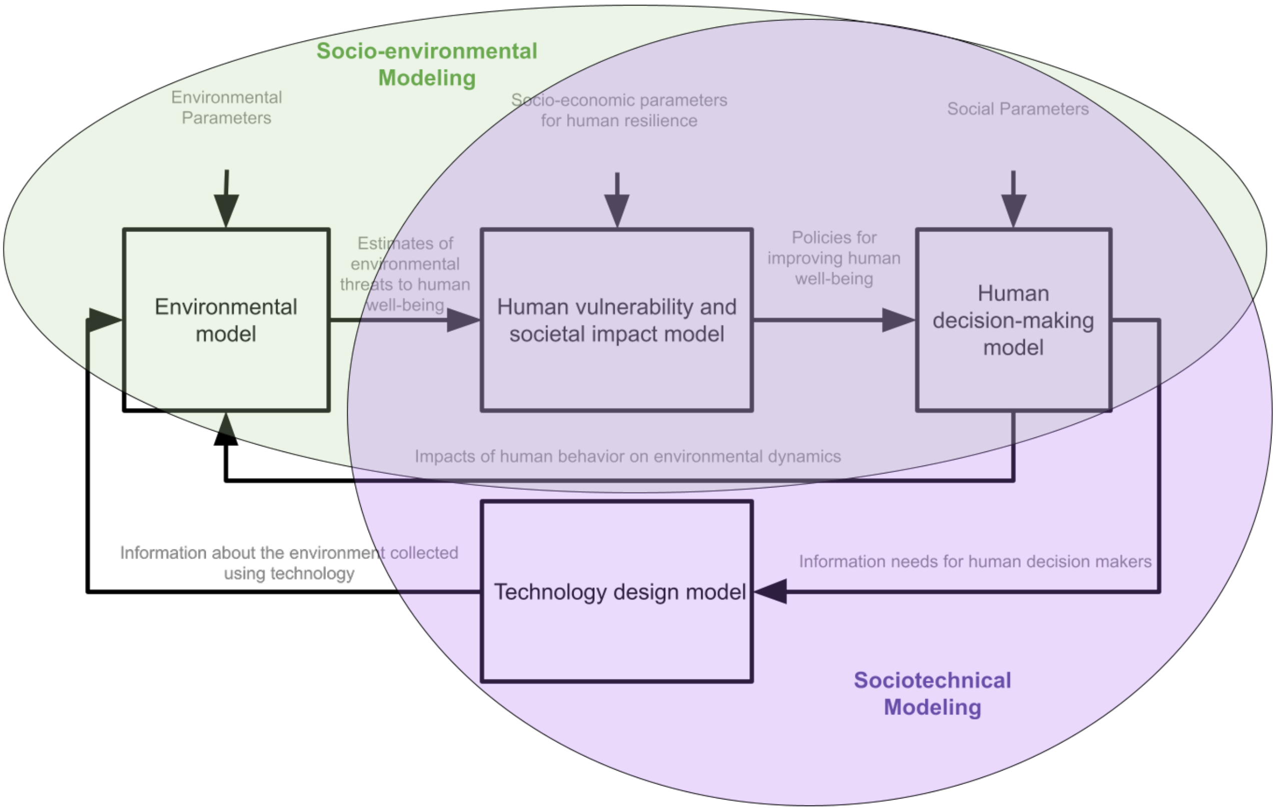

Figure 2: EVDT Diagram with overlaps domains of socio-environmental systems and sociotechnical systems

This however only explains the desire of an EVDT-like framework, not EVDT in particular, why does EVDT have four components when I have only enumrated three thus far?

It is necessary to address the latter question first. The answer is that most treatments of STSs and SESs mask two different types of “social” components to the systems in question. For example, Tripod is a “smartphone-based system to influence individual real-time travel decisions by offering information and incentives to optimize system-wide energy performance” [38]. Tripod is built on the TripEnergy model, which in turn combines an environmental submodel (vehicle emissions), a societal impact submodel (energy consumption and trip lengths), and a human decision-making model (driver behavior) [39]. Tripod adds further detail to the human decision-making model, by having a built in estimation of impact of different incentives to influence driver behavior. Finally, Tripod itself is a technological system impacting the other domains. Thus Tripod is an instance of a SETS, though its creators do not refer to it as such. We can see here that ‘socio’ can refer to the impact on humans (economic, health, educational, etc.), the behaviors of humans, or both (as in Tripod). EVDT must therefore make such a distinction, spliting ‘socio’ into the vulnerability / societal impact and human decision-making.

