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A Value-Based Framework for Process Alignment in Complex Provisioning Systems

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INTERDISCIPLINARY ENGINEERING

ABSTRACT

Provisioning systems are human-built, process-based systems whose activities are directed toward providing something of value to another entity. The things provided are not limited to any one type but may include, for example, objects, services, and information. Systems under consideration herein are limited to those that are human based, decentralized, and complex.

"Human based" means that many of the agents and all the customers of the system are human. "Decentralized" means that agents act beyond central control. Such a system presents different challenges from one in which tasks are delegated from a central authority. In a decentralized system, agents are not regulated by a single set of procedures, motivations, and goals. They act independently, but for some parameter of interest, attempt to act cooperatively. The term "complex" is used in the ordinary sense of not easily understood. Research revealed that other factors contributed to complexity, including "client recirculation", whereby customers repeat steps in the process, and the subjective nature of many decisions made by agents.

Driven by a motivation to understand and design improvements for this category of provisioning system, a plan for investigation was developed. This included investigating the potential role of interdisciplinarity and designing models of the subject system from different theoretical perspectives. A research goal was articulated: develop a framework for improving information and value exchanges toward process alignment in complex, decentralized provisioning systems.

Proposed contributions of the research include the following: The communication channel was identified as a significant generalized feature of provisioning systems. Conant's method of structural analysis was adapted to include semantic weight of impact to client outcomes. The presence of an accessible database was identified as important for effective and efficient transmission of information. A strategy termed "process-alignment" was proposed, whereby only value-objects that increase client value are exchanged. Client-reported information was recommended for facilitating an extension of the point of provisioning. A model was presented of the management of adjustments to provisioning by automated processes. Lastly, a framework was presented for the improvement of information and value exchanges toward process alignment in the subject systems.

Keywords: provisioning, decentralization, modeling, value, process, management

DEDICATION

This work is dedicated to my parents – Albert and Bonnie Lipscomb.

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LIST OF ABBREVIATIONS

API	application programming interface
CJP	Community Justice Programs
IOT	internet of things
NRC	National Research Council
TAR	technical action research

CHAPTER 1

DEVELOPMENT OF THE RESEARCH PLAN

Motivation

The motivation for the instant research arose from the experiences of practicing law for twenty-three years. The American legal system represents an attempt to manage human behavior, and as such is very complex. Probate courts, in the main, attend to the legal ramifications of birth and death, while a multitude of other courts deal with the range of human events that may occur between them. Experience revealed that clients struggled with life problems that brought them into the legal system. They also struggled with the requirements of the system itself.

Participation in the justice system is significant. A local example will serve for illustration. In Jefferson County, Alabama, 75,227 new cases were filed in the Circuit and District Courts in 2021 (Alabama Unified Judicial System, 2021). Each case represents a request for relief or a conflict between two or more parties. The legal system provides its customers services, information, and products in the form of legally actionable documents.

It may be said, then, that the legal system is a provisioning system. The term “provisioning” is used here in the ordinary sense of “the act or process of providing” (Merriam-Webster, 2022). The benefit of using such a general term is that it can describe a category of systems without limitation as to type of items exchanged. Items exchanged in a provisioning system may include, but are not limited to objects, information, and services.

The situation described previously – a client struggling with a problem, turning to a system for relief, then having trouble navigating the system's requirements – is not limited to the law. It may exist in any complex provisioning system. Healthcare systems, for example, are known for their complexity and may be, therefore, vulnerable.

Involvement in healthcare systems is significant. A local example will illustrate. In Jefferson County, Alabama, UAB Hospital received 118,839 emergency room patients in 2021 (UAB, 2021). Every patient represents someone who is seeking relief and who may be required to navigate difficult system requirements. Healthcare providers provide their clients services, information, and products.

One agent for complexity in provisioning systems is decentralization, a state in which agents act beyond central control (Schmidt, 1991). A tendency may be observed among organizations to move toward centralization, then away from it (Bankauskaite & Saltman, 2007). As organizations develop, it may be deemed desirable to control every aspect of product production or service delivery, then for various reasons, it is no longer.

An example of this can be found in the history of the Ford Motor Company, which for many years sought to achieve vertical integration. Vertical integration exists when a company owns and integrates the supply chain of its product (Katherine, 1986). Ford finally reached this goal in 1927 then, later, abandoned it (Britannica, Henry Ford). This tendency can also be seen in American healthcare. An example from mental health care is discussed in chapter three.

A decentralized system presents different challenges from one in which tasks are delegated from a central authority. In a decentralized system, agents are not regulated by a single set of procedures, motivations, and goals. They act independently but for some parameter of interest, attempt to act cooperatively with other agents. This can lead to an uncoordinated network that, for a client, can result in gaps and duplications in services (Intagliata, 1982). Management techniques have arisen to deal with decentralization. Case management is one of those tools. Its operation is described in chapter three.

The complexity of the systems under investigation suggested an interdisciplinary approach. By this term is meant a research method that integrates knowledge and tools from two or more disciplines toward a common goal (NRC, 2014). The instant research required knowledge and methods from the domains of engineering, medicine, business, education, and law. Guiding this effort was the concept of “convergence”. Convergence is examined in some detail in chapter two.

The earliest ambitions for the present work were to perform research that combined engineering with medicine, and to understand, through modeling, a complex healthcare delivery system from an engineering perspective. Later, the scope of the work was extended beyond healthcare. A more abstract and generalizable identification of the systems under analysis was conceived as those that are involved in provisioning as described above. It was proposed that in this way, research results could be applied to complex, decentralized provisioning systems generally.

As the work progressed, more narrow ambitions were conceived. These were to identify the modeled system’s value propositions, and to propose solutions to the challenges of provisioning those propositions. Value proposition, or value objects, are the items exchanged by participants in the provisioning system (Felicia & Jaap, 2019). The concept of value propositions is explicated in chapter four. Other ambitions included devising means for increasing a client's access to services as well as means to increase the efficiency of the delivery of services. The concept of access to services is discussed in chapter five.

Defining the Systems Under Consideration

The research described herein involved an effort to understand and design improvements for a certain class of process-based, human-built systems whose activities can be described by the term "provisioning". For this work, the ordinary sense of the word will suffice, which is "the act or process of providing" (Merriam-Webster, 2022). This level of abstraction allows for all transfers without limitation as to type. What is exchanged may include, for example, objects, information, and services.

That said, the set of systems of interest herein was limited to those that, by their makeup, are nontrivial. This is so for obvious reasons. Only when the system is sufficiently difficult to manage and improve upon will the methods and tools described herein be necessary. Two terms are used to describe the limitation: complex and decentralized.

It has been proposed that the term "complex" does not have an adequate definition, nor one agreed upon in the sciences (Ladyman, Lambert, Wiesner, 2012). One attempt involved a list of thirty-one definitions that included considerations of emergence, uncertainty, and numerosity (Richardson & Childers, 2001). No attempt has been made in this dissertation to define a set of provisioning systems that rise to a certain determinable level of complexity. Instead, the term “complex” is used in the ordinary sense of “difficult to understand” (Cambridge Dictionary, 2022).

The term “decentralization” is also one without a settled definition. It began to be used during the era of the French Revolution to mean decisions made by agents without central control (Schmidt, 1991). The term has also been used to mean that within a single organization, managing and decision-making have been transferred to lower levels of the organization. In other words, they are being delegated (Bankauskaite & Saltman, 2007). In this dissertation, decentralization will be used in the former sense: that agents of the system are acting independently. These agents are not regulated by a single set of procedures, motivations, and goals. They act independently, but for some parameter of interest attempt to cooperate with other agents.

Finally, an assumed term exists in the definition of the chosen area of research: human. Provisioning systems could be digital, automated, and serve other such systems without directly involving humans. Telecommunication and weapons guidance systems are examples of this. It is assumed herein that many of the agents of the provisioning systems under investigation will be human and that the clients will be human. The purpose of not adding the qualifier “human” into the already overly long “complex, decentralized provisioning system” is to avoid the appearance of circumlocution.

Employing the meanings defined above, it can be said that the area under investigation is complex, decentralized provisioning systems.

Research Goal

Driven by the motivation to understand and design improvements for complex, decentralized provisioning systems, a plan for investigation was developed. Five specific tasks were identified as being the important for the effort:

1. Investigate the role interdisciplinarity may play in the research.
2. Select research methods.
3. Develop an understanding of the generalizable features and activities of the subject systems.
4. Design models, from different theoretical perspectives, of the features and activities of the subject systems.
5. Develop a model of a digital application representing proposed improvements.

A sufficient level of understanding had to be reached before a suitable research goal could be articulated. This was first expressed in terms of developing a framework for the improvement of information and value exchanges in the subject systems. Later, a concept termed "process alignment" was developed. Although discussed more fully in chapter four, it should suffice here to say that process alignment is a condition of the system whereby all value exchanges that occur are for the benefit of the client. The research goal can be stated as follows:

Develop a framework for the improvement of information and value exchanges toward process alignment in complex, decentralized provisioning systems.

