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ACCULTURATION OF SYSTEMS THINKING FOR REQUIREMENTS NEED ANALYSIS FOR SMART ENERGY CITY DEVELOPMENT: A CASE STUDY IN ACCRA

BISMARK APPIAH ADDAE & LING ZHANG

Department of Management Science and Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing, China

ABSTRACT

The acculturation of Systems thinking (ST) for the development of Smart Energy City, (SEC), is crucial for its success. Smart Energy City can be seen as a sustainable component of the whole complex system of Smart City with the core aim of sustaining the energy needs of the city. Smart Energy City is itself a complex system and can be perceived as a Systems of Systems (SoS-SEC) comprising of other sub-systems both internally and externally, all interacting with it. Analyzing SEC from a simple cause and effect point of view similar to reductions is not enough to understand its complex nature. System thinking goes deeper, considering issues such as unintended consequences, circular interrelations between cause and effects, time delays and boundaries of the system, and it is useful in the requirements analysis of Smart Energy City Development.

Again, the successful development of Smart Energy City faces challenges from both technical and non-technical point of view. To fully dissipate its successful development, it's identified challenges that form the basis of its development has to be fully addressed and factored into the system requirement stage of its development. This paper suggests the need for the analysis of the system requirement needs of Smart Energy City development be carried out through the art of systems thinking modelling, taking into consideration the interdependencies not a snapshot of various needs that ought to be addressed in the development. This is so because the various needs of Smart Energy City are not independent but interrelated somehow. System thinking helps to wholly understand the Systems of Systems nature of Smart Energy City.

This paper presents an adapted Systems definition for Smart Energy City Development (SECD) that integrates the general core functions of Smart Energy City (SEC). Also the synergies existing between Systems of Systems and Smart Energy City, SoS-SEC is established and finally, the exploration of the strengths and weakness of systems thinking is also established with emphasis on how and when both can be capitalized in its use. Systems thinking does not only ensure that the right needs are addressed but also can help optimize decision making process through its loops functionality. This concept was applied to a case study of Smart Energy City development in Accra, where systems thinking was adapted during the system requirement stage to analyze the causal hypothesis for smart energy city development.

KEYWORDS: Systems Thinking, Systems of Systems, Smart Energy City, System Requirements & System Interdependencies

INTRODUCTION

As globalizations grow, complex systems erupt naturally and artificially and not many arguments can support the need for the adoption of system thinking in managing these phenomena. With the rise in world population concentrated in the cities, smart system and integration should also be enhanced in direct proportionality not only to embrace the needs of the people but as well as ensure efficiency and minimum or no negative environmental impact, (VTT Research Centre, 2015). Nations are increasingly being interconnected, with a growth in our social systems with each increasing the interdependencies of other systems in a new complex way.

These complex interconnections inevitably stipulate cause-ripple-effects in another, establishing a whole complex cause hypothesis of interdependencies within the systems, (Arnold & Wade, 2015). More so, organizations operates in a more complex and uncertain context stipulated by social reforms leading to quicker dynamic pace, high dependency on surroundings as well as increased complexities, (Lindahl & Hallberg, 2014). Viewing Smart energy city development as core sustainable components of a smart city, city makes it complex systems of systems with a high level of integration required for its success. Looking at how complex a smart energy city is, managing it with a simple traditional approach of breaking the whole into parts for easy analysis (reductionism) can be useful in understanding individual components but not efficient enough to be generally applied in understating the overall outcome of the system.

The US Department of Defense (DoD), defines Systems of Systems as a set of arranged systems that results when independently useful systems are integrated into a larger system which deliver a unique capability, (Dahmann & Baldwin, 2011). Systems thinking has been used and defined by various authors in a more different way to suit their requirement analysis of an existing system or one that is yet to be developed, however the the core elements of dealing with issues such as complexity, interconnectedness, emergence identification, cause and effect relations, dependability etc. isn't missing.

