ICED13
INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED13
19-22 AUGUST 2013, SUNGKYUNKWAN UNIVERSITY, SEOUL, KOREA

A METHODOLOGY TO SUPPORT STRATEGIC DESIGN AND MANAGEMENT DECISION-MAKING IN ENTREPRENEURIAL SYSTEMS: A CASE STUDY IN MOBILITY ON DEMAND (MOD) TRANSPORTATION

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ABSTRACT

This paper introduces a methodology to support strategic design and management decision-making in entrepreneurial systems that are called to evolve towards more complexity. It describes a framework to capture the early dependencies between the components and stakeholders of an enterprise organization that faces a wide array of uncertainty in a start-up environment. The methodology consists of two steps: 1) a layered DSM representation, and 2) flexibility analysis. The first step provides a systems-level representation of the enterprise, and enables quick identification of opportunities for flexibility. The second step enables thorough and quantitative analysis of opportunities for flexibility to support strategic design and management decision-making. The concept of flexibility, often associated to real options, is exploited as a way to deal pro-actively with uncertainty, which is prevalent in a startup environment. It provides entrepreneurial systems with the "right, but not the obligation, to change and adapt over time as uncertainty unfolds." The proposed methodology is applied as demonstration to the analysis of a startup system in the sector of mobility on-demand transportation.

Keywords: mobility on demand, strategic design, organizational system, design structure matrix, flexibility in engineering design, real options analysis, transportation

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1 INTRODUCTION

Very often entrepreneurial ventures are embarked on with little more than a seemingly good idea, wanton ambition and unyielding passion. The evolutionary and dynamic nature of start-up organizations, in general, coupled with the uncertainty of the world in which they venture makes such unbridled enthusiasm potentially detrimental to their long-term success, as the organizations themselves become increasingly complex. Such uncertain conditions call out for a methodology in which such an organization can consider all of its options given the current state of affairs to ensure that the strategic decisions being made will assure the greatest potential for continued growth and long-term success.

In this paper we introduce a framework to establish such a methodology by considering Company X, which is a start-up company operating in the very dynamic and locally untested Mobility on Demand (MoD) market space offering shared electric automobile and bicycle first and last mile transportation services. Representing such enterprises as complex systems, we propose an approach relying on DSM methodology and flexibility analysis to help start up companies, like Company X, make better strategic decisions as they manage the uncertainty of the early development and growth stages of the organization. This involves investigating the relationship between components and sub-components of the organizational system, and considering opportunities to optimize the management of uncertainty by means of flexibility and real options. It is proposed that such a framework will provide the ability to identify and optimize strategic decision making while conducting the day-to-day operations and long term objectives of the growing organization.

The paper proceeds as follows. Section 2 establishes new enterprises, like Company X, as complex systems and discusses precedents in existing literature. Section 3 describes the framework being proposed to support strategic design and decision-making. Section 4 describes the result of applying the framework to the real life organization of Company X. Section 5 discusses further work being undertaken which builds on the framework and Section 6 concludes on this ongoing study.

2 BACKGROUND

From an engineering perspective, systems are often thought of as large complex physical entities that require the coordination of many interactive parts. However, this paper proposes that the organization itself is, in fact, a complex system and thus subject to DSM and flexibility application. As such, this section establishes precedent by discussing what has been previously published in literature regarding organizational systems, DSM methodology and flexibility analysis.

2.1 Defining the Organizational System

The NASA Systems Engineering Handbook defines a system as the combination of elements, which include all hardware, software, equipment, facilities, personnel, processes and procedures, that function together to produce the capability to meet a need (NASA 2007). As a commercial organization, which was inherently created to meet a particular market need and is inclusive of the characteristics sited, it is reasonable to visualize and characterize Company X as a complex system based on the NASA definition. However, characterized by human and technical interactions, it is perhaps more definitive to describe such organizations as socio-technical systems. Badham et al. (2000) suggests that socio-technical systems have five key characteristics including, interdependent parts, the pursuit of goals in external environments, an internal environment comprising separate but interdependent technical and social subsystems, the ability to achieve goals by more than one means and performance relying on the joint optimization of the technical and social subsystems.