The first task, which pertains to interdisciplinarity, is discussed in chapter two. The second task, determining research approaches, is discussed below. Tasks three and four, understanding and modeling the systems, are discussed in chapters three and four. The fifth task, modeling a digital application, is discussed in chapter five. The resulting framework is presented in chapter six.

Research Approaches

The methodology of the research was based, in part, on principles of design science. Design science has been defined as the scientific study and creation artifacts built to solve problems (Hevner, March, Park, & Ram, 2004). The goal here is not to build tools to solve a particular problem but to understand the problem and the available methods of solving it. The artifacts so developed may include methods and models (Hevner et al., 2004).

A literature review of research methods revealed that many encourage modeling. One method relevant to the instant endeavor is electronic commercial services development, which includes digital application development. Here, an accepted method is the production of conceptual models (Mylopoulos, Borgida, Jarke, & Koubarakis, 1990).

To guide model development for the research, the technical action research (TAR) method was employed (Wieringa, 2014). The TAR method involves: 1) identifying a problem to be solved, 2) proposing a solution, 3) applying the solution, and 4) reflecting on the solution in a real-life context. The aim of the final step is to deepen understanding of the problem and the solution, and to improve the solution for the next iteration. While appearing simplistic, TAR proved to be helpful in guiding the research. Many of the results can be attributed to the employment of the final step of TAR.

The TAR method focuses attention on the artifacts produced, including models, rather than on the problem itself. In this way, it aligns with requirements engineering, which is also model based (Hotie & Gordijn, 2019). In sum, the project's focus on modeling is aligned with interdisciplinary research, use-inspired research, design science, commercial services development, technical action research, and requirements engineering.

In commercial services development, many activities must be performed. For purposes of the instant research, two are significant. First is the identification and development of value propositions. These are the things of value that will be exchanged with customers. Second is the designing of a process for the provisioning of the objects of exchange (Hotie & Gordijn, 2019). In chapter four, the theory of value-object exchange is discussed along with efforts to model such exchanges in the systems under investigation.

Decomposition, Modeling, and Engineering Design

A literature review of modeling methods revealed a connection between engineering development and scientific investigation. This relationship, broadly speaking, is discussed in chapter two. For purposes of the present chapter, in which development of the research plan is of concern, the focus is narrower. To this end, it can be said that engineering design and scientific modeling have different end goals. Those are construction and understanding, respectively. Even so, both designing and modeling serve to represent in simplified form the system under analysis from the standpoint of a given parameter of interest. It is through the decomposition of a complex system to render it more understandable that designing and modeling have common ground.

Herbert Simon defined design as the devising of a system or process for the improvement of an existing situation (Simon, 1996). This process involves the making of selections among alternatives. This activity, however, is constrained. Bounded rationality is the idea that decision-making is limited by three factors: access to information, the decision-maker's cognitive ability, and the time available for the decision to be made (Simon, 1955).

Optimal decision-making would require an individual to identify all alternatives and their outcomes, then to weigh these outcomes accurately. This endeavor is thwarted by the limitations of information, ability, and time. It is in this sense that rationality is "bounded", and therefore, attempts at sufficient design are constrained.

Modeling also requires decision-making as to what to represent and how. Thus, designing and modeling can both be understood as efforts to manage limitations on decision-making. Available tools can be used to improve information access, provide computational aids, and reduce the time for making decisions (Robbins, 2013). Two significant activities in designing and modeling are decomposition and abstraction.

For a system of sufficient complexity, the challenge of defining its architecture may be significant (Conant, 1972). One tool for doing so is decomposition. Decomposition is the reduction of the number of details in consideration by dividing the space into partitions. Each partition, then, will represent a subsystem or subprocess within the overall system. Herb Simon proposed grouping the areas of the system by strength of relationship (Simon, 1996). These and other methods have been formalized by researchers in a common framework (Tuncer, Tanik, & Allison, 2008).

Abstraction can be considered an extension of decomposition. Abstraction takes the subsystem components that have been defined by decomposition, then groups them together by a generalization of the interfaces between them (Moses, 2003). Through the activities of decomposition and abstraction, a complex system can become more understandable, and the design of an improvement more manageable.

This is so because designing a solution requires first that the system under observation be understood to the extent that a mechanism of cause and effect can be determined that fits the designer's parameter of interest. Next, requirements must be identified that express the influence that must be made on the mechanism to produce the desired result. From these requirements, a design is developed. The design process generates an abstraction of the requirements that will satisfy the implementation of the solution. From this perspective, engineering is the effort of moving from requirements through design to implementation (Chikofsky & Cross, 1990).

Modeling is the process of representing a system in terms of a parameter of interest in a consistent manner and described in terms of the modeling language. Parameters of interest may include processes, transactions, knowledge, designs, and metrics (Robbins, 2013). As such, modeling could be described as knowledge reengineering, or the transformation of preexisting knowledge into a form more suitable for a different use. In this process, the ontology of the information initially described becomes realigned to the ontology of the expected application (Hoekstra, 2010).

The modeling process can be seen to facilitate two instances of knowledge reengineering. The first occurs when the system under investigation is decomposed in terms of the chosen modeling language. The second occurs when knowledge gained from a reflection on multiple models is integrated into a new, overall understanding of the system (Robbins, 2013).

This is the business of the instant research: a proposed framework for the improvement of complex, decentralized provisioning systems. Use of the framework promotes the first instance of knowledge reengineering through the development of process, information, and value-based models. Use of the framework promotes the second instance through reflection on the knowledge gained by multidisciplinary modeling toward the design of improvements to the system.

For the Benefit of the Client

A final research approach must be addressed: the purposeful discrimination toward the interests of the client as a customer of the provisioning system. The final step of TAR is a recommendation for the investigator to reflect on the models built in a real-word context (Wieringa, 2014). Reflection is like designing and modeling in that it requires a selection among alternative considerations. In the present research, there is often a selection in favor of the client's interests in participating in the provisioning system. While the needs of the system and agents of the system are considered, there is a purposeful return of focus to the client. The most significant expression of this is in the recommendation, in chapter four, of process-alignment whereby only exchanges that benefit the client are made.

Outline of the Dissertation

The concepts used to build this dissertation come from a diverse set of fields, including history, philosophy, psychology, engineering, medicine, business, education, and law. A literature review of domain diverse research is provided in chapter one.

Results suggested two propositions: that multiple-discipline projects can achieve results different than single-discipline projects, and that innovation can be achieved by means of the investigation of models and artifacts. A subset of domain diverse research, known as "convergence", is explicated as the theoretical foundation of the present work. The recommendation of use-inspired basic research is next discussed. Research into the barriers to performing interdisciplinary research projects is provided along with proposals for their amelioration.

The research task of understanding the generalizable features and activities of complex provisioning systems is pursued in chapter two. Decentralization is identified as an agent for increasing the complexity of provisioning systems. A literature review is provided of the development and deployment of case management as an administrative tool for confronting fragmentated services delivery.

A flow chart of the activities of a generalized case management system is provided and detailed. Results suggested that two additional agents of complexity were client recirculation, whereby the client recycles through provisioning sequences with modification, and adjustment subjectivity, in which many adjustment decisions are subjective. Results also suggested that the flow of information through the system was of sufficient significance to warrant further investigation.

A literature review of information theory is presented in chapter three. Claude Shannon's mathematical theory of communication is discussed. The implications of the information concepts of fidelity, efficiency, and memory to provisioning systems are set out. Information-based models of the generalized case management system are presented and detailed. A modified version of Conant's method of structural analysis, employing the semantic representation of impact to client, is described. Results suggested that complex provisioning systems should provide an accessible database where all gathered information is stored and can be retrieved.

Modeling from a different theoretical perspective is discussed in chapter four. The tracking of value-object exchanges is described as a method for understanding the worth of provisioning from a given parameter of interest. The selection and functioning of a software modeling tool, PArchitect, is explained. This is a commercial digital platform for value-based modeling, computation, and emulation.

Next is described a case study for the modeling of a case management system using PArchitect. Results suggested that a client can increase value throughout the sequence of services, a fact of consequence to the completion of the provisioning plan. The recommendation of "process alignment" is made whereby only value objects that benefit the client are exchanged.

A case study involving the modeling of a mobile digital application is discussed in chapter five. The use-case is described as a self-reporting healthcare application in which the treatment provider can adjust the plan of care between office visits. The modeling of this application is detailed using PArchitect. Results of this effort suggest that the automation of a range of treatment adjustments can be made based on protocols set by the treatment provider.

In chapter six are discussed the contributions and limitations on the research as well as proposed future work.