The successful implementation SECs is important for a sustainable transition of urban energy systems. An enhanced cooperation of cities towards area utilities and smart energy city has numerous benefits including improved grid resilience and improved quality of life for citizens (Callaway, 2016). However, the success of smart energy city faces a lot of interconnected problems. Accra has to be a smart energy city in order to help the country achieve its upper-middle income status. One important aspect from the system engineering point of view is the asking of the question, WHAT does the system, smart energy city need in its development? How can we determine fully the requirements of this system? and how can we develop and achieve this in a resource deficient city? Since virtually no comprehensive research has been done in this field, this research then adapted cultures from Systems thinking, ST, in analyzing what Accra needs to factor in its Smart Energy Development starting by first analyzing her current energy situation and challenges related to smart energy city. The research focused on smart energy city as systems of systems (SoS) through a careful analysis of its components interacting with its environment, in this case smart city This was useful because the interdependencies of each constraints was fully analyzed and not assumed as an independent entity.

BACKGROUND INFORMATION

A Systems thinking is a Tran's disciplinary approach that contributes to meeting the need for an improved problem formulation, requirement gathering as an important step for the development of a specific system or systems of systems, in this case Smart energy city. Systems thinking are useful in addressing the challenges of requirements, taking into consideration its interrelated complexity of which it is the belief of the researcher as the true nature of a smart energy

city. It is a powerful analysis tool not only useful in requirement engineering analysis but also for the analysis of the whole outcome of the process from a system point of view. With reductionism, emphasis is being placed on the effect A (cause) has on B(effect), but systems thinking goes deeper and believes B has an influence on A and the behavior exhibited by B is not only as a results of A but other factors emanating from its environment, (Shaked & Schechter, 2017). Hence the adaption of Systems thinking in recent years yields an increased efficiency to fully understand the structures and dynamics of complexity, (Lindahl & Hallberg, 2014) and so is necessary for a Smart energy City.

What then are systems thinking? Systems thinking can be seen as an approach to a problem that considers how components within the whole system operates and interact over its lifecycle, how to optimize the design, implementation and evaluation (Kapp, Simoes, DeBiasi, & Kravet, 2016). Other definitions can be seen in literature about systems thinking such as its ability to enable one to grasp and manage complex and uncertainty in which there are no simple answers. Also defined as a mental effort to uncover endogenous source of system behavior; again defined as a frame work of seeing interrelationships rather than things, for seeing patterns rather than static snapshots; and also defined by INCOSE as a way of thinking used to address complex and uncertain real world situations with emphasis on interconnected technical and social entities which are hierarchically organized producing emergent behavior, (Freeman, Yearworth, & Cherruault, 2014).

According to (Shaked & Schechter, Systems Thinking for School Leaders, 2017), systems thinking is simply defined as a way for humans beings to understand systems with emphasis being put on systems as a functionally related assemblage of interacting, interrelated, or interdependent elements forming a complex whole. Systems thinking can be seen as a way of thinking that perceives the 'whole' first with its fits and relationship. The focus of systems thinking is dynamic in nature considering all forms; vertical, horizontal and circular not limited to the conventional style of thinking where it takes liner path. A systems thinking assumes randomness and unanticipated or unpredictable consequences within the risk analysis framework. It focuses beyond simple cause and effect within a given situation providing a long term thinking approach to the problem, (Ponto & Linder, 2011).

The Systems thinking ignores independencies and believes that everything is dependent on something and that the behavior of a system depends on the nature of relations of its sub components. In smart energy city, dynamism is associated to its development especially the fact that human beings emanate as an integral part and therefore reductionism is no longer appropriate for dynamic systems. It falls short of managing the complexity of smart energy city with its simple way of seeing the world, (Morgan, 2005). Systems thinking approach is ideal for analyzing requisite needs to smart energy city development due to its strong ability of allowing a complete interrelation of other sub components of the system and its environment.