Understanding the relationship between the system components and how that relationship may be affected by environmental changes, whether it is internal or external to the organization, is critical to effectively managing the organization to future and prolonged success. Faced with an ever dynamic market place and thus regularly confronted with uncertainty, it is proposed that understanding such relational detail is perhaps even more critical to an entrepreneurial organization, which has to adapt based on an ongoing learning curve, as it grows. In proposing what they deemed the “Adaptive Cycle”, Miles et al. (1978) state that the dynamic process of adjusting to environmental change and uncertainty of maintaining an effective alignment with the environment while managing internal interdependencies is enormously complex, particularly for new organizations. Understanding these relationships is a critical initial step in enabling better strategic decision-making and thus enhancing opportunity for long-term success. As such, the use of Design Structure Matrix (DSM) methodology is proposed as a means of enabling such relational understanding.

2.2 DSM Precedence

Browning (2001) describes four types of DSM applications, including component-based or architecture, team-based or organization, activity-based or schedule and parameter based DSM's. Indeed, since first being introduced by Steward (1981), DSM methodology has been applied to a wide variety of engineering design problems. Eppinger and Browning (2012) profile forty-four sample applications covering a wide range of industries and addressing a multitude of problems in their book discussing the state of the art in DSM research. The breadth of case studies available easily demonstrates their value in constructing and gaining useful insights regarding complex systems.

At first glance, it would seem logical to apply the Organizational DSM, which is used to model organization structures based on people and/or groups and their interactions, to model the relationships inherent to an organization. While there is ample literature regarding DSM application to organizational systems, most examples focus on a specific attribute of the organization such as processes, functions or work teams. However, not all elements having relational properties within an organization can be easily categorized in such a specific manner. In addition, such acute focus often fails to consider the interdependencies between the multiple system domains. Mikaelian (2008) defines a DSM as a matrix representation of the dependencies within a single system domain, and instead proposes the use of a Coupled Dependency Structure Matrix (C-DSM) to capture the larger organizational perspective. She describes C-DSM's as larger scale models which consider the relationships within and between multiple domains of the same system. As a response to other models which "lacked scope such as adequately including both social and technical aspects of a system", Bartolomei et al. (2012) introduced the Engineering System – Multi-Domain Matrix (ES-MDM) which defines a structure that consists of six classes corresponding to five engineering system domains. By considering the broader perspective of the organizational system and detailing the relationships between the multiple organizational domains and their sub-components, it is proposed that areas of uncertainty critical to decision requirements can be highlighted. As such, design and management solutions considering a more flexible approach, as a way to deal pro-actively with uncertainty, can be considered via more formal real options analysis techniques, considered next.

2.3 Flexibility Precedence

Flexibility can be defined as the ability to respond to future changes in a complex system or in its environment (Fricke and Schulz, 2005). It is often associated with the notion of a real option, providing the "right, but not the obligation, to change a system in the face of uncertainty." (Trigeorgis, 1996). Complex systems are inevitably subjected to uncertainty that can easily impact the long-term success of the design project if not considered appropriately. As such, real options advocates rely on financial analytical techniques to support decision-making in projects significantly affected by uncertainty. de Neufville and Scholtes (2011) state "it is not obvious which flexibilities will add the most value to a project". Often the objective of flexibility analysis is to establish an awareness of real option possibilities that may be implemented to enhance lifecycle performance. When considering complex systems the identification of areas of uncertainty and flexibility potential is often subjected to the expertise of the design engineer (Cardin et al. 2012). However, several methodologies based on change analysis have been proposed for identifying uncertainty and enabling flexibility consideration.

