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Article

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ENRICHMENT OF SYSTEMS THINKING FOR PROBLEM SOLVING IN ENGINEERING SYSTEMS USING THE HERMENEUTIC LOOP: CASE STUDIES FOR DESIGNERS IN THE FIELD OF REMOTE COMMUNICATION

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ABSTRACT

The systems thinking approach to problem solving is a dynamic and productive approach. However, emphasizing only the objective aspects of a phenomena and neglecting their subjective aspects can decrease its problem solving power. In order to enhance the problem solving power of systems thinking, it is proposed in this article to enrich systems thinking by using the hermeneutic loop. This applied research adopts practical aspects of systems thinking and hermeneutics in understanding and solving problems more effectively. The proposed approach is comprised of an additive loop, named the hermeneutic loop, concerning simultaneously "the whole system and its parts" and "subjectively and objectively". Requirements of systems thinking are highlighted involving the holism and life cycle of the system. A summary of the considerations for systems thinking regarding holism and lifetime are as follows: (1) feedback in lifetime, (2) feed forward, (3) combining human and tools, (4) resources, (5) stock and flow and (6) carrying capacity (saturation). The utilization of this enriched systems thinking is investigated in three real engineering design processes, including case studies for designers in the field of remote communication. As the result, the proposed enriched systems thinking provides an improved understanding of the whole, which improves the solving power of the designers of components, and adds subjective product design to the objective design.

Keywords: Systems thinking, hermeneutic loop, problem solving, system design, remote communication, antenna design.

INTRODUCTION

Complicated engineering systems are usually divided into their components, which are designed, simulated, fabricated and measured separately. Understanding the whole system by the designers of each component can significantly improve the system's performance and efficiency. While designers in an engineering system should create value for the customers or higher-level designers, they have to understand the value chain (upstream and downstream of the system). By studying the value chain, designers can provide the basis for quality improvement, operation development, ease of application, and reducing the cost, time, risk and loss. The value chain and value analysis concept is a well-studied topic in the literature and employed for various purposes (Zamora, 2016; Fartookzadeh & Fartookzadeh 2018; Azizi et al., 2023). Swinging between the parts and the whole of engineering systems as an enhanced form of systems thinking is also a well-known concept, such as the concurrent engineering concept, which means the design and implementation of the whole and the components are performed, simultaneously (Stjepandić, 2015). However, the hermeneutic loop concept is different and more comprehensive in some aspects as will be explained, shortly. In fact, the concept of concurrent engineering is an instance of the hermeneutic loop (Harris, 2015).

The hermeneutic loop is denoted as a cyclic logic against sequential logic. It means that while constructing the whole, the components are constructed simultaneously, by employing the technologies or the design team. In other words, if the required technologies are not available, the design team can be replaced. It is more than the whole and the components, the catch ball is for the future and the present, meaning that the future can be brought to the present time. Instead of waiting for sequences to go to the next step, the design team can study the future by using prototype, simulation and narration. There are toolboxes for this purpose, and they are follows: 1) technologies that grant access to low cost swing, 2) teamwork; there are people that can gather the components to find the solution without having access to the technologies, and 3) solution bank; an inclusive memory in a design office consisting of solutions which have been designed for extendibility in the beginning.

In order to enhance the problem-solving power of systems thinking, it is proposed in this article to enrich systems thinking by including a hermeneutic loop and add simultaneous subjective-objective thinking to systems thinking. Therefore, the research question is:

How can the hermeneutic loop enhance the problem-solving power of systems thinking?

In answering this question, one must first discuss some new aspects of applying systems thinking to engineering applications, and the requirements of systems thinking will have to be highlighted concerning the holism and life cycle of the system. Then enrichment of systems thinking by using the application of the hermeneutic loop in oscillations between the components and the whole of engineering systems is discussed. Finally, the utilization of this enriched approach in three real engineering design processes is investigated.

Consequently, the proposed enriched systems thinking provides an improved understanding of the whole, which can lead to the purposeful design of the components by the designers, and subjective product design in addition to the objective design to improve the whole system. In addition, it will help to facilitate the observation of the future in the present time by using cyclic logic instead of sequential logic.

SYSTEM THINKING

Systems thinking has been adopted in multiple branches by the technology and management communities. A common approach to understanding a system is to understand its components and the relations between them (Behl & Ferreira, 2014; Kádárová et al., 2014). A viable study in this issue is the division into hard and soft systems thinking, which is based on fault detection-isolation and value improvement models, respectively (Williams et al., 2013; Siriram, 2012). Hard systems thinking is usually involved with particular objectives and goals of a concept, which should be divided into divisions. However, soft systems thinking does not confront determined objectives. An interesting model for systems thinking is the iceberg metaphor to indicate the visible and hidden layers of a complex system (Stroh, 2009; Badham et al., 2020; Monat & Gannon, 2015). One of the hidden layers includes underlying systemic structures, which is a place for design thinking. Systems thinking can be employed to improve the design power; hence, it is not completely separated from design thinking. A conceptual framework for indicating the differences and convergences between design thinking, entrepreneurial thinking, and systems thinking has been presented by Patel and Mehta (2017). Further research and discussions about design thinking have been presented in the recent years (Pande & Bharathi, 2020; Eisenbart, et al., 2022). In addition, multiple case studies on the development of systems thinking and system modeling are available in the literature (Vahidi & Aliahmadi, 2019; Singh & Singla, 2021). Systems thinking has been used frequently in operational research (Cabrera et al., 2018) and evaluation theories (Chen, 2016; Gates, 2016). In particular, Chen (2016) has studied major theoretical perspectives of reductionism, systems thinking, and pragmatic synthesis, and their contribution to evaluation, and Gates (2016) revisited systems thinking and complexity science in evaluation theories. Another usage of systems thinking is the improvement of the creativity and innovative ideas in engineering systems (Johannessen, 2013; O'Kane, 2015). Besides, innovation and innovative work behavior from other aspects have been studied in the literature extensively (Ali et al., 2020; Noor et al., 2018).