Table 1: Showing Strengths and Weakness of Systems Thinking Approach

Systems Thinking	Reference	Remarks
Focus on complex interrelationships within the system	(Freeman, Year worth and Cherruault 2014), (Shaked and Schechter, Systems Thinking for School Leaders 2017) (Mathews and Jones 2008)	A good tool for long term solution since all relating parts are considered
Deviates from reductionism and focuses on the 'whole' in its analysis	(Kapp, et al. 2016), (Shaked and Schechter, Systems Thinking for School Leaders 2017), (Sun, Hyland and Cui 2014)	This does not support the misconception that reductionism isn't good but a better way analyzing the SoS nature of SEC.

Table 1: Contd.,		
Has the ability to model complex systems	(Mathews and Jones 2008), (Kapp, et al. 2016), (Sun, Hyland and Cui 2014)	This helps to easily understand graphically the interactions of all requirement needs of the system
It is useful in soliciting requirements needs at the initial stage of systems development.	(Edson 2008)	It is capable of soliciting all needs necessary for development and can accommodate large data in its modeling
A powerful method for system loop analyses	(Ponto & Linder, 2011), (Kapp, Simoes, DeBiasi, & Kravet, 2016), (Sun, Hyland, & Cui, 2014), Carey, et al. 2015 (KIM, 2000), (Leischow, et al., 2008)	This unique functionality makes an essential tool in decision and policy analysis
Focuses on system dynamics and structural modeling	(Sun, Hyland and Cui 2014)(William M. Trochim, et al. 2006), (Aronson 1996), (Leischow, et al. 2008)	Can translate interrelations into structural modeling and can analyze system dynamics
Decisions and modeling is done under uncertainty, data imprecision and vagueness	(Year worth 2014), (El-Jardali, et al. 2014)	This is one major shortfall of system thinking, where decision are normally imprecise and vague
Can model cause and effect relationships	(Kapp, et al. 2016), (Freeman, Year worth and Cherruault 2014)	A good tool for causal hypothesis analyses of results
A good qualitative decision supporting tool	(Sun, Hyland and Cui, A Designed Framework for Delivering Systems Thinking Skills to Small Business Managers 2014), (Carey, et al. 2015), (Kim 1999),(Year worth 2014)	It cannot handle quantitative data. Well, maybe not its use but can be enhanced.

(Elsawah, McLucas, & Ryan, 2015), highlighted in their work about the so-called ‘first wake up ‘call for the need of systems thinking by Checkland, who was a systems engineer, in his write-up he said,“We found that although we were armed with the methodology of systems engineering and were eager to use its techniques to help engineer real-world systems to achieve their objectives, the management situations we worked in were always too complex for straightforward application of the systems engineering approach”. The challenges in requirements elicitation including role of the system observer, nature of system requirements in complex situations and influence of the system environment was highlighted according to (Katina, Keating, & Jaradat, 2014). A careful analysis of systems thinking, see table 1, shows that it is a powerful tool for requirement gathering except for a few lapses which can be improved by other methods depending on the goal of the project.

Based on all of these supported literature and practical experience, it can be concluded that 1) Systems thinking is important for understanding system requirements, 2) Smart energy city requirements cannot be fully understood with a snapshot analytical tools, 3) The outcome of the whole of a system is as a results of the behavior of its sub components, 4) There are complex interdependencies existing between components of SEC as a systems of systems and 5) Requirement analysis in systems engineering is important for the development of a system, in this case, Smart Energy City.

System Definition of Smart Energy City

According to Transform definition of smart energy, it is one that is highly energy and resource efficient and is increasingly powered by renewable energy sources; it relies on integrated and resilient resource system, as well as being driven by innovative approaches through the application of information, communication and technology in meeting its objectives. Also, according to the same report, Smart energy city ensures a livable, affordable, climate-friendly and engaging environmental processes that supports the needs and interest of its users and is based on sustainable economy, (Nielsen, Amer, & Halsnæs, Definition of Smart Energy City , 2013).