Many of these methodologies focus on identifying the potential for change for the inherent components of the greater system. Siddiqi et al. (2011) proposed a posteriori design change analysis which considered the temporal, spatial and financial view of the systems' collective change activity. Koh et al. (2012) introduced an indirect dependency modeling technique that uses a matrix-based approach and drew on the Change Prediction Method (CPM) proposed by Clarkson et al. (Clarkson et al. 2004) to generate change indices for individual system components which can then be used to assess the changeability of the engineering system.

While these examples focus on changeability analysis, such tools can also be used more specifically to identify opportunities for flexibility. For example, Hu and Poh (2012) proposed a sensitivity-based methodology that considers both direct and indirect exogenous uncertainties to identify flexible design opportunities. Suh et al. (2007) proposed a methodology that considers the Change Propagation Index (CPI) and switching cost to determine which system components are most suitable for flexibility consideration. While a similar CPI calculation is used here to assess Company X, such a technique has not been used to identify flexibility opportunities in the context of a startup organizational system.

2.4 Summary

An important gap from the above literature is that analyses have typically been done on well defined systems such as product architectures and otherwise relatively well defined enterprises (Mikaelian et al., 2011; Bartolomei et al., 2012). It is unclear how complexity and uncertainty can be handled in a new and evolving environment of an entrepreneurial organization. The system may not be well defined as it is required to become more complex over time. Therefore, the main contribution of this study is to suggest a DSM-based methodology that can be used to analyze strategic design and management decision-making in such a context, considering in particular, a startup environment where information is scarce, and relationships are initially difficult to establish. The methodology is described next, and demonstration of the application is then demonstrated on MoD entrepreneurial system, Company X in section 4.

3 ESTABLISHING A FRAMEWORK

This paper introduces the framework depicted in Figure 1 and discussed in ensuing sub-sections as a methodology for enhancing strategic design and decision-making in a startup and highly uncertain environment. While the individual components of the proposed framework have been informed by existing literature, the novelty resides in how it is applied in an entrepreneurial context.

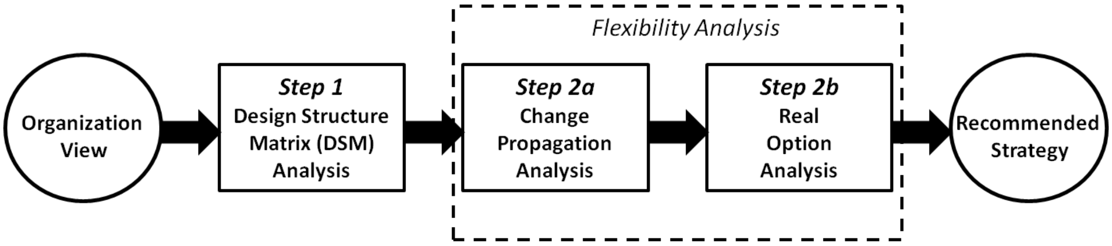

Figure 1. Proposed framework to analyze strategic decision-making in start-up enterprise

3.1 Step 1: Using DSM Methodology to define organizational relationships

While using a modeling technique to identify the relationships between the various components of a physical product is fairly easy to visualize, applying such a technique to a socio-technical system such as an organization is not as obvious. For this reason it is useful to borrow from what has been proposed by “Enterprise Architects” regarding enterprise architecture frameworks. To this effect, Rhodes et al. (2009) proposed an enterprise architecture framework that includes eight views including, strategy, policy, organization, process, product, service, knowledge and IT. However, while the Rhodes proposal captures views common to many organizations it suggests a standard application to all enterprises.

The methodology proposed here begins with establishing an architecture that is customized and unique to the organizational system under consideration. Reclassifying a view as a domain, the architecture should consider all key domains that shape the entire structure of the organization. From this unique perspective it is reasonable to treat the different organizational domains as “components” of the larger organization and thus subject to DSM component-based modeling. However, unlike hardware products where the physical dependencies have more defined boundaries, each of the high level domains are fairly broad in scope and therefore, the dependencies are more varied in nature. For example, in the case of Company X, three types of services are offered including eCar, eBicycle and eShuttle services. While similar in many ways, each has a unique dependency profile when compared to the other organization domains and their sub-elements. As such, it is beneficial to introduce a layered DSM approach that decomposes the higher level domains into their sub-elements to instill more defined borders and thus more accurate dependency analysis.