Systems thinking by using the combination of group concept mapping and system dynamics has been introduced by Lich et al. (2017). Thinking systemically or systemic thinking is another area aligned to the systems thinking's concept, and have been used in some case studies (Hester, et al., 2013; Ngana, 2015; Spitas, 2011). Systems thinking in relationship to the complex system governance has been studied by Jaradat and Keating (2016). Methods of situating functional abstraction in systems thinking for engineering design have been studied by Tomko et al. (2017). Most of the above references are related to design and engineering systems in addition to understanding the human factors which have been highlighted in the literature (Godfrey et al., 2014; Papantonopoulos, 2004). Finally, holism is an inseparable feature for systems thinking, and this has been investigated in the recent literature extensively (Jackson, 2003; 2006; Muhammad, et al., 2021; Platzek & Pretorius, 2020; Kodama, 2019).

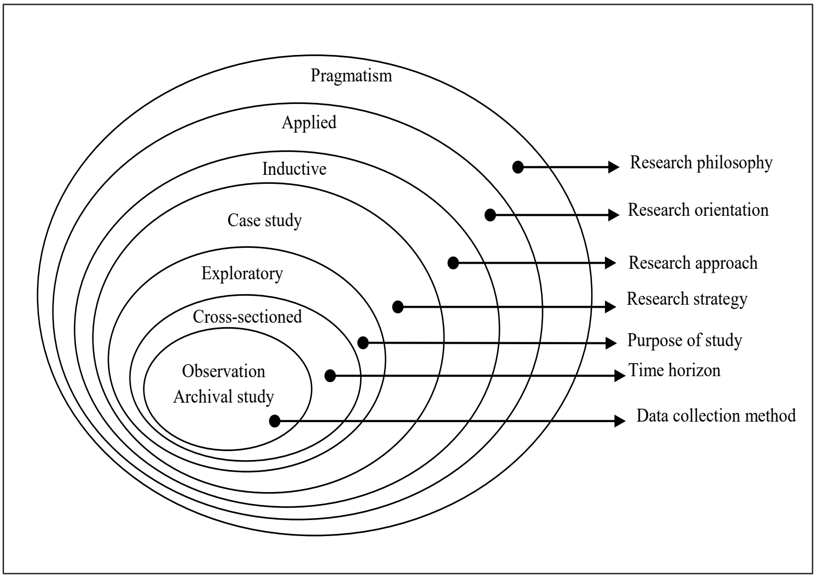
Subsequently, improving the design intuition and ability by illuminating the 'whole', which is a mysterious entity same as the design concept by using systems thinking, and bringing the future to the present time by using the cyclic logic and hermeneutic loop is the purpose of this paper. The unknown layers should be elucidated by using a cyclic logic involving a mixture of hard system and soft system, in contrast with the classic sequential approach.

METHODOLOGY

According to the research onion (Saunders et al., 2019), this study is performed as shown in Figure 1. The philosophy of this research is pragmatism and as an applied research, it has adopted the practical aspects of systems thinking and hermeneutics in understanding and solving problems more effectively. A comprehensive introduction and history of hermeneutics are readily available (George, 2021), indicating the role of Friedrich Schleiermacher, Wilhelm Dilthey, Martin Heidegger, Hans-Georg Gadamer, Paul Ricoeur and others in its formation. In addition, a thorough literature review of the systems and cybernetics is accessible (François, 1999), including the works of Wiener, von Neumann, von Bertalanffy, von Forster, Ashby, and others. In fact, hermeneutics and phenomenology, and their similarities and differences, have been studied from multiple aspects by multiple researchers. It is usually believed that Martin Heidegger was the first one who connected these two. Besides, Geniusas and Fairfield (2020) provided a thorough history of hermeneutics and phenomenology, which connects post-Husserlian hermeneutics (presented by Martin Heidegger, Hans-Georg Gadamer, and Paul Ricoeur) with classical phenomenology (presented by Edmund Husserl, Max Scheler, and Maurice Merleau-Ponty), and brings hermeneutics and phenomenology into dialogue with each other.

Figure 1

Research Onion



However, the research strategy of this paper is the case study, in which data about three cases in the field of remote communication is analyzed inductively. The purpose of this research is to explore the synergy between systems thinking and hermeneutics which can enrich problem solving. From the viewpoint of the time fame for this study, this research is cross-sectioned because it was performed in a single period of time and finally data was collected by observation and archival study.

In the aspect of the trustworthiness of this research, it should be mentioned that because of the basic differences of quantitative and qualitative researches, qualitative researchers have disagreed about positivist terms such as validity, reliability, rigor, and propose terms such as trustworthiness, verisimilitude, relevance and plausibility (Freeman et al., 2007). In this research, the following two strategies were adopted to ensure the trustworthiness of the research:

1. Prolonged engagement: Long-Lasting theoretical and practical engagement in the field of study.
2. Persistent observation: Identifying the most relevant features and elements to the issue under study (Korstjensa & Moser, 2018).

It is worth noting that abduction can be used as a theory development approach in pragmatism; however, it is not the only allowed approach. Furthermore, restricting the approach in pragmatism is in opposition with the spirit of it, because pragmatism does not adhere to any single system of philosophy and reality. Hence, the researchers are free to choose research methods, techniques, and procedures that meet their needs and goals.

In addition, it is worth noting that multiple methods for the hermeneutical process have been introduced by the researchers. For example, an interesting picture of the elements of the hermeneutical process based on Gadamer's view has been introduced by Vlăduţescu (2018). It introduces six steps for this process as follows: 1) observing that something addresses us; 2) conducting an agreement about what is addressing us; 3) common language of mutual recognition, and symmetry; 4) understanding the world of work of art, things and opinions; 5) communication of meaning; and 6) openness to alterity and fusion of horizons which crown final understanding and final agreement with itself and with other. However, in this paper we use the hermeneutic loop, which denotes that a system as a whole can be understood based on understanding its components, as well as understanding each individual part refers to understanding from the whole (Harris, 2015; Palmer, 2009).