Acculturating systems thinking into the systemic definition of smart energy city by nature as an approach to problems through the asks of 'What?' Why? When? Who? And 'How?' of the various components of a system influences each other. What then is a system? And how can smart energy city definition be modified to suite a system? A system can be defined as ''as an assemblage of objects united by some form of regular interaction or interdependence'' (Mele, Pels, & Polese, 2010). A smart energy city can then be defined as an interrelated systemin which people, technology and energy resources are sustainably optimized and interoperable at the city scale ensuring a livable, energy efficiency, affordable, climate-friendly, sustainable economy and sustainable energy system integrations are met for user consumption.

SYSTEMS THINKING METHODS

A Systems thinking is a methodology that aids in the visualization of interrelationships existing between complex systems. With the focus on the fact that the adaption of systems thinking methods helps in the understanding of pertinent issues that need not to be ignored during systems development, this includes, the understanding of the world through a modeled complex system, interrelationship analysis and conceptualization as well as the integration of the system, (Mathews & Jones, 2008). It can be thought of as a language with a specific focus on how to view the world. Through its utilization we can better understand the complex interactions of a circular causality through its feedback loops, simply put the effect 'a' has on 'b' and 'b' on 'a', (KIM, 2000). Figure 1 shows a systems thinking behavior for smart energy city development: a case study in Accra, Ghana.

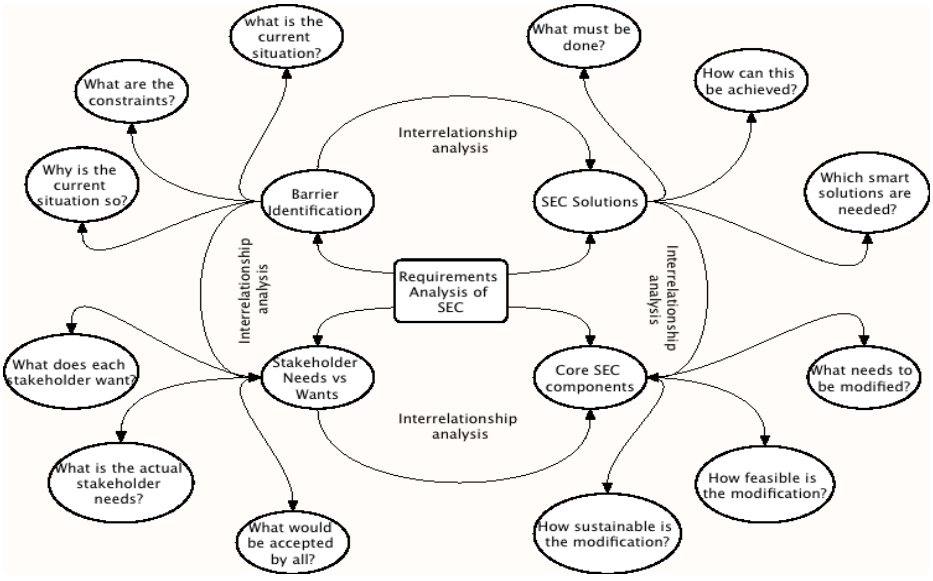

Figure 1: Systems Thinking Behavior for SEC Requirements using UML Tool

Though systems thinking has been with us since ancient times, its recently receiving a rather quick attention and regarded as a maiden way of thinking to understand global levels of complex systems. System thinking provides an overview of simply analyzing a problem situation and an approach to problem solutions, (Edson, 2008). As Well, systems thinking follow certain assumptions that firstly, systems and problems can't be addressed through the reduction of the system to their individual components; secondly, it should be seen as an ordered methodological process of understanding problem situations and identifying possible solutions to these problems. Three components found in this process according to the same report are; understanding the system external context, understanding the system itself and developing solutions through a systematic investigation.