The layered approach suggests an iterative process by which the DSM methodology is applied to increasingly detailed views of the enterprise architecture framework, starting from a fairly high-level, low-resolution view. Considering the organization from its very high level architecture first provides a quick understanding of the system, before going into the detailed and highly uncertain aspects of subsequent lower-level views. Such a methodology is better suited for startups, as opposed to mature systems, because it encourages focus on the high-level system elements first, enabling quick identification of areas most susceptible to change, and thus sanctioning more detailed focus on areas of interest via subsequent lower layer DSM analysis. This also speeds up the analysis in an environment where the organization may not be well-known, in contrast to DSM applications to product development where the system is fairly mature and well-defined.

It is shown in Section 4 that applying such methodology to the customized view of Company X will enable an analysis that identifies the unique dependencies inherent to the organization. Identifying these areas of uncertainty suggests that flexibility and real option analysis can be considered and applied as a means of enhancing decision-making and providing better solutions for strategic deployment and operations.

3.2 Step 2: Applying flexibility analysis

This paper is proposing the use of flexibility analysis as a means of supporting better strategic decision-making in the day to day and long term management of an entrepreneurial organization. This paradigm is appropriate, especially since a start-up company faces significant uncertainty from multiple sources (e.g. market, regulations, finance). Indeed, Danilovic and Browning (2006) suggest that uncertainty stems from the (often flawed) assumptions about the dependencies among system components and advocate the need for information exchange within and between domains and people to provide better solutions to problems.

Modeling Company X utilizing DSM methodology will provide access for more detailed analysis defining relationships within the organization that may not be obvious, but are perhaps suitable for flexibility considerations. As such, applying a flexibility analysis methodology is advocated for leveraging the relationships identified to enable consideration of multiple decision options for how to proceed. The flexibility methodology proposed involves a two-step process including both a change analysis and real option analysis.

3.2.1 Change propagation analysis

Leveraging the Change Propagation Analysis (CPA) methodology proposed by Suh et al. (2007), a similar change analysis technique comparing Company X organizational domains is used to identify areas within the organization that are most favorable for further real option analysis. For a particular design component i, CPI_i expresses the difference between the amount of change information ΔE_{in} propagating "in" a component from components connected upstream, and the amount of change ΔE_{out} propagating "out" to other downstream components. For a system with *n* components, CPI is calculated as shown in Equation (1):

$$\text{CPI}_i = \sum_{j=1}^{n} \Delta E_{j,i} - \sum_{k=1}^{n} \Delta E_{i,k} = \Delta E_{out,i-} - \Delta E_{in,i} \qquad (1)$$

Based on Eckert et al. (2004), a system component that receives more change than it creates (CPI < 0) and is called an absorber (A as shown in figure 3). A component that receives the same amount of change as it creates (CPI = 0) is called a carrier (C). One creating more change to downstream components than it receives (CPI > 0) is called a multiplier (M), and represents potential areas to embed flexibility. The CPA methodology is applied to each DSM layer successively. Doing so enables the identification of increasingly specific areas of uncertainty, and thus more insight to flexibility and real option analysis potential, without the immediate need to go through a full fledged analysis, as done by Suh et al. (2007). In contrast, the nature of the process suggested here is iterative, with attention and resources focused on increasing levels of details.