CHAPTER 2

ON THE NATURE OF CONVERGENCE ENGINEERING

Introduction

One of the earliest decisions made for structuring the research was that it should involve the knowledge and tools from multiple disciplines. In this chapter, the reasons for this choice are set out in terms of history. Although the desire to pursue domain-diverse research has risen to the national level in recent decades, the precursors of such extend back hundreds of years. Different forms of domain-diverse research are examined herein with a particular focus on one known as “convergence”. The chapter concludes with a discussion on the relationship between engineering design and scientific investigation, and proposal is made to employ engineering design as an organizing framework for domain-diverse research teamwork.

During the 1990s, significant work was performed on challenges arising from domain-diverse projects. In their book, *Fundamentals of Computing for Software Engineers* (Tanik & Chan, 1991), Tanik and Chan expressed the opinion that optimal artifacts and processes could not be developed out of a single discipline. They proposed that the knowledge, tools, and techniques of diverse disciplines should be integrated to produce novel results. The authors explained their reasoning through an imaginary engineering assignment, which is restated below.

Three separate, single-engineering-discipline teams were given the same task: design an embedded cruise-control system. Although not expressed as a requirement, it was assumed by each team that the artifact should be designed using the tools and techniques of each team's respective domain. As a result, the mechanical engineering team built a mechanical system, the electronics team built an electronic system, and the software team built a software system (Tanik & Chan, 1991).

It was proposed by the authors that a preferable cruise-control system would have integrated components from each domain. It was further submitted that the act of assembling a multidisciplinary team would be necessary, but not sufficient, to produce collaborative work. The authors offered that this was so because "sound engineering principles, techniques, and tools do not yet exist that systematically deal with this intertechnology interface problem" (Tanik & Chan, 1991).

This statement exemplifies the search to develop tools to facilitate success, a motivation that drives research into domain-diverse project groups. This effort continues to the present day. As will be shown, organizing and running a domain-diverse research group involves unique challenges.

Six years after publication of *Fundamentals*, it was proposed that a solution would involve "systematic knowledge integration (meta-fusion)" (Tanik & Ertas, 1997). This was a recognition of the fact that each domain contains a unique set of knowledge and jargon. For the participants of two different domains to work together, common ground must be created. Two tools were recommended for achieving this: systems integration through abstract design, and combinatorics. It is notable that these proposals were made in the context of design and information, which became important to subsequent research.

Regarding information, the authors focused on its generation and transmission. They presented a table setting out the origin and characteristics of different methods of creating and disseminating knowledge, shown below as Table 1 (Tanik & Ertas, 1997). In the table was presented a historical progression toward integration.

Table 1

Dissemination of Knowledge

Method	Era	Teaching	Automation Need	Social Machinery
a) Deductive reasoning (Plato) b) Observation and logic (Aristotle)	Platonic/Aristotelian	Primarily based on authority and regurgitation	Minimal	Plato's Academy Aristotle's Lyceum
Experimentation (Descartes)	Cartesian-Mechanistic	Primarily based on instruction	Increased	Universities
Meta-fusion (systematic knowledge integration)	Combinatorics/ Integration	Primarily based on facilitation	An integral part of the method	Integrated Universities and polytechs guided by institutes of technosciences in the technopolices of the next century

Note: From "Interdisciplinary design and process science: A discourse on scientific method for the integration age" by M. Tanik and A. Ertas, 1997. *Transactions of the SDPS Journal of Integrated Design and Process Science*, *1*(1), p. 76-94. Copyright 1997 by Society for Design and Process Science. Reprinted with permission.

Also in the 1990s, the desire to pursue domain-diverse research was expressed through the publications of professional societies and journals. An example of this can be seen in the Society for Design and Process Science, founded in 1995. The first issue of the *Transactions of the SDPS Journal of Integrated Design & Process Science* was released in 1997. In the editors' introduction, it was explained that their intention was to "cross the boundaries back and forth not only in mathematics but between mathematics, physics, economics, management science as well as engineering" (Ertas, Ramamoorthy, & Tanik, 1997). This society and journal continue to the present day.

More recently, interest in discipline-diverse research has reached the government institution level. In 2014, the National Research Council (NRC) issued a report on the funded research in the area. The editors of the report focused on a particular form of domain-diverse research, which was given the label of "convergence". Relevant aspects of the report will be discussed in some detail *infra*.

The foregoing illustrates that concerted efforts have been made to develop frameworks for domain-diverse research. History can provide context for this work. In the next section will be presented an historical sample of science and technology advances that have been made by employing domain diversity. Attention will be given to characteristics held in common. In subsequent sections will be explored the different kinds of domain-diverse research, and the need to investigate the best ways to organize and operate teams. It will be argued that such efforts may be grounded in the knowledge and tools of design and information processes.

The Legacy of Domain-Diverse Research

The most striking examples of historical, domain-diverse progress can be found in the 17th and 18th Centuries, often referred to as the Scientific Revolution and the Age of Enlightenment, respectively. In the work of Galileo, Carnot, and Faraday can be seen the qualities and benefits of domain-diverse research. However, to understand what made these achievements revolutionary, it is worth considering what was established before.

In the ancient empires of Mesopotamia and Egypt, and the great feudal societies of India and China, technological advances were made. Yet there was little scientific advancement. Rules of thumb were used, which were based on observation, repetition, and improvement. The emphases were on craft over design, utility over analysis, and procedure over conceptual understanding (Dimarogonas, 1997). Although giant structures, such as the pyramids, are often referenced in discussions of the origins of engineering, such efforts were less design, and more trial and error. It is reasonable to assert that the first exponents of rational, systematic, development spoke Greek.

In Classical Greece, the search for reason led to a focus on analysis and concept. Greek speakers made systematic attempts to organize the knowledge of the forces of nature, as well as the technological uses of forces of nature. They performed analyses of nature as well as mechanical devices by applying logic and geometry (Dimarogonas, 1997). As will be seen, an important factor in the breakthroughs of the 17th and 18th Centuries was a knowledge-integration that combined the analysis of nature with the analysis of engineered objects.

Engineering efforts can be divided into the categories of working with gravity, heat, electromagnetism, information, and systems (Blockley, 2012). In each of these areas, the Ancient Greeks established paradigms that held fast for over one thousand five hundred years. It was the domain-diverse research of 17th and 18th Century researchers that pushed beyond these paradigms. For purposes of illustration, research efforts in gravity, heat, and electromagnetism will be discussed.

Research on Gravity

Regarding gravity, Aristotle (c. 384-322 BC) maintained that the movement of objects was a consequence of their natures, in this case their *gravitas*. This was a teleological argument whereby phenomena were described in terms of their purpose. For example, an object containing the element earth, it was held, will move downward because that is in the direction of its home. Similarly, fire will move upward to the moon because that is in the direction of its home (Principe, 2011). Aristotle described this as "natural motion" in his work, *On the Heavens*. (Guthrie, 1939, 300a20). The peripatetic philosopher distinguished natural motion from "unnatural" or "violent" motion, such as what occurs when one object is struck by another, in his collected work, *Physics*. (Wicksteed & Cornford, 1934, 254b10).

This conception aligns with a central question of the Greeks: what is the nature of things? This conception led the Greeks to explain the natural movement of objects by their nature, and that nature by what elements make them up. The idea that motion is based upon a substance's nature was a conceptual flaw that predominated until the time of Galileo (1564-1642).

Another flaw of Aristotle's physics was his failure to comprehend relationships of the dissimilar. Magnitude, then, could only come from a relationship between two like quantities, such as two distances. Because velocity and speed involve dissimilar quantities – time and distance – Aristotle could not make an account of acceleration (Blockley, 2012).

Galileo Galilei (1564-1642) challenged these assumptions by performing an inclined plane experiment. This he described in his 1638 work, *Dialogues Concerning*

Two New Sciences (Crew & Salvio, 1914). For this experiment, Galileo rolled balls down a ruled incline, then measured their descent using a different quantity: time. In doing so, Galileo made explicit a relationship of the dissimilar. Further, his method simplified the number of elements under examination. He idealized the event such that the object's "nature" was excluded from consideration.

This approach allowed Galileo to build a mathematical model of the subject of study, a hallmark of the Scientific Revolution. It also allowed him to create standards of measurement and data collection. This, too, was a revolutionary move, because it ran counter to another paradigm of Ancient Greek thinkers: the preference for rationalism over empiricism.

Plato (c. 428-348 BC), like the Pythagoreans before him, believed that the constant change he observed in the world meant that observation was unreliable, and thus could not lead to "true" knowledge. For this, he turned to abstract geometrical objects, numbers, and concepts. This perspective he expressed in his work, *Phaedo* (Fowler, 1914, 96-100).

Galileo, with his empirical method and experimental results, came to understand that force was responsible for movement, and that force was related to acceleration. This understanding led Galileo to the concept of inertia that would eventually influence Isaac Newton (1642-1726) to develop a theory of gravitation.