Various approaches to enhance systems thinking have been developed. Amongst the many, stand the popular 'iceberg' systems thinking approach and the soft systems method, SSM. The iceberg model divides thinking processes into three levels. Namely; ***'events', 'patterns' and 'systemic structures'***, figure 2 shows iceberg systems thinking approach. Other literatures extend these three levels into an extended form, making it five, including ***'mental'*** models which describes our beliefs and assumptions of perceiving the world which gave rise to the systemic structures and finally, the ***'vision'*** as the fifth, explaining our future goals for what we want, a guiding force that determines our mental model (Kim, 1999). The first level, ***'events'*** actually what represents the visible part of the system being analyzed and mostly requires prompt attention. Most decision making processes take place at this level simply because at this level, the constraint is visible and evident to decision makers and analyses seems more concrete. However, according to this analogy, iceberg, it is a rather a glib way of thinking through a problem, since it does not solve the long term objective of the system being analyzed, but the short term, (Sun, Hyland, & Cui, A Designed Framework for Delivering Systems Thinking Skills to Small Business Managers , 2014).

The 'iceberg' approach helps in understanding how systems fit into a broader context. A deeper understanding of a system implies the need to understand the accrued memories of events, displaying repeated trends when put together as a series over time; this was termed ***'patterns'***. The ***'systemic structures' which*** is the third describes the relationships existing between the various components of the system.

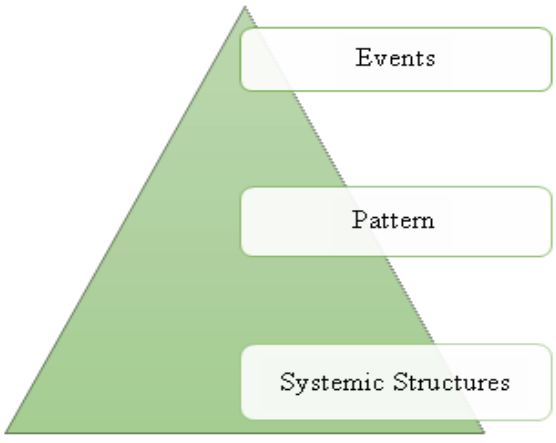

Figure 2: Iceberg Systems Thinking Approach

Source: Three level of 'iceberg systems thinking method adopted from (Kim, 1999)

It describes the ways in which the parts are organized and connected which determines the patterns and events we analyze, (Kim, 1999). At the structural level, a causal hypothesis can be analyzed, highlighting the cause-effect

relationships existing between various components of the structure. The soft systems method, SSM was developed first by Check land which provides a unique expression for improving human activities in the field of systems. It has an extended usage in areas such as technology development and hybrid systems. The soft system methodology incorporates the understanding of system constraints and objectives, plausible system solutions, understanding of the operational functions of the system to help figure out the problems, and merges the to-be and as-is space to determine their feasibility at the operational level, (Edson, 2008). This functionality allows for an in-depth analysis for the requirement process of systems to be developed. In the development of smart energy city, it is important for the adaption of soft system thinking to deeply analyze and answer the questions of how? Why? When, What? And who? pertaining to the system to be developed.

Adapting Systems Thinking to Smart Energy City Development

Case Study

Accra is the capital city of Ghana with a population of about 2.277 million out of 28.033 million of the entire country's population, according to the United Nations Statistics Division (UNdata, 2017). This forms about 8.122% of the entire nation's population. The main challenge that the city of Accra face is its inability to keep a balance between its energy supply and demand, with demand side always outweighing supply, mostly leading to blackouts known as 'Dhumsor'. A holistic analysis of the energy situation was made and a new approach known as Smart Energy City was suggested. As one of its kind, little, if not none previous research interventions were found in this new approach. It was then important for an in-depth analysis for the requirement gathering of the research development, hence a system thinking method was adapted. This paper highlights how systems thinking helped in the barrier analysis of the requirement gathering stage and result analysis of the strategic policy implication for governments and other stakeholders.