3.2.2 Real options analysis

Having identified areas of consideration for flexibility, real options analysis is applied to quantify the value and rank order different design and management strategies that deal pro-actively with uncertainty. Inspired by the method proposed by de Neufville and Scholtes (2011), a basic lifecycle performance model like Discounted Cash Flow (DCF) is used first to evaluate the different design alternatives under deterministic conditions. A suitable metric such as Net Present Value (NPV) can then measure lifecycle performance to find the best design and management alternatives. Second, uncertainties are introduced into the model using various probability distributions and Monte Carlo simulation. A large number of possible scenarios is generated, which consider the expected NPV (ENPV) and other metrics (5^{th} percentile of distribution to quantify the downsides or Value At Risk, 95^{th} percentile to quantify the upsides or Value At Gain, volatility, etc.) to compare alternatives. Third, flexibility is embedded in the model by altering certain design parameters based on some decision rules. For example, for Company X a decision rule may include exiting the bike service should the profit generated from the service fall below a certain threshold. Finally, the value of flexibility is measured by comparing the new ENPV to that of the base case design, and sensitivity analyses would be carried out to verify the results. Section 4 demonstrates how the proposed framework can be applied to analyze a startup MoD system such as that of Company X.

4 INDUSTRY APPLICATION

Providing last mile transportation, Company X is a green energy advocate offering a strictly electric mobile fleet, which includes both bicycles and cars. A goal of the organization, which is unique from other players in the transportation sector, is to offer one-way drop off capability without penalty. Current transportation providers typically require customers to return the vehicle to the point of departure or pay an additional fee. Both the electric vehicle commitment and the ability of one-way use demonstrate areas of uniqueness that may impact the relationship between the organization domains and their inherent sub-components, thus influencing specific decision requirements of the organization. As such, the ensuing sections demonstrate how DSM modeling and flexibility analysis may be useful in determining such unique decision points in greater detail and thus enabling better strategic decision making specifically customized for Company X.

4.1 Analyzing Company X

Figure 2 provides a high level descriptive model of the Company X organizational system. Focusing on service delivery, it details the key elements included in the infrastructure and operations domains that support that delivery process. It also emphasizes the relationship of the key stakeholders including clients, the work team and partners to the organization.

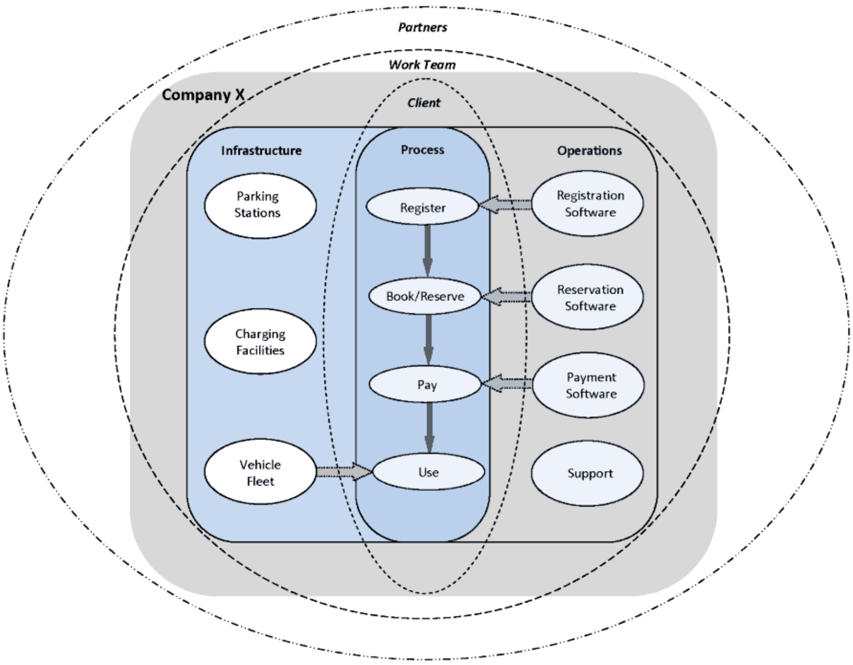

Figure 2. High-level Company X descriptive model

While this descriptive model highlights some key relationships within the system regarding service delivery, it is lacking when describing how the organization functions and interacts both internally and with its wider environment. Nevertheless, the model guides in the thinking process towards developing the enterprise architecture framework including the key domains that describe Company X and are used as inputs for DSM modelling. Table 1 describes the architecture and unique domains that have been proposed to provide a systems-level representation of Company X.