1. What is happening in the natural environment?
2. How will humans be impacted by what is happening in the natural environment?
3. What decisions are humans making in response to environmental factors and why?
4. What technology system can be designed to provide high quality information that supports human decision making?

5 Systems Engineering

You identify systems engineering as one of your reading areas. Define how you are using the term “Systems Engineering” and briefly discuss the state of the art of the field. Situate your work within the Systems Engineering field (considering both research and practice). What are the roots of methods, concepts and theories that you draw upon? What aspects of Systems Engineering theory and practice do you seek to improve upon with your work?

Systems engineering, perhaps due to its inherently interdisciplinary nature coupled with its roots in several different fields (aerospace engineering, civil engineering, mechanical engineering, etc.), has had numerous definitions proposed over the course of the past century. Some of these have been by individual authors, such as Maier’s ”*A multidisciplinary engineering discipline in which decisions and designes are based on their effect on the system as a whole*” [1], and some by international standards organizations, such as the international standards organization (ISO)/International Electrotechnical Commission (IEC)/Institute of Electrical and Electronics Engineers (IEEE) definition ”*Interdisciplinary approach governing the total technical and managerial effort required to transform a set of customer needs, expectations, and constraints into a solution and to support that solution throughout its life*” [40] . For the purposes of my work, the specific definition is not overly important, as I do not seek to create a foundational work of systems engineering, but rather to apply its theory and methods to a particular set of applications.

Nonetheless, I think the International Council on Systems Engineering (INCOSE) affiliated Systems Engineering Body of Knowledge (SEBoK) definition will serve nicely: ”Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on holistically and concurrently understanding stakeholder needs; exploring opportunities; documenting requirements; and synthesizing, verifying, validating, and evolving solutions while considering the complete problem, from system concept exploration through system disposal” [17]. It is the ‘interdisciplinary’ and ‘holistic’ nature of the field, along with the tools and frameworks that have been developed to apply this, that makes it most relevant for EVDT.

The primary systems engineering tools of interest include the aforementioned multidisciplinary optimization, which provides lessons on integrating models of different fields; systems architecture, which is useful for designing EVDT implementations themselves; and stakeholder analysis, as all EVDT applications inherently involve numerous stakeholders, often with different levels of power.

Other subfields that will be relevant later in the EVDT lifecycle include multi-stakeholder negotiation and decision-making, which contains numerous lessons on how structure communications to avoid deadlock or domination [41, 5, 42]; tradespace visualization and exploration [41, 5, 43, 44, 45], which contains lessons on how to present complex information to stakeholders and enable them to navigate their options; and epoch-era analysis, which is useful to considering how a system may evolve over time in an high uncertainty domain [46, 47].

Also underlying the EVDT framework is that the field of systems engineering can be, in some sense, redeemed for some of its past failures. While the field has had enormous success in enabling the design of increasingly complex technical systems over the course of the past century, reesults of its applications in sociotechnical and socio-environmental-technical systems are much more bleak. Such applications were envisioned since the middle of the 20th century, at least. US Vice President Herbert Humphrey said in 1968 that ”The techniques that are going to put a man on the Moon are going to be exactly the techniques that we are going to need to clean up our cities” [48]. In the same year, the RAND Corporation established a multi-year attempt to bring systems analysis and engineering to urban planning. Around the same time the American Institute of Aeronautics and Astronautics (AIAA) hosted meetings on urban technologies to bring aerospace expertise to bare on the urban crises of the time [48]. It was a heady time, with engineers themselves feeling

”that, having reached the moon, they could now turn their energies to solving the problem of growing violence in cities along with other urban ”crises” [49].