CONTRIBUTIONS

In this section, we prove how systems thinking can be enriched by the hermeneutic loop and in the next section this concept is explored in three real cases.

Systems Thinking in Engineering

Systems thinking has some critical features that can be examined from two main aspects, i.e., the whole (super system) and the time (lifetime duration). Some features of the systems thinking are as follows:

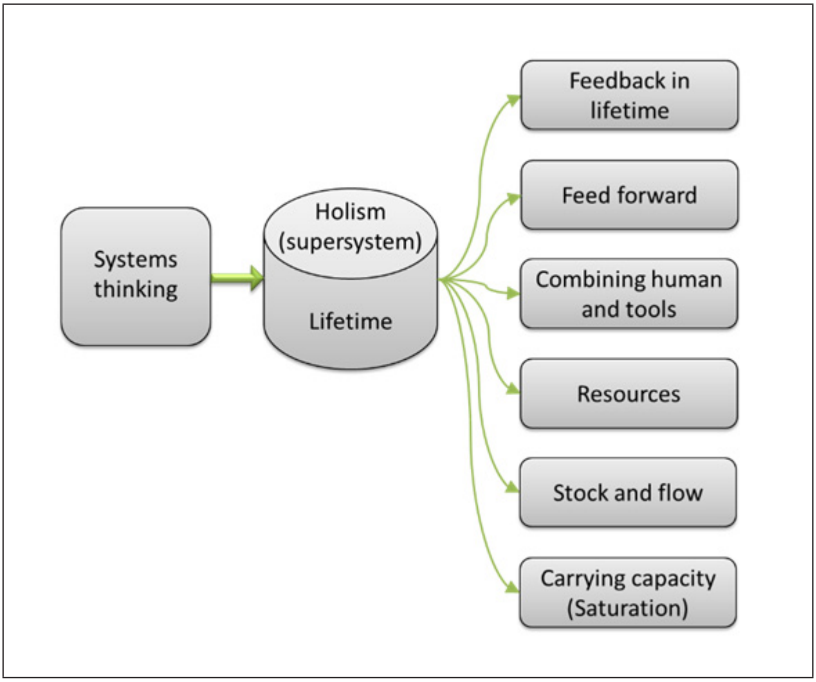
1. Bearing in mind the feedback for each system in its lifetime,
2. Considering a more beneficial tool, the feed-forward, to prevent the threats,
3. Combining the human and tools; how can the system be combined with the humanistic subjects such as the mistakes, mental limitations, etc.
4. Considering the resources, including all resource types: material/spiritual, visible/invisible, etc. Nevertheless, something considered as rubbish in a position, can be a resource in another position, such as the smoke and warmness in some systems that can be recycled. In addition, a barrier from an aspect can be a resource from other aspect, such as the air for an airplane.
5. The relation between integral and differential or stock and flow in the system; system obtains memory and special specifications from its stocks. In order to understand a complex system, it is important to realize that usually one aspect is that it has stock, which can be reduced or increased by the flow. Obvious examples are the traffic system and the users in a network system.
6. Considering the concept of capacity limitation and saturation is also another factor. It is concerned with aspects, such as the parking spaces for cars in cities, the issue of air pollution, etc. These natural limitations are themselves signals for more vital limitations. For example, in Mazandaran province in Iran, there are good places for vacations. People can enjoy nature through its rivers, mountains, valleys and beaches. However, the limitation of its unfit roads is a natural limitation for saving and securing the Mazandaran ecosystem. Meanwhile, by using new

instruments and constructing machineries and by developing multiple tunnels and bridges, the roads have become wider and the trips become faster and easier. When the natural capacity of the ecosystem is ignored, the forests and beaches are therefore, being destroyed.

Summary of these considerations for systems thinking is indicated in Figure 2.

Figure 2

Systems Thinking: Holism and Lifetime Considerations



The applications of these concepts are vital for sophisticated systems. In other words, systems thinking designates situation-dilemmas in any important project, such as the dilemmas of boundary, time, resource, saturation, limitation, ergonomic, etc. These are, indeed, hidden problems (or silent killers in medical terminology) that systems thinking makes apparent.

Systems thinking involves holism from different aspects, such as the following:

1. The interactions; what are the interchanges of the system with its environment?
2. The disciplines from a higher view, which are important for an advanced designer who tries to find solutions in problematic situations,
3. The value chain, function analysis and value engineering (Fartookzadeh & Fartookzadeh 2018; Fartookzadeh & Mokhtarianpour, 2014),
4. In combining the strengths of the human and the use of tools, the ergonomic holism should be considered regarding the limitations of human diagnosis, processing, speed and understanding.
5. Environmental challenges such as water, soil, air and electromagnetic waves; here an important general challenge is the saturation of these environmental resources.

Engineers usually encounter malfunctions of some parts of a system in different times. It is important to consider the golden time challenge in the design and ensure there is time consciousness. This concept can be observed in nature. For example, in the human body it can be observed clearly in the teeth. The primary teeth are for infants who cannot protect them well and the permanent teeth will be bestowed upon them when they grow up. This example and many others indicate the amazing aspect of time consciousness in God's creation. It can be a good example for engineering designers. They should classify the failures and establish a hierarchy for them. The hierarchy helps to control the failure modes in system design, which occur in the simulations, engineering prototypes, industrial prototypes, etc.

One of the most infamous failures is the Challenger disaster (Herndl et al., 1991). It is commonly reported that the reason was the lack of testing the O-rings in low temperatures before launching the space shuttle, a kind of external failure that occurs at the end of the value chain. It is comparatively advantageous for the designer to encounter the failure in the design phase or the early stage measurements before involving the customer, which is known as the internal failure.