Most relevant to this discussion is that the precision required for Galileo's experiments compelled him to investigate timekeeping. For his experiments, Galileo relied on an ancient technology: the water clock. He pushed for the development of a new, more precise technology, that being the pendulum clock. Galileo drew up plans for his son to construct a pendulum clock, but neither lived long enough to see the project to completion. Based on this work, Christiaan Huygens (1629-1695) built a pendulum clock in 1656. Galileo, through his cross-fertilization of time-keeping technology and basic research, had achieved a paradigm shift in physics (Matthews, Clough, & Ogilvie, 2019).

Research on Heat

Regarding heat, the Greeks focused, again, on the "nature of things". Greek-speaking investigators often explained heat in terms of the natural qualities of fire. Fire was considered to be an element, which itself was a constituent of different substances.

Aristotle argued that heat was a quality but not a quantity in his work, *On Coming-to-Be and Passing-Away* (Forster, 1955, 333b). This conception was a significant limitation because it meant that heat could not be analyzed using mathematics. Later, Hero of Alexandria (c. 10-70) built what may have been the first heat engine, but it was regarded as merely an amusement. In sum, the Greek thinkers did not quantify heat and failed to grasp the significance of the use of heat to do work.

Beginning in the 17th Century, heat engines were developed to power textile mills and pump water from mines. Many such engines were designed to be driven by water, gas, or vapor. Significant cross-fertilization between available technologies occurred during this time (Cardwell, 1971). Advances in technology were made by Thomas Savery (1650-1715), Thomas Newcoman (1664-1729), James Watt (1736-1819), and Richard Trevithick (1771-1833).

Yet it was Sadi Carnot (1796-1832), a French military engineer, who innovated by making a study of the steam engine itself. Through this effort, he initiated the science of thermodynamics. In a true interdisciplinary move, Carnot used scientific methods to investigate the efficiency of a technological artifact. He documented this in his only published book released in 1824: *Reflections on the Motive Power of Heat and on Machines Fitted to Develop This Power* (Thurston, 1943).

Through Carnot's work, the steam engine came to be understood as an embodiment of human knowledge about natural processes. The operation of the steam engine made explicit the capacity of heat to generate work, something not immediately apparent in nature. Carnot's knowledge-integration established thermodynamics as the first branch of theoretical physics that was not based on Newton's laws of motion (Cardwell, 1971).

Like Galileo before him, Carnot build a simplified, idealized model of the subject under investigation. In Carnot's perfectly insulated, frictionless, and leak-proof model, heat turned water to steam, the steam did work, then was condensed to water again so the cycle could begin anew. This "ideal engine" allowed for a mathematical understanding of heat efficiency and promoted the establishment of standards in measurement and data collection.

Galileo's inclined plane experiment integrated his new method of investigation with a technological device, the clock. Cartnot's research integrated Galileo's investigation method with the investigation of a technological device itself, the steam engine. The work was fruitful. Carnot's results lead to advances in science, such as the first and second laws of thermodynamics, and the development of products, such as the steam train (Blockley, 2012).

Research on Electromagnetism

On the subject of electromagnetism, Greek-speaking researchers were divided. Explanations proceeded once again from a tendency to attribute motive forces to the internal nature of things. Thales (c. 624-548 BC) posited that the magnet had a soul, and this was used to explain its ability to move other objects. Democritus (c. 460-370) claimed that the cosmos contained only atoms and void, and that like attracted like. Iron magnets contained more void, he argued, and was the reason they attracted iron shavings (Barnes, 1987).

Plato gestured at an explanation in his work, *Timaeus*, but it was not particularly coherent (Bury, 1929, 80c). Aristotle argued that actions at a distance could not occur unless there was some medium to carry the effects – a *spiritus mundi* (Principe, 2011). In sum, the Ancient Greek thinkers failed to comprehend the existence of independent and invisible forces that could act upon objects.

A Roman, Lucretius (c. 55-15 BC), proposed an effluence theory to explain magnetism. This he set out in his didactic and scientific poem, *On the Nature of Things* (Smith, 2001). In addition to providing discussions on physics, technology, evolution, and atomism, Lucretius wrote verses to explain how magnets work. His proposal was that some substance emitted from the magnet. This substance created a vacuum, he claimed, that pulled objects toward the magnet.

The effluence theory predominated until the time of William Gilbert (1544-1603). In the late 16th Century, Gilbert began a scientific investigation on magnetism. Like Galileo, Gilbert called for the use of experimentation in his book from 1600: *On the Lodestone and Magnetic Bodies and on the Great Magnet the Earth* (Mottelay, 1893).

Gilbert’s work inspired cross-disciplinary investigations on electromagnetism. These included the building of a static electricity machine by Otto van Guericke (1602-1686); the use of kites to investigate lighting by Benjamin Franklin (1706-1790); nerve-conduction studies by Luigi Galvani (1737-1798); the development of a continuous-supply battery by Alessandro Volta (1745-1827); and the design of an electric generator by Michael Faraday (1791-1867).

Faraday’s design combined the knowledge and technologies from many disparate works in electromagnetics. His research began when he was asked by the scientific journal, *Annals of Philosophy*, to write an historical account of electromagnetism. Faraday systematically reproduced previously designed experiments in electromagnetism (Blockley, 2012). Notably, experiments were selected by their relevance to electromagnetism, not to their domain of origin. Faraday went on to design engineered artifacts to understand this natural phenomenon.

Faraday’s work led to a paradigm shifting idea: that electromagnetism is not a substance, but a field. This spurred James Maxwell (1831-79) to develop equations that would fuel developments in science and engineering and would lead to important applications. The history of the development of electromagnetic knowledge reveals that researchers in the field were combining knowledge from different domains to achieve new results. This history also demonstrates the benefits of Faraday’s domain-diverse approach.

Characterizing Research Combinations

From the above examples, it can be seen that science and technology research can be combined in different ways. It has been proposed that each combination has certain characteristics (Tanik & Alexander, 2016). According to these authors, when two technologies are integrated, a technological innovation can result. Yet very little scientific innovation is likely. This is often described as “product research”. When two sciences are integrated, a scientific innovation can result. Yet here, little technological innovation is likely. This is often described as “basic research”.

When a science and a technology are integrated, two results are possible based upon which one is driving the research. When the findings of scientific research are leveraged to design a new technology, it is often described as “translational research”. When the abilities of a new technology are leveraged to facilitate a higher level of scientific research, it is often described as “transformative research”. A simplified version of the table developed by Tanik and Alexander (2016) is presented below as Table 2.

Table 2

Research Type Combinations

Convergence	Technology	Science
Technology	Product Research	Transformative Research
Science	Translational Research	Basic Research

Note: From "Convergence: A systematic route to innovation" by M. Tanik, & J. Alexander, 2019, Presented in the program for *SDPS 2016 World Conference Orlando, Florida, December 4-6*. Unpublished. Copyright 2016 by Society for Design & Process Science. Adapted with permission.

From the above survey, a few observations can be made. Every breakthrough discussed involved the integration of a life science or physical science with a technological artifact, to wit, the product of engineering. Also, every breakthrough involved the building of a mathematical model, and the creation of standards for measurement and data collection. The importance of these components to domain-diverse research has recently been extolled by the National Research Council, as will be discussed in the following section.

The National Research Council's View of Convergence

In 2014, the National Research Council (NRC) issued a report on a particular form of domain-diverse research known as "convergence" (NRC, 2014). The report covered many topics, but three are relevant here: the meaning of convergence, social barriers to success, and the need to develop implementation frameworks.

The NRC defined convergence to mean an "approach to problem solving that integrates expertise from life sciences with physical, mathematical, and computational sciences, medicine, and engineering to form comprehensive synthetic frameworks that merge areas of knowledge from multiple fields to address specific challenges" (NRC, 2014). The authors explained that convergence "represents a way of thinking about the process of research and the types of strategies that enable it" (NRC, 2014). In other words, convergence is a meta-research concept.

It was proposed that convergence work requires an "open and inclusive culture"; that researchers be "conversant across disciplines"; and that there be established a common set of concepts, metrics and goals (NRC, 2014). The ideal work-product was described as "combinatorial innovation" (NRC, 2014).

The report authors proposed that convergence work was important because diverse groups "generate innovative solutions to complex problems" (NRC, 2014). To support this, they cited research that suggests that diverse teams outperform homogeneous teams (Hong & Page, 2004; Horowitz & Horowitz, 2007). They also cited research that suggests that diverse teams demonstrate greater creativity (Stahl, Maznevski, Voigt, & Jonsen, 2010).

To delineate the different types of domain-diverse research groups, the report authors defined team terminology in the following ways. Unidisciplinarity occurs when researchers from a single discipline work collaboratively. Multidisciplinarity occurs when researchers from two or more disciplines juxtapose their separate efforts by compiling results (NRC, 2014). Interdisciplinarity occurs when researchers integrate knowledge and tools from two or more disciplines toward a common goal. Such cross-fertilization and combination require more attention to team management and communication. Transdisciplinarity occurs when researchers cross boundaries to build comprehensive frameworks or synthetic paradigms. Such work is directed at solving “real world” problems (NRC, 2014).