Almost immediately, such grand ideas met with difficulties. While recounting the full history of this trajectory is beyond the scope of this work, one can get a sense of it in quotations from urban planners of the time and since:

> The systems engineers bring some expertise and substantial pretensions to the problems of the city. Their prinicpal system expertise seems to be relative to complex organizations that are mission oriented. There is in any case a good deal of difference between the mission of reaching the moon, and the mission of surival and welfare for soceity and the city. The systems engineer can in general deal best with subsystems and specific tasks, and he therefore suboptimizes. This is a charitable description. [50]

“Trying to solve ‘earthly problems,’ especially urban problems through aerospace innovations had shown that ‘transporting the astornauts from terra firma to land on the lunar sphere, travel hither and yon over its surface, and then back home to Houston’ was a comparatively simple task. [48]”

This perception continues to the present day. Figure 3 situates systems engineering and analysis among other intellectual schools of urban planning. It is positioned on the far left of the figure, indicating that the field (or at least the listed authors associated with it) ”look to the confirmation and reproduction of existing relationships of power in society. Expressing predominantly technical concerns, they proclaim a carefully nurtured stance of political nuetrality. In reality, they address their work to those who are in power and see their primary mission as serving the state” [49].

The reasons for these negative outcomes and perceptions are manifold, but among them was that, while proponents of socioal applications of systems engineering argued that it would transform urban planning and decision-making into scientific endeavors [48], such an espousal tended to be more of an aesthetic argument, rather than one grounded in fact. It is a preference for the simple, regular, controlled, and ‘rational’, all of which are, in fact, hideously artificial[51].

Thankfully, among contemporary systems engineers this perspective is a view that is largely considered to be outmoded. Instead, in the guise of theories of complex systems and chaos, they have adopted Jane Jacob’s view that “intricate minglings of different uses are not a form of chaos. On the contrary they represent a complex and highly developed form of order.” [52]. Systems engineering has moved away from prescription, embraced multi-stakeholder analysis and negotiation, applied chaos and complexity theory, and made use of probabalistic modeling.

Nonetheless, the negative reputation of systems engineering does persist, and not without reason. For example, “One cannot know about the history of media stereotyping or the nuances of structural oppression in any formal, scholarly way through the traditional engineering curriculum of the large research universities from which technology companies hire across the United States. Ethics course are rare” [53]. For another:

> Many who seek to harness computational power for social justice tend to find affinity with systems engineering approaches to social problems. These perspectives assume that complex controversies can be solved by getting correct information where it needs to go as efficiently as possible. In this model, political conflict arises primarily from a lack of information. If we just gather lal the facts, systems engineers assume, the correct answers to intractable policy problems like homelessness will be simple, uncontroversial, and widely shared. But, for better or worse, this is not how politics work. [54]

This historic preference of the impersonal and ‘objective’ versus the personal and ‘subjective’ is by no means unique to systems engineering. It can also be found in economics, jurisprudence, education theory, political science, and even moral philosophy [55]. The development of stakeholder analysis has helped to bridge the gap between these two and thus rectify this traditional deficiency. In fact, the use of stakeholder analysis in contemporary systems engineering is, in a way, a step away from the world view that sees “human beings as unknowable black boxes and machines as transparent,” a viewpoint that ”surrenders any attempt at empathy and forecloses the possibility of ethical development” and is a tacit “admission that we have abandoned a social commitment to try and understand each other” [54].

Furthermore, while not discussed previously, the Space Enabled philosophy of research (and thus of EVDT) involves a level of participation and collaboration that goes beyond stakeholder analysis. We actively work with partners who are embedded in the application context and seek to enable them to take charge of their own situation. By paring complex SETS theory with such collaborative planning theory, we can thereby avoid many of the traditional problems of systems engineering [56].