Identifying the failures in this phase can reduce the costs and dangers. External failures can be predicted and managed as well. This can be done by considering the Poka-Yoke (inadvertent error prevention) or system fuse in the system design (Shingo, 1986). Also it is possible to convert most of the external failures to internal failures by testing and making conditions similar to the real usage world. This is actually a part of product life management (PLM).

Another factor that should be considered for an engineering system is the extendibility, which means that the system should be prepared for future improvements. The new requirements of customers should not lead to platform change; 'common platform' is necessary for the system. Now successful designers think about the family of products instead of one single product (Siddique, 2000).

Here an important question arises on the recognition of challenges in an advanced system design by using system approach thinking. How can the holism and time concepts indicate the challenges? Making the system design interactive and preventing the designers from being shocked is indeed the main purpose. In other words, the experiments from a regular progress and during the time can be costly, time consuming and harming for a designer. As an alternative, one can obtain the knowledge earlier by systems thinking within a hermeneutic loop.

Single loop learning is to move forward with trial and error, which means that if an approach did not work try another one. In double loop learning, one observes the inefficiencies of the approaches encountering failures and amends those (Jaaron et al., 2017). A designer should be aware of the intrinsic negligence of a human-being and should not expect full attention, permanently. By double loop learning, a designer learns how to encounter problematic situations. These challenges should be predicted by a set of guidelines and checklists obtained from similar situations. Hence, the proposed guidelines are indeed some efforts for knowledge improvement of designers, since they are affected by limitations in consciousness and perception, and do not have complete access to the unlimited extent of human knowledge.

Systems Thinking Enriched by the Hermeneutic Loop

The hermeneutic loop is initially defined as a philosophic concept for the understanding of the human being from himself; however, we extend the concept for engineering applications as follows. Understanding a general concept depends on understanding its components and for understanding the components, the whole should be understood as well. Therefore, there is an additive loop between understanding the whole and the parts. This is for understanding an already existing phenomenon. However, the hermeneutic loop can further help by creating a new concept or designing an engineering artifact. This interactive fashion of designing can be obtained by swinging between the whole and the parts (Harris, 2015; Palmer, 2009).

Viable examples of this concept can be observed in software engineering and coding. One begins from some parts of a code to provide a general function and the code will be evolved by swinging between the general concept and the elements. In addition, the whole can be modified and the effects can be implemented on the parts. Furthermore, the parts may include lower order parts and the wholes may be parts of higher order wholes. Therefore, there is a hierarchy between elements and generalities.

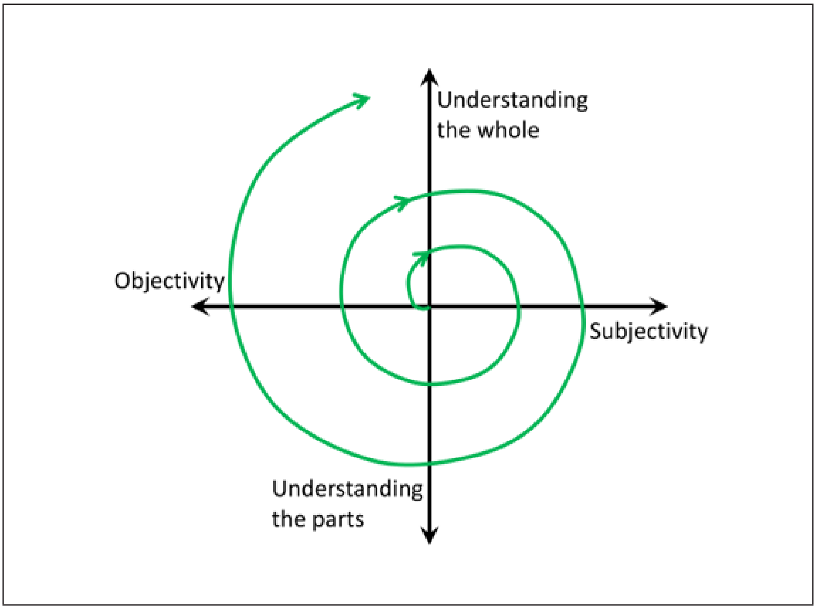
In other words, one can define a value chain, which has upstream and downstream for components and generalities. Connections among the loops of chain are usually lost. Intrinsic negligence puts our focus on the current loop, while there are obvious connections between different loops. The connections can bring about value creation, despite the fact that inappropriate connections can produce damages such as imposing high tolerances for lower orders, suffering from low qualities than desired for the system, etc.

Such a cyclic logic can create subjective solutions instead of an objective solution, which can reduce the costs, significantly. For example, a problem for the Magnetic Resonance Imaging (MRI) of little children was their being denied from resting inside the device and their movement during imaging. An objective solution is to feed them sedative drugs to prevent the problem. However, in the subjective context the main problem was recognized as the fear of children from their positioning in the device. In addition, studying their experience showed that it was not a good experience for t hem. The result was to change the scary place to an adventure. In which the children began to love it when a game plan was introduced to the process, and making the MRI experience as part of a game (Boulton, 2016). This case study shows that moving between objectivity and subjectivity can open new windows in solving problems.

Consequently, subjective solutions are defined as the solutions that begin from the higher-level understanding of engineering systems in the mind and objective solutions are obtained from parts of the system and their applications and compositions outside. Swinging between understandings of the whole and the parts of a system with the subjectivity and the objectivity produces an evolving hermeneutic loop, which can be illustrated as shown in Figure 3.

Figure 3

Additive Hermeneutic Loop between Understanding the Whole and Parts, Objectivity and Subjectivity



Engineering systems are non-human systems, which are inherently objective; they do not have any mental map and perform according to their design, without any intentionality. Therefore, these systems do not have a mind and self-awareness. They are objective realities and the transformation of input to output is pre-determined within them. Even the complexity is algorithmic in engineering systems, so they are usually called complicated instead of complex. The complexity is started from the humanity effects. Therefore, objective and algorithmic complex systems are named as complicated systems.