The difference between transdisciplinarity and convergence is not obvious from the provided definitions. However, it appears that convergence is a subset of transdisciplinarity in that it has a narrower focus. In convergence, the focus is on integrating the life sciences and medicine on the one hand, with the physical sciences and engineering on the other, to promote a “third revolution” in life sciences (NRC, 2014).

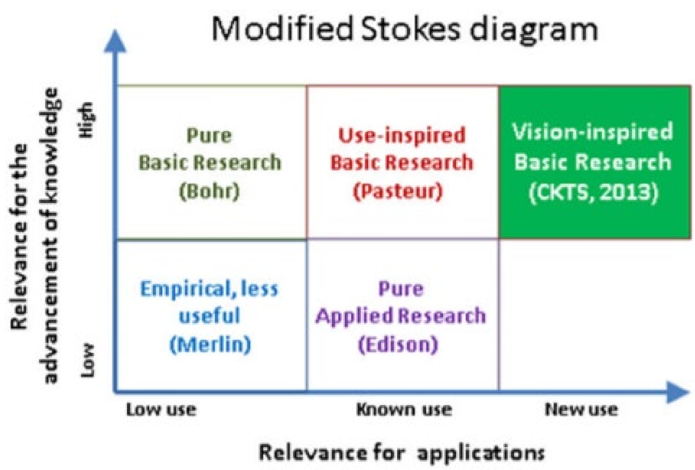
The NRC authors proposed that to achieve convergence, it is “imperative” that the life sciences embrace the continuum between research and application, something said to be well understood by the physical sciences and engineering (NRC, 2014). This seems to suggest that one of the NRC’s goals for research on convergence is this: socially associate practitioners of the life sciences, and medicine on one hand, with practitioners of the physical sciences and engineering on the other, such that the former take on an application mentality.

The type of research contemplated here, that which connects research to application, has been described as “use-inspired basic research” (Rococo, Bainbridge, Tonn, & Whitesides, 2013). In that conception, it was proposed that there is a range of research activities involved in a cycle of integration and divergence. In the creative phase, areas of knowledge are developed through pure basic research and empirical research. In the integration phase, diverse knowledge is brought together to create a new framework through use-inspired basic research and pure applied research. In the divergence phase, spin-off applications and elements are developed through vision-inspired basic research. These, in turn, become the basis of creative phase research, which begins the cycle anew.

A simplified graphic of this idea was presented in a later work by two of the same authors (Roco & Bainbridge, 2013). This is presented in Table 3 below.

Table 3

Modified Stokes Diagram



Note: From "The new world of discovery, invention, and innovation: Convergence of knowledge, technology and society" by M. Roco and W. Bainbridge, 2013, *Journal of Nanoparticle Research*, *15*, p. 1496. Copyright 2013 by Journal of Nanoparticle Research. Reprinted with permission.

The convergence report authors proposed a second requirement to facilitate development from research to application: engineers must communicate the usefulness of mathematical analysis to the practitioners of life sciences and medicine. It was posited that engineers approach problems through quantification. The NSF report authors proposed that the nature of biological systems is such that the mathematics required to model and analyze them are “extremely sophisticated” (NRC, 2014). Therefore, integrating the engineering approach into life sciences is a “major goal” for convergence (NRC, 2014).

Next, the authors proposed that the biomedical sciences need help to achieve data reproducibility. By comparison, engineering was said to possess the tools for developing common measurement standards, and guidelines for collecting data (NRC, 2014). This suggests that collaborations with engineers could help practitioners of the life sciences to create standards for measurements and data collection.

Barriers to Convergence

Now that the specific meaning of convergence has been set out, and the goals of such research has been explicated, it is worth considering what the report authors thought hindered success. The authors expressed that from the beginning, those who pursue convergence “face a lack of practical guidance in how to do it” (NRC, 2014). The obstacles to convergence “have as much to do with interpersonal interactions as they do with science at the boundaries between disciplines” (NRC, 2014).

It can be said that training in every discipline involves instruction on how research questions are formulated, the methods and models used to answer them, and the acceptable presentation of results. In short, students are socialized to form bounded “in-groups”. The report authors proposed that a consequence of this is that members of diverse-discipline groups will form weaker social bonds with each other; and experience more tension, less trust, and more difficulty in achieving goal interdependence (NRC, 2014). It is proposed herein that these same obstacles exist for any domain-diverse team, not just a convergence-based team.

Multiple case studies into team science have been funded by the NSF and NIH. Relevant here are the analyses that suggest that communication is a key component to success. For example, an analysis of 62 collaborations that received 3-year support from an NSF program suggested that lower positive outcomes were associated with institution-spanning collaborations compared with single-university collaborations. The institution-spanning collaborations were associated with reduced information sharing, which the use of technology, such as email, did not overcome (Cummings & Kiesler, 2005).

In another study, researchers compared the work of two institution-spanning research groups. The more collaboratively successful group shared similar cultures and communicated effectively. The less collaboratively successful group approached research from different epistemic perspectives. In that situation, individual researchers conducted their own research, but failed to collaborate (Corley, Boardman, & Bozeman, 2006). The NSF report authors proposed that the management of a convergence research team requires special attention to social interaction and communication. A proposal for addressing this issue will be presented in the following two sections.

With the obstacle to convergence identified (social dynamics), and the key component of success named (communication), the NRC report authors went on to explain the over-arching goal of convergence research. That is to "identify and understand the factors that influence the outcomes of research which successfully integrate diverse inputs…" (NRC, 2014). In other words, research on convergence is an effort to find how the manipulation of social dynamics and communication affect outcomes. From this work, a productive organizational framework may be built.

Design as a Convergence Activity

From the foregoing discussion, it can be seen that conversations about the “what”, “how”, and “why” of discipline-diverse research have been active for decades. Different proponents have had different focuses. However, a central theme has been the need for effective communication. Further, this communication appears to be affected by social dynamics.

These propositions are supported by the Google Re: Work research project (Rozovsky, 2015). For this effort, the Google research team investigated the factors that influenced team effectiveness in the context of delivering and marketing high-quality software. The results suggested that the number one determinant was psychological safety within the team. Number two was dependability of team members. Number three was structure and clarity – that team members have clear roles, plans, and goals (Rozovsky, 2015). These results were based in part on the work of Amy Edmonson’s work on psychological safety (Edmondson, 1999).

If these propositions are valid, then attitudes will play a significant role in the success of domain-diverse research projects. It is proposed herein that three held attitudes about domain-diverse research may be beneficial to outcomes. The first is that domain-diverse research is productive. The second is that every domain represented in the group has something to contribute. The third is that design and information processes can provide a common ground.

In this chapter, the first proposition has been supported in the “legacy” section *supra*. The second proposition is assumed to be self-evident, even though it is not universally held to be true. The third will be supported in this, the “design” section.

It may be said that scientists answer questions and engineers solve problems. Common to both, however, is the rational, systematic development of a solution to a question or problem. This method can be called design. Although engineers tend to claim the term as their own, design is a concept that cuts across engineering and science. Engineers design artifacts and processes, while scientists design investigations. This connection can be illustrated through the etymologies of two words central to these disciplines: *designare* and *logos*.

Design comes from the Latin *designare*, meaning “to designate” (Merriam-Webster, 2022). The terms “insignia”, “sign”, “seal” and “signal” all derive from *designare* and convey a sense of “let me draw a picture for you” (insignia), leave my personal mark (sign), put on the final touches (seal), and communicate it (signal). An engineer draws up specifications and blueprints, and then supervises manufacture. The product is signed, sealed, and delivered.

The roots of *designare* emphasize the plans themselves, but these provide a view into the planning process. In this sense, the word refers to the purpose, planning or intention that exists behind an action, fact, or material object. In this way, design refers to the plan and the planning.

The recipe for a doughnut is its design. Yet a doughnut is also designed to be delicious. The “hows” and “whys” are central to the concept of design. Related to this is the fact that for the ancient Greeks, an object's use and meaning were one and the same (Dimarogonas, 1997).

These design qualities can be seen in scientific investigations. The scientist must construct an investigable question, then build an investigation such that the results shed light on the question. Unless the question and investigation are properly specified and communicated, unless it is properly designated, then replication is not possible. Unless the investigation is goal-directed, investigators will be merely exploring.

The design of a scientific solution is called "investigation" and includes the important characteristics of empiricism: observation and experimentation. Scientists seek to understand the mechanisms of cause and effect. The design of an engineering solution is called "engineering design" and includes the important characteristics of limitations and demands, and production of the artificial. Engineers seek to build mechanisms of cause and effect.

The duality found in the word "design" is closely related to a duality found in the word "*logos*", a concept central to science. *Logos* is an Ancient Greek word that means "reason" (Merriam-Webster, 2019). Yet it is also used to refer to the reasoning behind an object or event. A pursuit of *logos* leads to logical answers and solutions. Many scientific disciplines have *logos* in their names. Biology, for example, is an investigation into the reasons, or the "hows" and "whys", of biological systems.