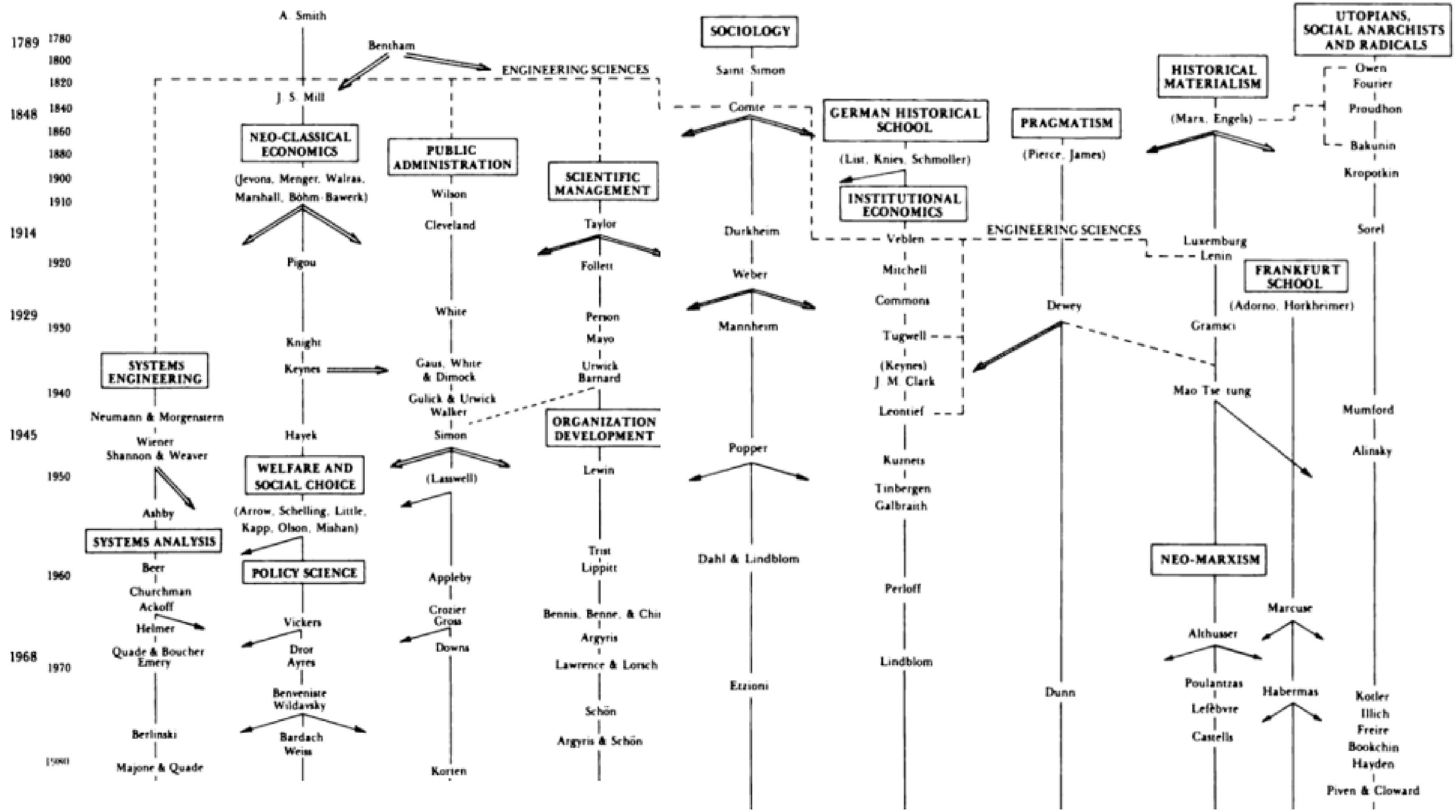

Figure 3: Timeline of intellectual influences on American planning theory. From [49]

6 Organizational Policy

“You include Organizational Policy as one of your reading areas. Please define what you mean by this term. What are the opportunities to be gained by using Systems Engineering to describe, explain, evaluate or prescribe organizational policy?”

Organizational policy is here intended to refer to policy, decision-making, and politics within an organizational stakeholder. It includes decision-making policies, mechanisms of institutional learning and memory, capability development, etc. This is to be contrasted with society-oriented policy, such as laws, regulations, and enforcement, which is largely covered within the Contextual Area of my General Examinations.

Understanding organizational policy is important for my work because many of the stakeholders involved in EVDT applications are large organizations with complex internal mechanisms and long histories. On the technology front, while those organizations developing, launching, and operating satellites has significantly increased in diversity in recent years, the field is still dominated by major government agencies and large corporations. Even some of the newer actors are complex enough to warrant a thesis studying their operations [57]. Meanwhile, societal and environmental impacts are firmly within the jurisdiction of government agencies, and such agencies are also major (though certainly not sole) expressions of human decision-making.

Fortunately, systems engineering has a long history of interacting with organizational policy, above and beyond stakeholder analysis. The traditional counterpart to the systems engineer, who handles the technical system architecture and design, is the program manager, who handles the organizational policy that drives the system design. As Rebentisch pointed out, a lack of mutual understanding and coordition between these two roles can negatively impact the system development [58].