A four-step stage was developed to fully analyze the requirement needs of smart energy city development in Accra using systems thinking. These four stages are Barrier identification analysis, stakeholder analysis, smart energy city core components analysis and proposed smart energy city solution analysis, figure 3 shows the four-step system thinking approach for requirement analysis for smart energy city development. This four major stages were then broken down into the three 'iceberg' systems thinking approach, see figure 4, to better probe through questioning, the requirement needs of smart energy city development, SECD, in Accra. A focus on the 'whole' as a multiplying function of the behavior of its subsystem not the sum of it and also its loop/feedback functionality allowed for its adaption for analysis.

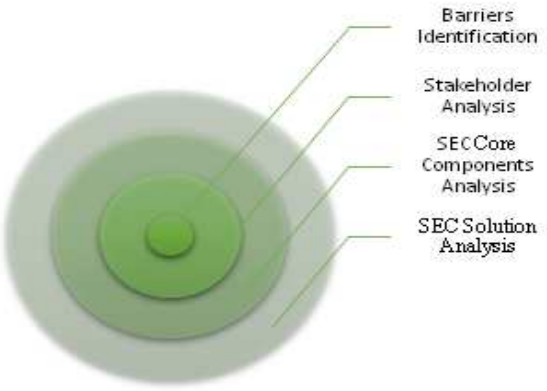

Figure 3: A Four-Step Systems Thinking Approach for SECD Requirements in Accra

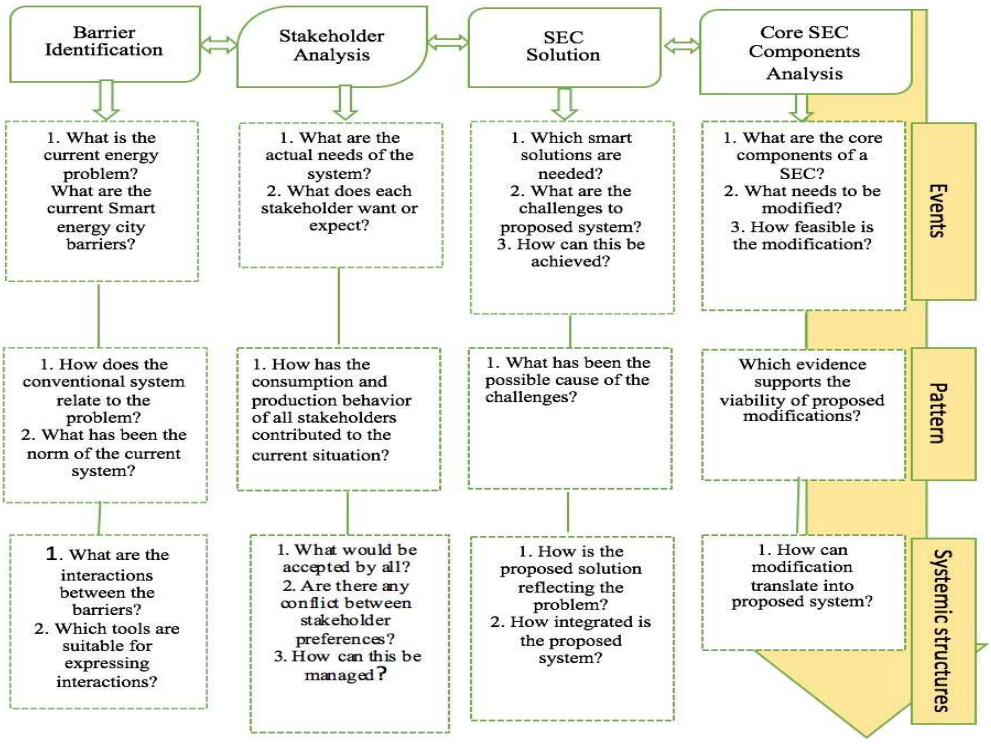

Figure 4: Showing the Adapted Iceberg Systems Thinking Approach to Requirement Gathering for SECD in Accra

ANALYSIS OF RESULTS

The strengths and weakness of Systems thinking can both be explored and adapted for better enhancing decision making. Decision making can be illustrated as the process of defining goals, gathering relevant criteria and alternatives as well as evaluating those alternatives to delineate their importance and downsides and making an optimal selection from table 2, it can be inferred that in addressing the systems of systems nature of smart energy city with its complex nature, is one good tool for its analyses. With the present energy issues facing the city of Accra, the whole complex nature of the requirement needs of smart energy city was fully analyzed using systems thinking. The various interactions within its various subcomponents allowed for a complete incorporation of the needs which was grouped under four stages, refer to figure.