It can be seen, then, that both *designare* and *logos* refer to the "hows" and "whys" of an inquiry. The roots of *designare* emphasize specification, and the roots of *logos* emphasize rationality. However, the concepts cross over: design is a systematic and rational process, and scientific investigation requires strict specification. It is proposed herein that the connection between these two concepts, which are central to engineering and science, can be used to bring the two domains together in a transdisciplinary way.

Over time, the term “design” has become associated with an organizational framework from which to do design work. The “design process” steers project groups, step-by-step, through productive ways of moving the work toward a single solution considered to be “best”, given the criteria and constraints.

Two of the NRC’s stated goals for convergence research is to find a common language for doing convergence work and to steer research toward application (NRC, 2014). Design is proposed herein to be that common language and guiding principle. Design is a transdisciplinary idea that can provide common ground for collaborations between scientists and engineers. The terms, tools, and knowledge of the design process can be used as an organizing framework for building domain-diverse teams.

The Need for Convergence Training

Strategies for forming and participating in a convergence team are neither obvious nor intuitive. Because of this, training may be beneficial. There are substantive differences between the types of project groups that include members of different disciplines. These differences may not be known to participants. The differences may lead to interactions being less effective.

Tanik & Fielder (2017) described multidisciplinary groups as those that join disciplines without concern for integrating them. Interdisciplinary groups are those that integrate disciplines without dissolving the disciplinary boundaries. Cross-disciplinary groups are those in which disciplinary boundaries are crossed to explain one subject in terms of another. Finally, transdisciplinary groups are those that join, integrate and cross disciplines by dissolving disciplinary boundaries. It may be noted that these definitions fit generally with those of the *Convergence* report (NRC, 2014).

At present, this final group type, the convergence team, is not common. As such, invited participants may be unfamiliar with its structure and expectations. Further, as has been proposed, in a convergence team the roles of participants “may become unclear since some of the traditional departmental, functional and geographical boundaries are diminished” (Fielder, Lipscomb, Güldal, & Tanik, 2017). Finally, there is the social dynamic aspect of convergence activity to be considered. In the *Convergence* report, this social component was considered to be a significant obstacle to success (NRC, 2014).

Convergence teamwork requires members to participate and listen in ways different than they would in traditional groups. In a traditional multidisciplinary group, each member represents an expert in a particular discipline. If a question or problem arises that falls into a domain, the domain expert is called upon. Generally, the opinion given is not questioned and is considered final.

In a convergence group, every member is expected to offer opinions and make suggestions regardless of the topic domain. Members are called upon to work in areas they know very little about. This collides with certain tendencies in human behavior regarding comfort and embarrassment. It also runs counter to the very concept of expertise.

Next, every member of a convergence group is expected to be receptive to opinions and suggestions made outside of the speaker’s expertise. Again, this is counter to notions of expertise. It may be difficult for members to listen with patience to a nonexpert's proposal. Convergence participation involves being able to consider how another person's ideas can expand or change what one is thinking.

For these reasons, convergence can be understood as an interpersonal skill, rather than an abstract intellectual construct. These participation skills are easy to understand but difficult to perform. The fact that group, and personal, dynamics are inherent in convergence teamwork suggest that research on these matters could be beneficial, and that a framework for improvement could be designed. From there, an efficient and effective team-training could be developed.

This work has already begun. In 2010, Paletz and Schunn presented their social-cognitive framework for multidisciplinary team innovation (Paletz & Schunn, 2010). The authors described domain-diversity as being a "particularly challenging" factor that is mediated and moderated by cognitive (i.e., personal) and social factors (Paletz & Schunn, 2010). Although it is beyond the scope of the instant paper to fully discuss the Paletz and Schunn framework, a few notes could be beneficial.

First, Paletz and Schunn argued that domain-diverse project work includes a "divergent" phase and a "convergent" phase. In the divergent phase, the goal is to generate a wide variety of ideas. In the convergent phase, the goal is to coalesce around a single high-quality output. Each phase requires different techniques that may not be cross-compatible. In the divergent phase, managed conflict and dissent must be encouraged. In the convergent phase, consensus must be encouraged. From the engineering perspective, it can be seen that what these behavioral scientists are describing, in broad strokes, is the design process.

The authors report two non-obvious results. First is that a certain kind of group conflict is to be encouraged to facilitate idea-generation. It was argued that dissenting opinions can lead to the search for additional information that can then be shared with the group (Paletz & Schunn, 2010).

Second is that the formal role of "expert" is to be encouraged to facilitate domain knowledge expression. It was argued that a cognitive error often held by participants in domain-diverse groups is that what they know is already known by others in the group. Therefore, an express designation that a member is an expert of a particular domain should encourage that member to share their domain knowledge with the group (Paletz & Schunn, 2010). It is proposed herein that the search for catalyst-tools for convergence must continue.

It may be easy to dismiss such "soft skills" work. Yet it is worth remembering that a consideration of the contributions of other disciplines is exactly what domain-diverse research is about. As was expressed earlier, the first beneficial value needed for productive convergence work is that every domain is equally valid and contributing. Perhaps the greatest lesson of convergence is that the human component is the most important of all.

The material presented in this chapter was enlarged upon from a paper submitted by the author for publication in the SDPS Journal of Integrated Design & Process Science (Lipscomb, Tanik, Gatchel, Krämer, & Jololian, in press).

CHAPTER 3

INFORMATION-BASED MODELING OF A CASE MANAGEMENT SYSTEM

Introduction

In chapter one, it was stated that the complexity of decentralized provisioning systems has given rise to different management techniques. In chapter two, the convergence mode of domain diverse research was described as combining knowledge from the domains of life science and medicine on the one hand, with physical science and engineering on the other (NRC, 2014). In this chapter, these two ideas are combined in a analysis of a tool developed for the domain of mental health care: case management. What follows is a presentation of an effort to model, using engineering domain knowledge, a health care system that uses this management tool.

Case management may be described as the coordination of disparate services for the benefit of an individual (Intagliata, 1982). Coordination is a key term here, as case management is not comparable to the simple activity of shopping for products or services, nor is it comparable to brokerage or concierge services.

The use of informal, coordinated assistance may occur when convenience or efficiency is desired. An executive might, for example, employ an assistant to perform several errands, and coordinate delivery. The executive might ask the assistant to pick up her child from school, feed him, then take him to soccer practice. This is not done because the executive is incapable, but because the use of an assistant is easier, and is a better use of resources.

The use of formal, coordinated assistance may be required by necessity. Three principal factors will drive this need. First, the task domain may require specialized skill or knowledge. A hospital patient, for example, may not be competent to perform a self-evaluation, select services, retain them, link them sequentially, and determine termination criteria. Second, services may be difficult to select because they are provided by a multitude of providers. Finally, each provider may maintain difficult-to-navigate and idiosyncratic processes that determine client access and retention. In sum, case management will be needed when the task requires specialized skills or knowledge, there are a multitude of service providers, and access involves difficult-to-navigate processes.

In its most general form, case management begins with the assessment of a client to determine what services are needed. Available service providers are evaluated for appropriateness. Services are then selected, linked (retained), and their delivery sequenced. Multiple sequence lines may be arranged to run in parallel. Service delivery, and the client's responses, are monitored to evaluate effectiveness. Termination criteria are determined for each service in regard to treatment efficacy, and in regard to how the ending of one service facilitates the beginning of the next (Intagliata, 1982).

Such coordination of services is the hallmark of case management (Agranoff, 1977). A flowchart of the case management process was developed for this project. That flowchart is presented below as Figure 1.