For example, the Chernobyl power plant disaster (Marples, 1988) is indeed because of subjective and objective issues. Although the system failed due to a flawed reactor design, the main reason of the failure was recognized as human error. This can prompt us to how the human factor can be important. How can a designer prevent human errors in design or manufacturing steps? A good alternative can be iterative design and manufacturing methods, which can transport the costly and important external errors to controlled errors in the design and manufacturing steps. For instance, a prototype model for simulating the operators' situations and testing several disaster scenarios, in the design and manufacturing phases, could prevent the disaster.

Another example is again the Challenger case (Herndl et al., 1991); from the experience of the O-ring failure, subjective understandings can be obtained for the designers and manufacturers. The designers and the manufacturers should obtain these understandings before it happens outside the system. In addition, communication between the designer and the parts manufacturer could prevent the occurrence of disaster by using disaster scenarios and enhancing the sensitivity of the whole team about the failure mode.

Here the approach is very similar to iterative solutions in applied mathematics, wherein a solution is guessed and by putting it in the equations, deviations are obtained, and the accuracy is improved in next steps. In the proposed model we have iterations between now and future and between the whole and parts (Kelley, 1999).

Designers of a system should have perceptions for different stages of the product, in the hands of the manufacturers and the users in different situations and in after sale services (repair and maintenance). Each of these perceptions produces satisfaction from the insights of designers, especially for the end user who is the most important. Consequently, subjectivity appears when the human factor comes into the design. Hence, designers should have two eyes, one which is technical associated and another which is human associated. Invention path in design process is not a one-way path, while invention drivers happen in a loop. This is why Porter (1990) says the sophisticated consumer is an important goal in the economic development of a country.

CASE STUDIES: SYSTEMS THINKING EXAMPLES IN REMOTE COMMUNICATION

In this section the utilization of systems thinking, enriched by the hermeneutic loop, is investigated in three real engineering design processes in the field of remote communication systems.

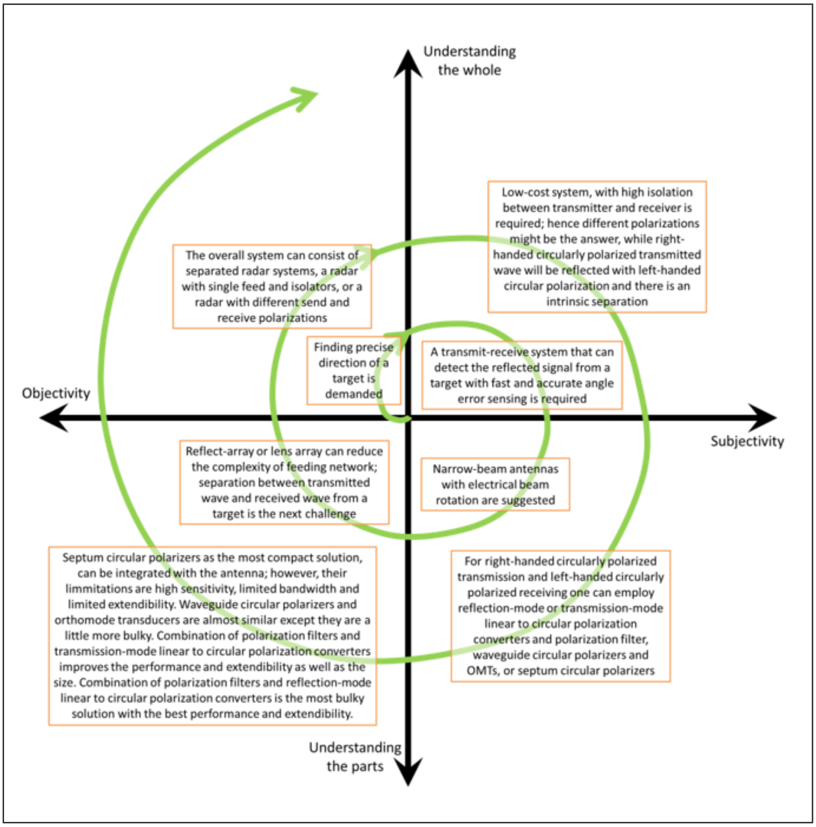
Radar Antenna Systems

First, it is interesting to observe how the hermeneutic loop can fill the gap of the previous study about radar antenna systems (Fartookzadeh & Fartookzadeh, 2018). Detailed explanations of the system are not repeated, only the role of the hermeneutic loop in improving the understanding of the system is emphasized.

The final goal of the radar antenna systems is to find the precise direction of a target, which is implemented by using the electromagnetic wave as the fastest contact. It should consist of a transmit-receive system that can detect the reflected signal from a target with fast and accurate angle error sensing. This overall understanding of the system will help the designers to find efficient solutions for designing the components and combination of them, leading to better understanding of the whole again, improving the components, and so on. This concept is illustrated with more details in Figure 4 for the radar antenna systems (Fartookzadeh & Fartookzadeh, 2018).

Figure 4

Hermeneutic Loop Corresponding to the Radar Antenna Systems



Note. Source is Fartookzadeh & Fartookzade,h (2018).