One approach that may be taken for a systems engineer to approach organizational policy is to view the organization itself as a complex system, as was done by Pfotenhauer et al. to understand complex international science, technology and innovation partnerships [59] (a particularly relevant application to EVDT).

7 Expanding EVDT

Write a brief reflection on what you expect to be the challenges of expanding EVDT in future work by a wider community. Specifically, how will the code be managed and welcome contributions from a widening circle of developers? Will EVDT continue to require participants to have strong programming skills? What options may be available in the future for EVDT project team members to develop new functions without needed to program? What will be the process to build EVDT user interfaces that are intuitive and easy for people from multiple backgrounds to interpret?

Prior to discussing challenges, it might be worthwhile to briefly discuss the envisioned trajectory of EVDT. To that end, here are some general goals of this research endeavour:

1. Facilitate sustainable development. This is primarily accomplished by linking together different domains as discussed earlier.
2. Lowering the barriers to access relevant datasets and analysis methods in general, and remote observation data in particular. This means not just getting it in the hands of more researchers, but getting it in the hands of more laypeople as well.
3. Building a community of practice around SETS applications.

At the moment, EVDT is still in its initial stages. While we have international partnerships involving several different projects at the moment, it is still fundamentally a Space Enabled endeavour. Furthermore, while prototypes have been made, in none of the ongoing projects has it reached an operational stage that has been actively used by collaborators or commuity members (though we are getting closer to this). One or more operational applications are necessary to demonstrate viability to the relevant audiences. Once this is accomplished, the next step should be to consolidate and standardize the underlying code, so as to facilitate furture improvements, as well as the reuse of materials for future contexts. Certain key functions that are currently missing in the EVDT prototypes will need to be added, including the easy importing of new datasets and the easy exporting of analysis results and visualizations. Additionally, the individual models and functions should be easily separable and able to be recombined.

Once the initial round of consolidation and standardization is complete, both the EVDT code and the application itself will need to be made available online, ideally through a browser interface. The former, which is already accomplished for the current prototypes, is necessary to enable collaboration between various developers. Strong online norms and collaboration tools already exist for open source projects. As is currently the case, the initial code moderators will be Space Enabled affiliated, with contributions welcomed from anyone and anywhere. As individuals become well-known and respected contributors, they will be invited to become moderators. Furthermore, by making the code available on an MIT license, we are enabling forking and the development of more closed-off variants, which may be necessary for some treatments of sensitive data.

The latter (making the application available online), which is only partially accomplished at the moment, is necessary to expand the userbase. While the internet is not universally available (and disparities of access should certainly be kept in mind moving forward), having an in-browser accessible version dramatically lowers the barrier-of-entry for EVDT.

As the number of applications increase and the code is refined, the various models used in the applications may themselves be the first members of an openly accessible library of models. Potential user groups could adapt and reuse EVDT components in other applications, without having to start from scratch. Initially this would likely still require significant code expertise, but it is entirely possible for functionality to be created to allow for 'plug-and-play.' A user may be able to, in browser or on desktop, select a geographic area of interest (e.g. the Sóc Trăng Province of Vietnam), select an environmental model (e.g. coastal forest health), a societal impact model (e.g. cyclone vulnerability), a decision-making model (land use conversion and conservation policy), and a technology model (satellite versus in-situ monitoring), all without writing a line of code (though perhaps being required to import new datasets themselves). All of this would require that a sufficiently large library of models be built up.

In addition to model interoperability standardization, the code moderators will need to specify accessibility norms as well, so as to ensure usability by individuals with a wide range of backgrounds. Existing prototypes have made some steps in this direction, by having multiple language options available. Thus far, this has been accomplished by existing language knowledge of code moderators as well as the occasional volunteer translator, but some more targeted efforts may be required in the future to specifically recruit translators for targeted languages.

Language is not the only accessibility barrier, however. Terminology, presentation, and interactiveness can also be differentiately accessible to different individuals, depending factors such as educational or cultural background. That said, these difficulties can be addressed via some of the same methods that are already core to the EVDT methodology: namely partnerships with local collaborators; stakeholder analysis; and iterative, participative design.

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