Systems thinking is more qualitative in nature and lacks the capability of numerical computations to buttress its expressions and to deal with the many imprecisions associated with its data; however a very powerful methodology in analyzing complex systems especially that of social systems with loop analysis functionality. With its analyses in 'loops', an in-depth view of the requirement needs of a system can be gathered, views of stakeholders to the system requirement needs can also be solicited. However, then comes the question, how do we deal with the imprecision of data, vagueness and uncertainties expressed by these stakeholders? Well, depending on the objectives of one's research various hybrid methodologies with fuzzy set theories can be deployed. This project used fuzzy-dematel, which helped system and project engineers to model the imprecisions associated to the qualitative data. However, much of this wouldn't be discussed in this paper due to its limited scope of objective but the proposed systems thinking approach captured the stage at where a certain methodology can be incorporated to deal with the imprecision associated to systems thinking, if the need be.

Again during the policy analysis of results to various stakeholders for the development of a system the strong loop/feedback analysis functionality of Systems thinking contributed to fully explain the circular cause and effect situation of the various component interrelations existing within the whole system. This was clearly demonstrated in the barrier analysis for the development of smart energy city in Accra as a case study. The various circular interrelations existing between the barriers to smart energy city development in Accra was analyzedand the long term requirement needs for the development of smart energy city solicited. This approach also ensured strategic decision making since the barriers to smart energy city development in Accra was then prioritized based on the weights assigned by experts (fuzzy-dematel) in analyzing their interrelations