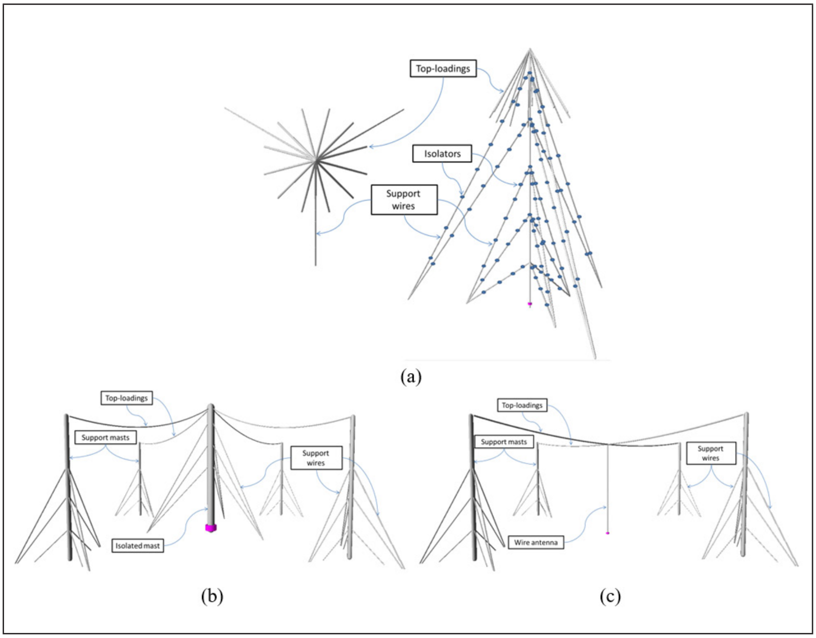
Transmitters of Loran Systems

The second case is about navigation systems, which are viable examples of using remote communication in engineering systems nowadays. Radio navigation systems originated from ground-based navigation in the last century and developed for satellite navigation, known as the global positioning system (GPS). Global navigation satellite systems (GNSS), camera-based navigation of vehicles such as the quadcopters and navigation using the autonomous robotic platforms are examples of the active areas of research on this topic (Grewal et al., 2020; Biswas & Veloso 2012; Engel et al., 2012; Moallem & Sarabandi, 2014). Yet, the ground-based navigation is an active area of interest as a backup for the GPS, best known as the long-range navigation (Loran) system (Fartookzadeh et al., 2014a, 2014b, 2015a, 2015b). This is our second case study of the effects of hermeneutic-enriched systems thinking in the development of an engineering system.

The operating frequency of the current Loran systems (Loran C) is 100 kHz, which has a 3 km wavelength. Such a wide wavelength is required for reducing losses in EM wave propagation to obtain the long-range transmission. Therefore, a simple quarter-wave monopole antenna for this application should be 750 m in height. The antenna height can be reduced by using top-loaded antennas instead of straight antennas (Johnson & Jasik, 1984). However, large masts, isolated from the ground, should be used as the antennas and the top-loadings should be held using additional masts or connected to the ground with isolators. Changing the duty of the masts from the antennas to the holders of some cables is acceptable, as the antenna can reduce the costs and produce added values (see Figure 5). For example, the masts are not required to be isolated from the ground, and isolations of the wires are enough. In addition, changing the shape of the antennas with cable structures is easier and less costly. Consequently, some cable structures have been proposed for use as Loran transmitter antennas (Fartookzadeh et al., 2014a; Johnson & Jasik 1984). As a basic introduction of the antenna design, it should be noted that the antenna reactance should be near zero for the resonance, which can be obtained using matching circuits or additional wires in the antenna structure (Johnson & Jasik 1984). Although, the near-zero reactance can be obtained by using additional wires, the radiation resistance of the antenna cannot be improved significantly due to the low height, which decrease the radiation efficiency. Nevertheless, an optimization-based method has been introduced by Fartookzadeh et al. (2014a) to obtain the highest possible radiation resistance in a certain size. However, this is also with the cost of bandwidth reduction, which has been compensated using bundled wires for the antenna (Fartookzadeh et al., 2015). Another important factor is the ground loss, which can be improved by using radial wires (Fartookzadeh et al., 2016).

Figure 5

Top-loaded Antennas for Loran Application

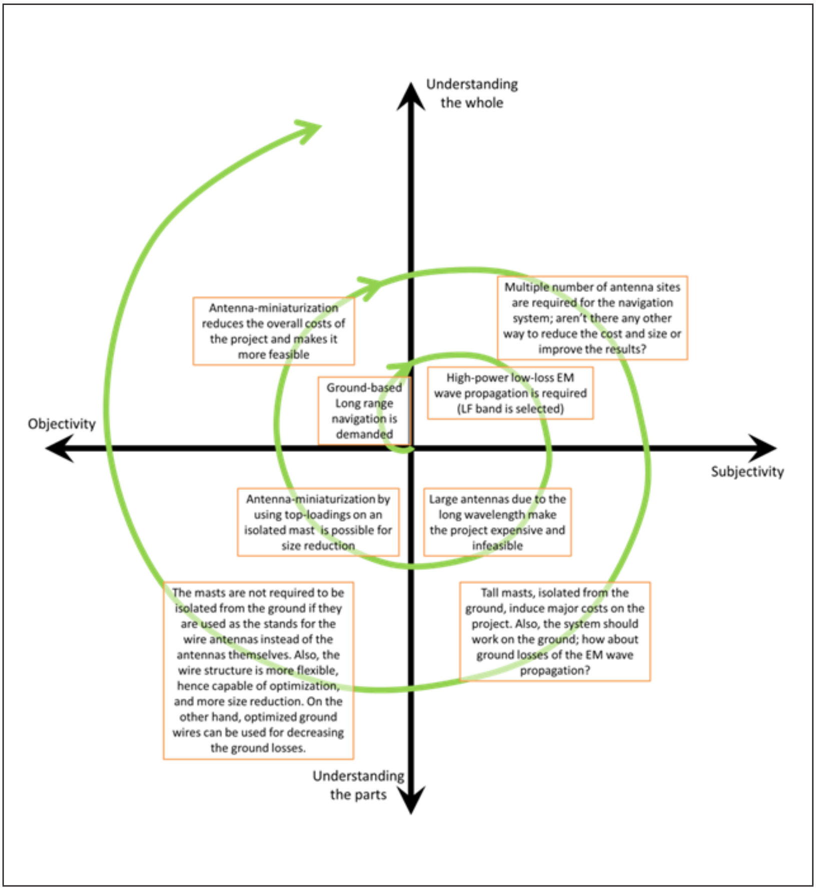


Note. (a) A typical top-loaded antenna with support isolators; (b) Using additional masts for top-loadings and; (c) Removing the central mast and using a wire as the main body of the top-loaded monopole antenna.