Table 1. Company X organizational framework and systems-level view

Domain	***Description***
Service	The product offered by the organization. For Company X this includes electric bike and car rental services and a chauffeured shuttle service.
Strategy	The vision and business model by which the organization will provide the services offered and expand its business. For example, the mix of services offered and related pricing are key strategy components.
Organization	The structure of the organization managing the day-to-day business needs. Typical of most early stage start-ups, Company X's structure is not clearly defined but expected to become more focused as the organization grows.
Infrastructure	The physical assets of the organization. For Company X this includes electric bikes and automobiles, parking facilities and the operations support system.
Stakeholders	The human element of the organization. For Company X this includes the current work force, customers, investors and other groups with vested interest in the types of services being offered by Company X.
Operations	The day-to-day activities required to provide the product being offered. For Company X this includes but is not limited to fleet maintenance, fleet rebalancing and registration/reservation support.
Technology	The technology utilized by the organization to provide the offered product. For Company X this includes fleet (self-piloted cars) and operations improvement.

4.2 Step 1: DSM analysis of Company X

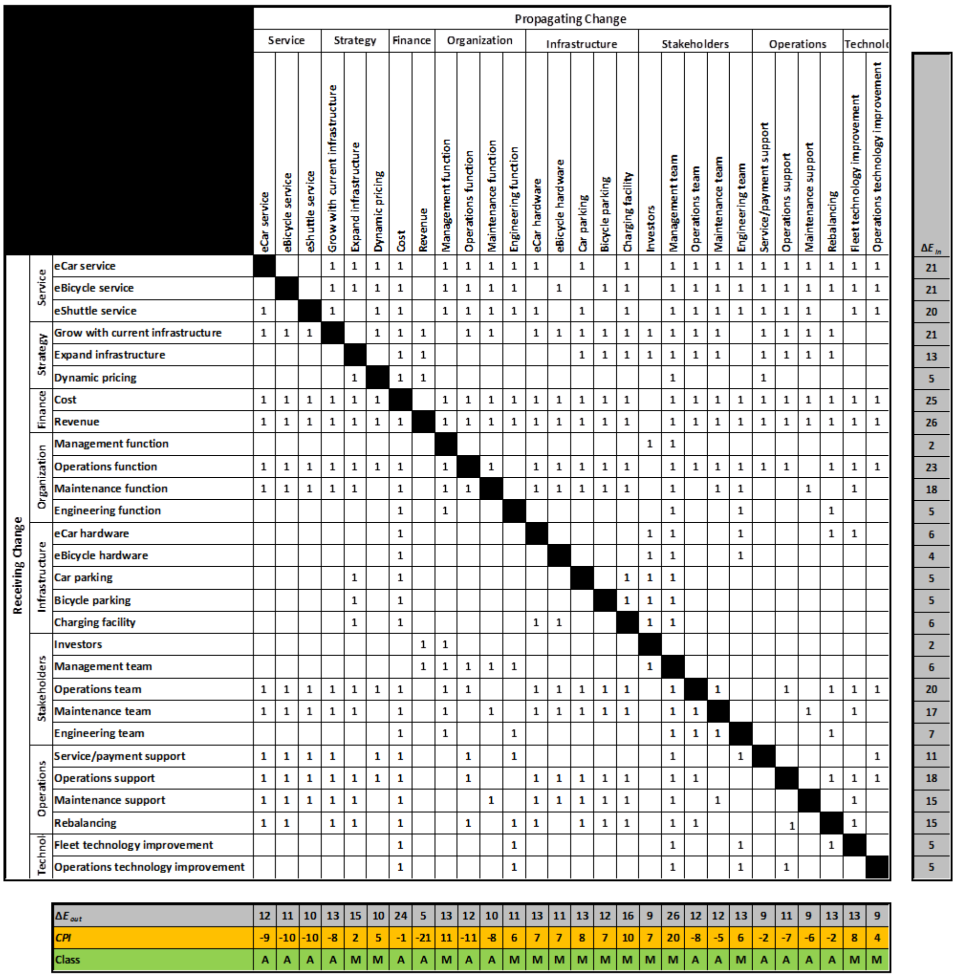

Figure 3. Company X 2nd Layer DSM analysis

Working closely with Company X, a high level DSM analysis (not shown for brevity) considering the main organization domains of Company X was constructed. Eppinger and Browning (2012) suggest that when modelling interactions for an organizational DSM it is helpful to focus on a single question. Therefore, the comparison was conducted considering the question: “For Company X to provide the service it offers if change occurs to A will it propagate to B?” Having constructed the high level DSM a CPA analysis was applied and identified flexibility potential for the system domains of strategy, organization, infrastructure, stakeholders and technology. Leveraging this result, Figure 3 shows the next iteration 2nd layer (i.e. more detailed) DSM analysis of Company X that was constructed considering each high level domain. The matrix suggests that the domain elements in the left column are “dependent” on the domain elements reading across the top. For example, the result indicates that the “Service” sub-element “eCar service” is subject to change depending on changes in every sub-element of “Strategy”. Reading down the matrix suggests that the domain across the top “affects” the domains read down the left side of the matrix. For example, “Infrastructure” sub-element “eCar hardware” only affects the “Service” sub-elements of “eCar service” and “eShuttle service”.
The results indicate substantial dependencies between the multiple sub-domains of Company X considered. This would be expected of a new socio-technical system in a startup environment, even when subjected to a specific question. However, even with a heightened level of dependency between the sub-elements of the different organizational domains, the result gives insight to the dependencies that can be initially considered and establishes the basis for further analysis. As expected the 2nd layer analysis provides more specific details of the inherent dependencies than the high level result did thus providing more specific focus on where flexibility and real options may be considered as discussed in the next section.