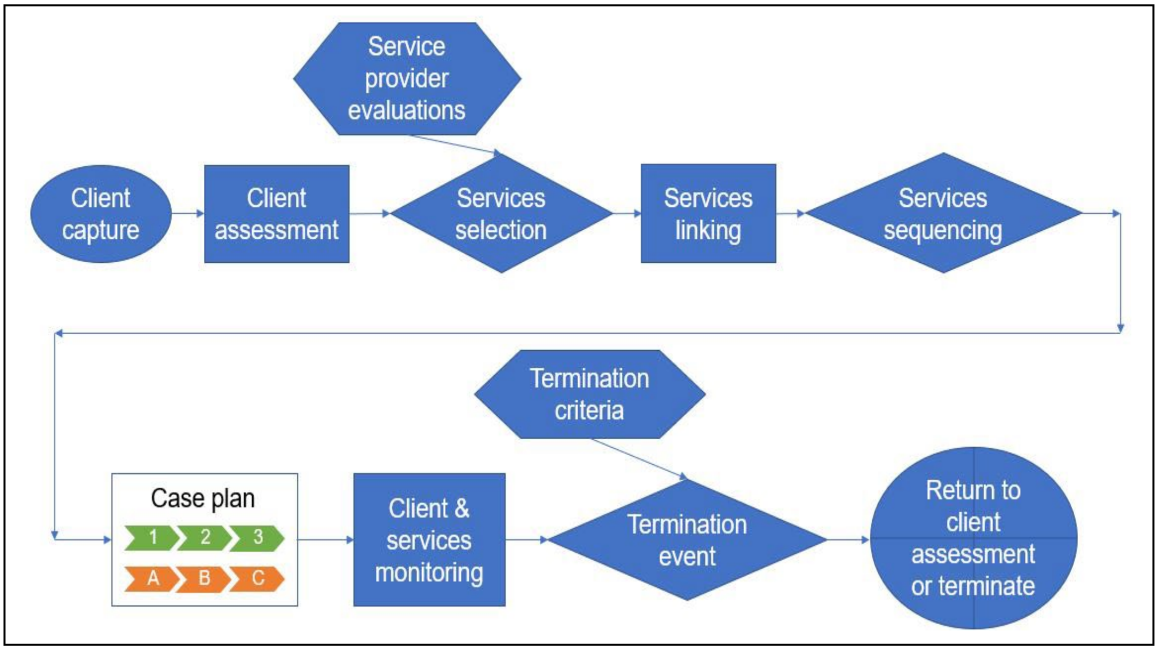


Figure 1. Flowchart of the case management process.

In Figure 1, the first station in the process, Client Capture, represents the activity of the client coming into the system by whatever means. This could be as simple as the client walking into an oil change shop or the more involved process of a client being arrested for a criminal offense and being incarcerated in a jail. The second station, Client Assessment, represents the examination performed to determine the client's needs. This could be performed by an agent of the case management system or by an outside service provider. The information gained here will be transmitted to the next station: Services Selection. Here, an agent or agents of case management will decide upon services available in the community from a list of providers determined to be suitable based on prior evaluations.

The next step in the process is Services Linking. Here, the case management system assists the client to connect with the selected service providers. This could be as simple as providing the client with a phone number or as involved in making an appointment and assisting the client with answering registration queries.

For Services Sequencing, the selected services, when there are more than one, are then set out in a sequence. While some service sets may not require significant sequencing, some may require a rigid order. For example, one will want to receive anesthesia before surgery, not after. Some service sets may require multiple sequence lines running in parallel, such as when a client is receiving physical therapy at the same time as drug therapy.

Together, the services set and the sequence lines represent the plan of care for the client and guide the activity in the next station: Client Services & Monitoring. Here, the client receives the provisioning items in whatever form. This step is monitored by the case management system for purposes of assessment. This will regard not only how the client responds to the treatment but also how the treatment is being provided.

Termination criteria will have been set by the case management system prior to the beginning of services delivery. This will allow monitoring to reveal when the client has reached the threshold of stopping. The Termination Event step represents the activity of the case management system deciding whether to move the client along to the next item in the services sequence, or to return the client to the assessment station for a change in the plan of care. The later will cause the client to recirculate through the steps of the process. Eventually, the client will reach the end of the plan of care and will exit the system.

The flowchart in Figure 1 does not reveal the way in which decentralization is an agent for complexity. This is because only case management, not the overall provisioning system it is intended to benefit, is represented. A reflection on the flowchart, a step recommended by TAR, does reveal, however, two additional agents of complexity: client recirculation and adjustment subjectivity.

By the term “client recirculation” is meant the tendency of the client in such systems to repetitively move through provisioning steps in a circuit. During each time around, the client may receive goods or services that have been altered to suit the client’s current needs, even if the same providers are involved. This behavior differentiates these systems from more straightforward ones such as assembly lines in which the recipients of provisioning moves through each station only once.

By “adjustment subjectivity” is meant the fact many decision points will involve subjective decision-making, rather than objective. This is a result of the fact that the systems under consideration are human based, meaning that many of the agents and all the clients are human. Although objectivity will be desired for termination criteria, subjectivity will be inevitable given the nature of the recipients and goals of provisioning. Consequently, human decision-making will be preferred, and the goal of automation will be more challenging.

Case management is a broadly applicable tool that can be used in areas where the fragmentation of services exist, such as law, disability benefits, employment, and health care. It was the intent of the present investigation to consider case management processes as broadly as practicable so that a generalized framework could be established. That being said, the investigation focused on healthcare, more specifically mental health care, as a representative domain for the application of case management. This is appropriate as it was in this domain that case management was developed.

To provide context for the present investigation, a brief review of the history of mental healthcare delivery in the United States will be beneficial. This history will illustrate one way in which human services delivery has become fragmented in the United States. It will also reveal how the tool of case management was developed as a response.

A History of Mental Healthcare Delivery in the United States

The practice of housing mentally ill persons in asylums can be traced back to the Middle Ages, but it proliferated in the 19th Century, especially in Britain (Porter, 2006). Public institutions were established in by the 1808 County Asylums Act. This enabled magistrates to build asylums in every county to house indigent mentally ill patients.

Patient populations increased rapidly. In the United States, for example, 150,000 patients were held in mental hospitals in 1904. By mid-century, the number of patients had increased by 927% (Shorter, 1997). Over-crowding and under-funding affected the quality of care. At the beginning of the 20th Century, asylums had become known for providing poor treatment (Fakhourya & Priebea, 2007).

Public scandal regarding asylum care was one agent of a popular movement toward deinstitutionalization. During World War II, many conscientious objectors were assigned to psychiatric hospitals. Several reported the abuses they observed to Life Magazine (Maisel, 1946).

Another agent of the deinstitutionalization movement was the advent of psychiatric drugs. In 1950, the first antipsychotic drug, chlorpromazine, known by the trade name Thorazine in the United States, was synthesized in France (Thuillier, 1999).

Chlorpromazine and other developed drugs helped mentally ill patients to live in less restrictive settings. In some cases, this meant a return to employment (Thuillier, 1999). Between 1955 and 1968, the residential psychiatric population in the United States dropped by 30% (Stroman, 2003).

In 1961, President Kennedy created the President's Panel on Mental Retardation. The panel issued a report with 112 recommendations for serving the mentally ill. In the report, the panel emphasized the need for a "continuum of care", and named case management as essential to that goal (President's Panel on Mental Retardation, 1962).

The panel defined continuum of care as the "selection, blending and use in proper sequence and relationship, [of] the medical, educational and social services required by a retarded person…" (President's Panel on Mental Retardation, 1962). The panel posited that the "process of assuring that an individual receives the services he needs when he needs them and in the amount and variety he requires is the essence of planning and coordination" (President's Panel on Mental Retardation, 1962).

In the early 1970s, the Department of Health, Education, and Welfare initiated the Services Integration Targets of Opportunity (SITO) grants. These funds stimulated investigations into service integration. Many integration techniques were developed with SITO grant funding, including client tracking systems, information management systems, resource inventories, and management organization (Morrill, 1976).

As the deinstitutionalization movement proceeded, services delivery to patients became diffused. The result is a fragmented, duplicative, and uncoordinated network of services (Intagliata, 1982). This is a key factor in the complexity of such systems, in the sense of being difficult to understand (Cambridge Dictionary, 2022).

The objective of case management, then, is to provide the client with a continuum of care. This objective has several dimensions, the first is that the services provided be comprehensive, coordinated, and adjustable to the client's needs over time (Test, 1979). The second is that case management enhance the accountability (Baker, 1981), accessibility, and efficiency of services (Intagliata, 1982).

The essential functions of the case manager are threefold. These are to link the client to services, monitor and assess services delivery, and monitor and assess the changing needs of the client (Intagliata, 1982). From the foregoing, it can be seen that the gathering and transmitting of information plays a central role in every dimension of the continuum of care.

Several areas of case management operate in a domain-specific way. These include deciding what set of services will be considered, the criteria of services assessment, the administrative requirements of linking services, the criteria of client assessment, the sequencing of services, and the determination of termination criteria. To build a generalizable framework for case management, it was held that domain-driven functions must remain the prerogative of the given domain. It is proposed herein that a reductionist approach reveals that the communication of information is a common, generalizable feature of case management.

In summary, the problem is fragmentation, the solution is coordination, and the agent of the solution is case management. The fuel of case management is information. For this reason, it was proposed that value could be gained by modeling the system under study from the perspective of the theory of information. It will be beneficial, then, to set out the development of this theory. The lessons gained therefrom were used to guide model development detailed herein.

Lessons of the Mathematical Theory of Information

Claude Elmwood Shannon was born in Gaylord, Michigan in 1916, and received a PhD from the Massachusetts Institute of Technology in 1940 (Gleick, 2011). During World War II, Shannon worked on developing an automated anti-aircraft gun. Shannon focused on the problem of compensating for errors in the data that came from range finders and radar (Mindell, 2002).