From the view of a system engineer promoting the systems thinking concept, the successful design of such an engineering system is based on interactions between the chains of designers for increasing the overall scheme of the system in cooperation. For example, connections between the antenna designer and the mechanical engineer can reduce the costs of the antenna structure and increase the robustness of the structure without losing its quality. For instance, this can be observed explicitly, in the changes of the form of the cables from square wires (Fartookzadeh et al., 2014a) to diagonal wires (Fartookzadeh et al., 2015a; 2015b). Another example of the interactions between the designers is between the antenna designer and the designer of the transmitter circuit, the latter shares with the input impedance of the antenna. It has been noted that the antenna has a small input resistance due to the low height with respect to the wavelength. Conversion of this small resistance to the standard 50 Ω impedance requires high-power matching circuits, leading to huge losses and costs. Therefore, in collaboration with the transmitter circuit designer this problem can be avoided, since the required impedance of the transmitter circuit can be reduced from the standard impedance without significant costs. These kinds of improvements obtained from systems thinking, can be regarded as the hermeneutic loops in engineering systems as illustrated in Figure 6.

Figure 6

Hermeneutic Loop Corresponding to the Loran Antenna Design in Figure 5

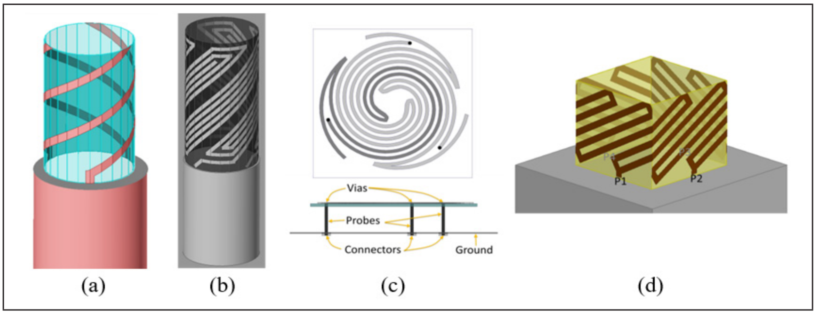


Satellite Antennas

The third example is the communication coverage of low-height satellites on the hemisphere. The antenna system of these satellites should have a wide beamwidth to cover a wide area on earth. Quadrifilar helical antennas (QHAs) are the most common antennas for this application. Multiple shapes for the antenna arms have been examined to improve the antenna patterns in a limited height. The capability of printing the antenna arms on soft substrates and constructing the antenna by rolling these substrates has made this process faster (Sharaiha et al., 1997). Moreover, it has been observed that the beamwidth of miniaturized QHAs can be changed by changing the total shape of the antenna from cylindrical to conical and inverted conical (Fartookzadeh & Armaki, 2016a). In addition, it has been implied that similar performance can be obtained by using the spiral shapes for the antenna arms instead of helical (Fartookzadeh & Armaki, 2016b). Hence, the antenna can be formed on a straight surface instead of a rolled surface. In addition, it has been indicated that the number of arms can be changed from four to arbitrary numbers and the only difference is on the required phase differences between outputs of the feeding networks (Fartookzadeh & Armaki, 2016c). Another way of eliminating the rolled arms is the polyhedron shapes for the antenna that can be obtained by using multiple straight surfaces. The square shape has been studied recently (Fartookzadeh & Armaki 2018), which can be extended to an arbitrary number of sides as we had for the spiral antenna (Fartookzadeh & Armaki, 2016c) (see Figure 7).

Figure 7

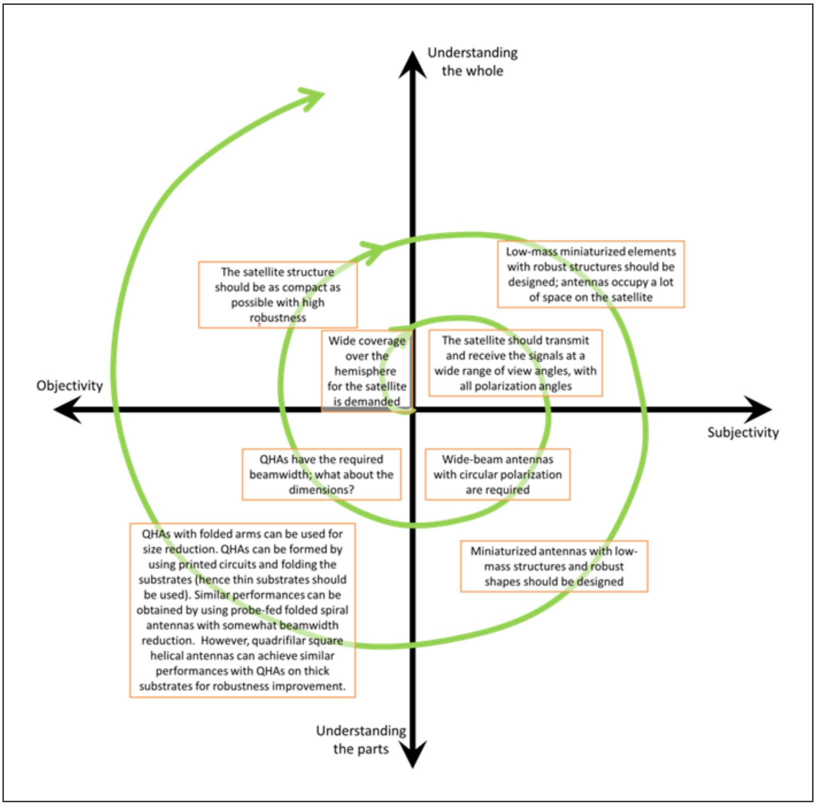
Evolution of Multi-fed Helical Antenna from Simple One to Polyhedron Helical Antenna



Note. (a) Simple antenna; (b) Multi-fed helical antenna with folded arms for size reduction; (c) Probe-fed folded spiral antenna to avoid substrate rolling with the cost of beamwidth reduction; (d) Polyhedron helical antenna (quadrifilar square helical in this case) to avoid substrate rolling without the cost of beamwidth reduction.