4.3 Step 2: Flexibility analysis of Company X

Figure 3 shows the CPA analysis that was applied to the 2nd layer DSM model result for Company X. As expected, the sub-elements of each of the high level domains not identified as “multipliers (M)” in the high level analysis were likewise not identified as multipliers here. However, for those high level domains identified as “multipliers”, the CPA result clearly shows more specific areas of uncertainty that were not as obvious in the high level analysis. The identification of a number of sub-elements of “Strategy” as areas of uncertainty is logical, as it would be for any organization that has multiple strategic options in growing their business. What is interesting for Company X is that Strategy sub-element “grow with current infrastructure" was not identified as a multiplier. This makes sense when considering that, while certainly not void of uncertainty, it is more known and not nearly as uncertain as strategies to expand the infrastructure or experiment with different pricing plans. The inclusion of each sub-element of “Infrastructure”, as areas of flexibility consideration, is somewhat expected, as Company X needs to optimize its location presence and fleet size in order to optimize the service offered and ultimately the profit of the organization. The inclusion of “Stakeholder” sub-elements “investors” and “management team” is also fairly obvious as both are critical to the early success of a start-up. The failure to secure early investor support and poor management can easily undermine the success of an entrepreneurial company before it ever really gets started. Not as obvious is the inclusion of engineering team. However, when considered from the perspective of a MoD start-up this is logical when considering the critical contribution they make regarding operation system and vehicle technology advancement. Also not as obvious is the inclusion of both “Technology” sub-elements as areas of uncertainty, however, similar to the logic supporting engineering function, technology advancement is very important in this developing industry sector.
Opportunities for flexibility can be generated by exploring the areas highlighted by the DSM/CPA analysis and leveraging the inherent expertise and experience of current Company X members. For example technology decisions may include whether or not to invest in technology advancement which could include upgrading the current operations support system or developing self-piloted cars. This is particularly pertinent to Company X where rebalancing the vehicle fleet is necessary in order to make one way travel possible. For example, should Company X continue to use manual labor to perform this task, invest in upgrading its operation support system to make the manual procedure more efficient, invest in developing and then upgrading their vehicle fleet to self-piloted vehicles when they become available or perhaps consider a pricing option such as dynamic pricing that induces customers to rebalance the fleet naturally. All of these options are areas of uncertainty that could be considered for flexibility analysis. The result may inform decisions on how Company X should expand its work force

to meet its long-term objectives. As the analysis suggests, for Company X, it can be speculated that the engineering function is most critical as it seeks to optimize its fleet and operations technology.