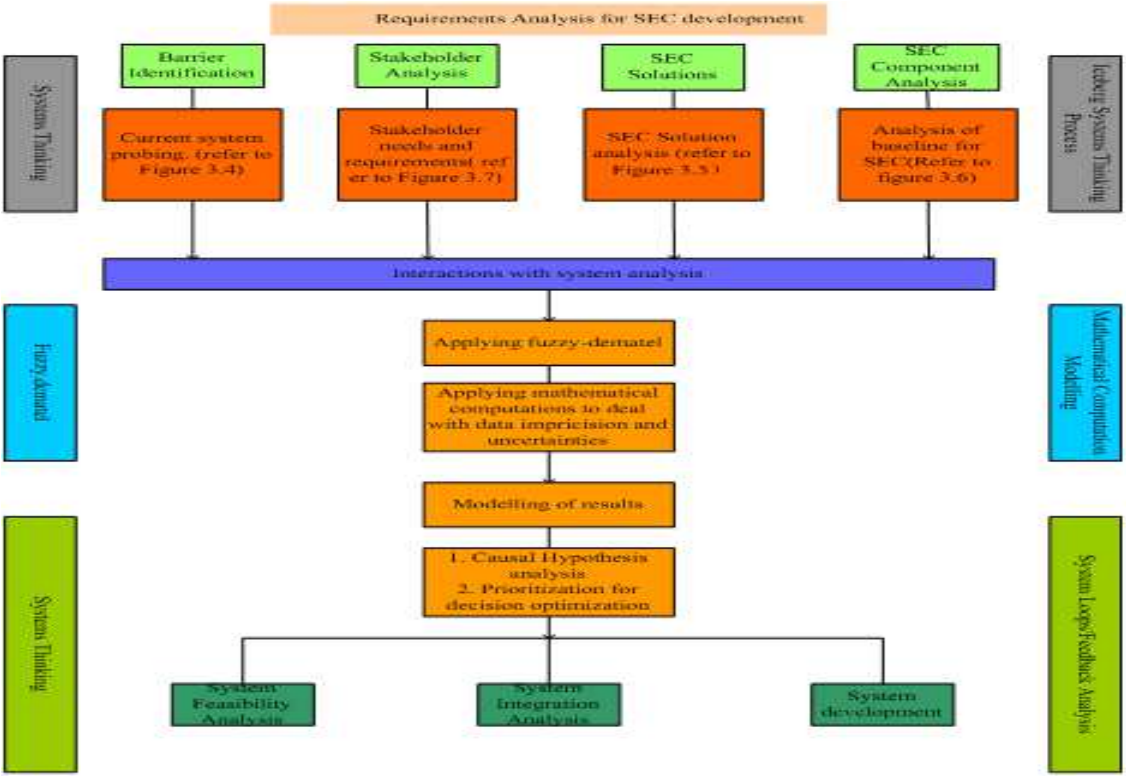

Figure 5: Showing Proposed Requirement Analysis using Both Systems thinking and Fuzzy-Dematel

NB: The mathematical computation stage was adopted to deal with the uncertainties of data expressed and also enhance strategic decision making, hence can be omitted or modified to suit one's own research/project objective.

Analyses with this approach, see figure 5, gave some advantages to the research on analyzing the various barriers to smart energy city in Accra. With this case study, not much had been done prior to smart energy city, hence the adaption of Systems thinking was useful in in probing into matters pertaining to the current energy situation in Accra and how smart energy city can be useful. Without much reference, Systems thinking systematic approach gives an in-depth analysis of what is to be modelled. With its fusion of Fuzzy-dematel, the many empirical evidence questions on the certainty and precision of Systems thinking is managed, (Gabus & Fontela, 1973), (Falatoonitoosi et al., 2013),(Lin, 2013),(He & Cheng, 2012) and (LIN, WANG, & TSENG, 2009). The researchers would like to emphasis that the adoption of fuzzy-dematel was used to deal with the imprecision, vagueness and uncertainties associated to data expressed by experts and stakeholders during the requirement stage. Again, depending on the objective of the project, decision optimization is to be enhanced in a world of resource scarcity, hence fuzzy-dematel can be used to rank and select based on its cause-effect

analysis and this stage can be omitted or modified to suit your research or project goals. Systems thinking loop functionality which pays attention to bothcause and effect group entities and their circular relations was the used in the analyses of the results. This in totality enhances policy driven analysis of what must be done to solve the problem of the system to be modelled. It also promoted a long-term solution to the system being modelled, which was included in the requirement gathering stage.

CONCLUSIONS AND LIMITATIONS

Conclusions

Requirement gathering analysis is important for the successful development of a system. The most important aspect of every development is its foundation. Most of the failure of a system is attributed to the requirement gathering stage and much attention has been devoted to manage the situation. The adaptation of Systems Thinking solves many of the qualitative problems during the requirement gathering stage of system development but falls short of a quantitative modelling approach but can be dealt with the fusion of other mathematical computations depending of your objectives. This approach was helpful in dealing with the complexities of smart energy city in Accra. In this research an attempt has been made in enhancing system requirement needs using systems thinking. In this research the strength and weakness of Systems thinking is established, a systems definition of smart energy city is coined, analyzing smart energy city from systems of systems point of view and applying icebergs system thinking approach to requirement needs of smart energy city; a case study in Accra.

Limitations

This research fell short in analyzing deeply the individual system interactions of the four stages for smart energy city requirement needs for Accra. This was however, deliberately ignored in this write-up for the case of simplicity in order to effectively communicate new knowledge. Apart from this, the new approach to system requirement gathering and other useful add-ups in this research is informing enough to contribute to the enhancement of requirement needs of a system to be developed. Future research can focus more on deeply analyzing what this paper deliberately ignored and suggest deeper contributions.

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