Figure 8

Hermeneutic Loop Corresponding to the Satellite Antenna Design in Figure 7



Examples of systems thinking in this case have been dealt with by Ippolito (2017). However, in our field of view, it appears first in the design of the total structure of the satellite and antenna design, since the satellite body is indeed the ground for the antenna and its shape has direct effects on the performance of the antenna. Antenna positions and shapes also have a significant influence on the performance. It is more than the common interactions between the antenna designers and mechanical fabricator of the antennas. On the other hand, conversation between the antenna designer and the trajectory manipulator of the satellite can improve the performance, significantly. Another remarkable example is the deployable antennas that can be used as the stabilization boom simultaneously (Olson et al., 2013; Tsuruda et al., 2009). The corresponding hermeneutic loop is depicted in Figure 8.

CONCLUSIONS

In order to enhance the problem-solving power of systems thinking, the concept of the hermeneutic loop was adopted in this paper. Systems thinking has some critical features that have been studied from two main aspects, i.e., by focusing on the holism and the lifecycle of the system. Systems thinking features can be specified as follows: 1) feedback in lifetime, 2) feed forward, 3) combining human and tools, 4) resources, 5) stock and flow and 6) carrying capacity (saturation). In a complicated system, designers are involved in some perpetual challenges between the whole and the parts. In addition, another challenge is between the early stage and the later stage, which means the product in the hands of the customer, should be predicted. A never-ending mystery in system engineering is the ongoing iterations of the whole and the parts.

However, since systems thinking emphasizes on the objective aspects of the phenomena and neglects their subjective aspects, systems thinking in this paper is enriched by using the hermeneutic loop and adding the subjective approach to its objective one. Particularly, it is proposed that one moves between the whole, parts, subjectivity and objectivity of a system, simultaneously. In order to explore the application of this new approach, three real engineering design processes have been investigated, including examples for designers in the field of remote communication.

Systems thinking is not separated from design thinking and it can improve the design intuition and ability. ‘Whole’ is not a clear issue and obvious entity, but a mysterious entity, the same as the design concept. There are unknown layers, which should be comprehended by using the swinging and the cyclic logic. In a classic view, a sequential approach is used to simplify a complex system. However, in the newer generation of systems thinking, involving a mixture of hard system and soft system, the cyclic logic can be used. On the one hand, design thinking is faced with a plurality of stakeholders on the demand and utilization side, and on the other, it is faced with a plurality of stakeholders on the supply side (i.e., team members and possibly the design organization), and in the next stage, suppliers and manufacturers. Each of these actors has their own individual and collective mental inertia. Often, administrative structures and relations, and established routines and mentalities cause escalation of divergence and loss of resources. This divergent group should enter the spiral of continuous learning in a hermeneutic loop.

The role of the hermeneutic loop and the investigated concepts in this paper on systems thinking can be clarified by using the well-known iceberg metaphor. A complete history of the iceberg metaphor for systems thinking is available in a book chapter by Badham et al. (2020). The summary is that there are some unseen layers in complex systems, such as the mental model, and underlying systemic structures and patterns, which lead to transform, design and anticipate; and there is a visible layer, events, which lead to react. However, patterns are considered as a visible layer in some references. Nevertheless, this is not the point in our conclusion. The point is that a complex system or complicated system can be considered as an iceberg, and the visible part can be grown by using the hermeneutic loop. In fact, there are some mysteries in the system, such as holism, time, place, language and values. In addition, there are some stock and flows throughout the system. Hence, a brief definition for a complex system can be specified as ‘a set of objective and subjective connected entities, including feedback loops and stocks and flows in the visible and hidden divisions, which become problematic in confronting with schema mysteries (holism, time, language, values and place)’. The hermeneutic loop can increase the understandings of a system by swinging between the components and whole of the system, i.e., it can increase the visible part of the system. This conceptual schematic is depicted in Figure 9. It can be observed that the visible and hidden parts have both subjectivity and objectivity sections. The hidden subjectivities and the visible objectivities are clear. However, for example, the production capacity can be considered as a visible subjectivity, and some rules, approvals and exemptions can be considered as the hidden objectivities.

It is worth noting that although the iceberg metaphor can be advantageous in that it indicates that there are the visible and hidden parts of a complex system, it can be confusing from another aspect, since it has a rigid and physically specified holism and it does not reflect the dynamics of a system.

Finally, advantages of the proposed systems thinking enriched by the hermeneutic loop over the conventional value engineering and function analysis methods (Fartookzadeh & Fartookzadeh 2018) are indicated in Figure 10.

Figure 9

Proposed Iceberg Model for Systems Thinking and the Role of the Hermeneutic Loop

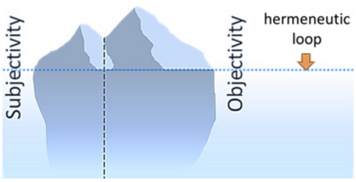
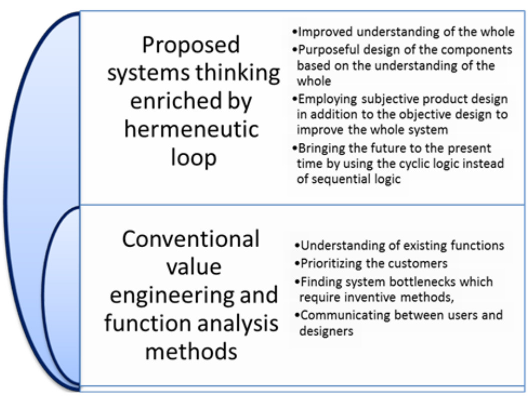


Figure 10

Improvements of Conventional Value Engineering and Function Analysis Methods



Note. The proposed systems thinking enriched by the hermeneutic loop (Fartookzadeh & Fartookzadeh, 2018).

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