While this paper demonstrates how opportunities for flexibility analysis related to strategic decision-making can be generated from the proposed framework it is suggested that further refinement will propose even better results. As such, further iteration of the framework proposed is under development and suggested as a key objective of future work progress.

5 FUTURE RESEARCH

Future research aims to address the limitations of this work. The next immediate steps are to further refine the framework and demonstrate its application is to conduct real options analysis of the flexibility opportunities identified. In this paper the first two steps of the framework proposed including DSM modeling and change propagation analysis have been demonstrated for MoD operator Company X. Further iteration of the framework will enable the identification of more specific component dependency and thus more specific uncertainty identification. For example, considering even lower layer domain views of the organization and/or proposing a more specific question and defining more specific sub-elements will enable more defined relationships between the different components. Such detailed consideration of the inherent relationships between components will enable clearer vision in determining organizational dependencies. As such, more exact flexibility opportunities can be identified and subjected to real option analysis using the steps inspired from the process proposed by de Neufville and Scholtes (2011).

The conclusions of this work are anticipated to contribute to the existing body of knowledge on DSM. Specifically, the DSM could be used to offer a broader, systems-level representation and description of entrepreneurial organizations. In addition, it will contribute to industry practice in terms of offering a framework and technique to identify potential components in the organizational system to embed flexibility as the system evolves, with an eye towards improving lifecycle performance. This approach will help build a system that is robust against future uncertainty. This analysis will support strategic decision-making with a quantitative economic assessment that can be compared to the cost of enabling flexibility. In this case, only the strategies offering higher expected economic value, as compared to the cost of acquiring the flexibility (e.g. acquiring the right to add more sites in the case of Company X), should be pursued by the start up organization.

6 CONCLUSION

Academic research has recognized, through descriptive writings and the proposal of tools and methodologies, the importance of both DSM methodology and flexibility analysis in the system design and implementation process. While there has been limited entry into the realm of combining the two, much of what has been written has been exclusive to one or the other. In addition, the work done has been mostly focused on physical products. Very little work considers the complexity of the enterprise.

In this paper we present the initial findings of work being conducted that embraces both DSM methodology and flexibility analysis to assess an entrepreneurial organizational system for enhancing strategic design and decision-making. By applying the proposed framework to MoD operator Company X, initial validation of the framework, as a working methodology, has been established via demonstration. However, there is scope to further refine the framework proposed and demonstrate its full application to the analysis of an entrepreneurial organizational system. For example, although the sample organizational system has been decomposed into its 2^{nd} layer sub-components, a limitation of this paper is that the framework has been applied at a high level and as such, potential specific opportunities are proposed in this broader context based on system actor expertise. It is proposed that further iteration of the DSM analysis to examine more defined sub-domain relationships will identify flexibility opportunities with minimal input from system experts. In addition, real option analysis has been proposed but not demonstrated in this paper. To that effect, future research is proposed to examine this topic in greater detail with the ultimate goal of establishing the framework as a solid methodology.

More specific to the MoD industry, this paper has demonstrated areas of flexibility consideration that are very specific to MoD transpoartation systems and Company X in particular. As such, optimistically, the framework and technique might well be exported to other countries that are interested in setting up a MoD transportation system in their country and thus help them understand the system and facilitate better decision-making in doing so.

ACKNOWLEDGEMENTS

The authors of this paper would like to thank Amedeo Odoni and Tom Lokenvitz for their participation and valuable support to this research. This project is funded by the Singapore-MIT Alliance for Research and Technology (SMART) Future Urban Mobility (FOM) IRG via grants WBS R-266-000-069-592 and R-266-000-076-592.

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