Shannon and his colleagues reported that “[t]here is an obvious analogy between the problem of smoothing the data to eliminate or reduce the effect of tracking errors and the problem of separating a signal from interfering noise in communication systems.” (Blackman, Bode, & Shannon, 1946). According to Vannevar Bush, chairman of the National Defense Research Committee from 1940 to 1941, the job was “applying corrections to the gun control so that the shell and the target will arrive at the same position at the same time.” (Bush, 1941). In other words, information was being provisioned to allow for coordination.

After the war, Shannon went to work for Bell Laboratories. There, he tackled signal-to-noise problems. Shannon worked on separating the signal from the noise, and compressing the signal to allow for more efficient transmission (Gleick, 2011).

From this work, and in collaboration with Warren Weaver, Shannon produced a book in 1949 titled, *The Mathematical Theory of Communication* (Shannon & Weaver, 1949). In it, Shannon took a reductionist approach, stating that the “semantic aspects of communication are irrelevant to the engineering problem." Instead, it was proposed that "[t]he fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point" (Shannon & Weaver, 1949).

According to Shannon, a communication system must comprise the following elements: an information source, a transmitter, a channel, a receiver, and a destination. The information source is a person or machine that generates the message. The transmitter must encode the message to turn it into a signal suitable for transmission. The channel is "merely the medium used to transmit the signal." The receiver decodes the message. Finally, the destination is the "person (or thing) at the other end" (Shannon & Weaver, 1949).

Three aspects of Shannon's model of communication are of particular importance to the instant research effort: fidelity, efficiency, and memory. Regarding fidelity, Shannon's model revealed the ubiquity of noise. "Noise" represents anything that can corrupt the signal, either predictably or unpredictably. Shannon explained that redundancy in the message ameliorates this problem. By repeating parts of the message, the receiver is given another opportunity to get the message despite the noise.

Regarding efficiency, Shannon showed that its achievement required a tradeoff. Increasing the redundancy of a message reduced the need for error correction, yet it also reduced the message's efficiency. On the other hand, reducing redundancy increased the need for error correction, but increased efficiency. The tradeoff, then, is between redundancy and compression, and between duplication and gaps.

Regarding memory, Shannon explained that “what is significant is the difficulty in transmitting the message from one point to another.” (Shannon, 1953). By use of the term “point”, Shannon meant another location and time. In this way, he suggested information storage and retrieval.

These ideas have relevance to the concept of provisioning: providing an item when and where needed so that it is actionable. Shannon’s mathematical communication solutions involved smoothing over a stream of bits so the receiver could receive the message as needed. They suggest Shannon’s work on the automated anti-aircraft gun: preparing tracking information so that the projectile can arrive when and where needed.

Shannon’s work on fidelity, efficiency, and memory has relevance to a decentralized provisioning system that employs case management. In this situation exists a potential for the duplication of services, as well as gaps. The role of the case manager is to smooth out the sequence of services so that the client can receive a continuum of care. In terms of information theory, case managers perform error correction.

Employing the ideas from convergence and information theory, it was proposed to develop a model of a case management system. The goals were to 1) understand how case management contends with the difficulties of a decentralized health care system, 2) document the strengths and weaknesses of the approach, and 3) devise tools for improvement.

It was decided that the first step would be to create a flowchart of the case management process. The result has been presented *supra* as Figure 1. The next step was to represent the flow of communication in the system.

Analysis of the Case Management System

From his model of communication, Shannon developed a notation for documenting a communication “channel”. He had defined the channel as “merely the medium used to transmit the signal.” (Shannon & Weaver, 1949). Yet his notation showed the connections between transmitters and receivers, as well as connection possibilities and probabilities.

In each case management application, the identity and number of transmitters and receivers will vary. However, during development of the model, a reductionist approach was used. The initial proposal was that there were three cardinal nodes: Case Management, Service Provider, and Client. For a given case, case management may involve multiple case managers in an administrative and hierarchical structure. These staff members, case managers, and administrators will exchange messages as part of their processes. However, for the sake of simplicity, it was considered that all internal case manager communications would be taking place within the set known as “Case Management”.

Similarly, for a given case, there may be multiple service providers assisting the client. For the sake of simplicity, it was considered that all interactions with all services providers would be taking place within the set known as “Service Provider”. From these assumptions, a graph was developed. In Figure 2 below is shown a graph of the fundamental case management communication channel in standard Shannon notation.

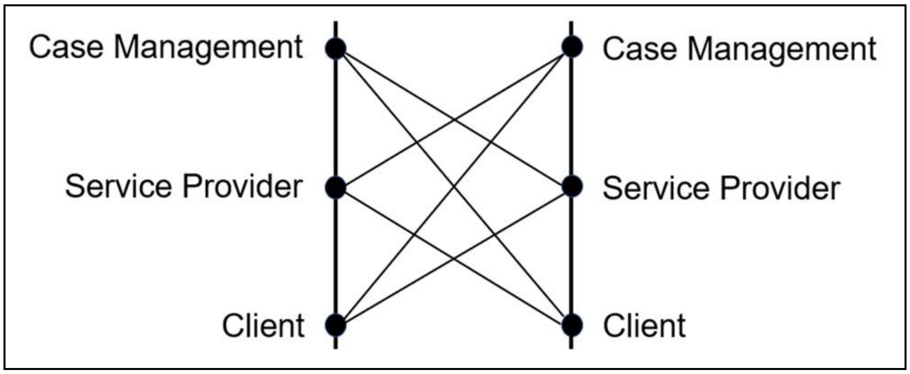


Figure 2. Graph of the case management communication channel.

From the graph, it can be seen that during the process of coordinating services delivery, Case Management will communicate with Service Provider and with Client; Service Provider will communicate with Case Management and Client; and Client will communicate with Case Management and Service Provider. It can also be seen that one side of the communication channel is a mirror image of the other. This fact allowed for a further simplification: the representation of the same channel as an error content graph. This representation is shown in Figure 3 below.

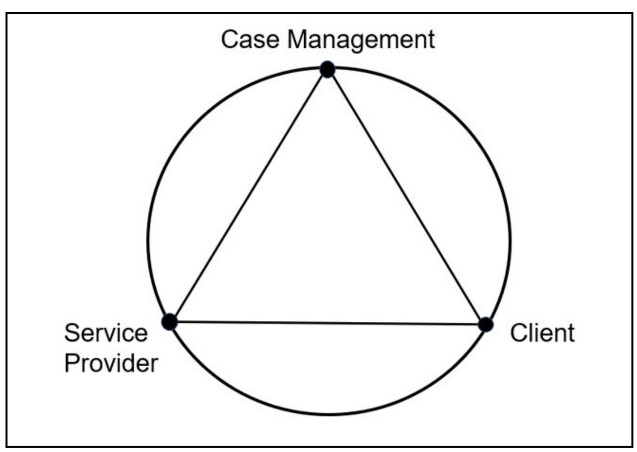


Figure 3. Error content graph of the case management communication channel.

In Figure 3 is represented the directional and ordered transmission of information around the unit circle. For example, in the instance of a client evaluation, it may be that the evaluation will need to be performed by a specialized service provider, such as a radiologist. The client will provide the service provider with information by making his or her body available for a radiography procedure. The service provider will process this information, then forward the results to the case manager.

Every transmission of information involves noise. Thus, when a message is retransmitted, more error is potential. If the client, for example, communicates a fact to the service provider who then passes that along to the case manager, there is an increased likelihood that this fact will be distorted.

The next step in model development was to apply Figure 3 to each stage in the case management process. The proposed technique was to count the number of messages exchanged between the nodes of the channel during each stage. This would allow a determination as to which of the nodes were most active.

To do this, a representative real-world case management system was required. For purposes of model development, an entity known as Community Justice Programs (CJP) was selected. CJP is a part of the Substance Abuse Division of the University of Alabama at Birmingham's School of Medicine, Department of Psychiatry and Behavioral Neurobiology. Broadly stated, CJP provides support in addiction recovery and mental health for individuals that have become involved in the justice system based on those factors. CJP has been the designated community corrections program for Jefferson County, Alabama since 1994 (UAB Department of Psychiatry, 2021).

Interviews with supervisors and case managers were performed to gather information on the information channel. Although informally gathered, the information gained was regarded as a reasonable starting point for model development. A more formal survey could be performed as future work.

Results are presented in the form of the unit circle in which the most numerous transmission exchanges are represented by a black line. The comparatively small number, or zero number, of exchanges are represented by no line. In other words, although in any given process communication may occur among all of the nodes, only the most active communication connections are represented, causing the figure to take a particular form.

This technique was applied to the flowchart of the case management process, which was originally presented in Figure 1. In Figure 4 below is presented that same flowchart, with the addition that communication graphs are now presented with their associated stages in the process. Three stages are not given communication graphs: services selection, services sequencing, and termination criteria. This is so because the communication that occurs at those stages are all internal to the case management system. As such, there is no communication connection to any other node. The results of this analysis are shown below in Figure 4.

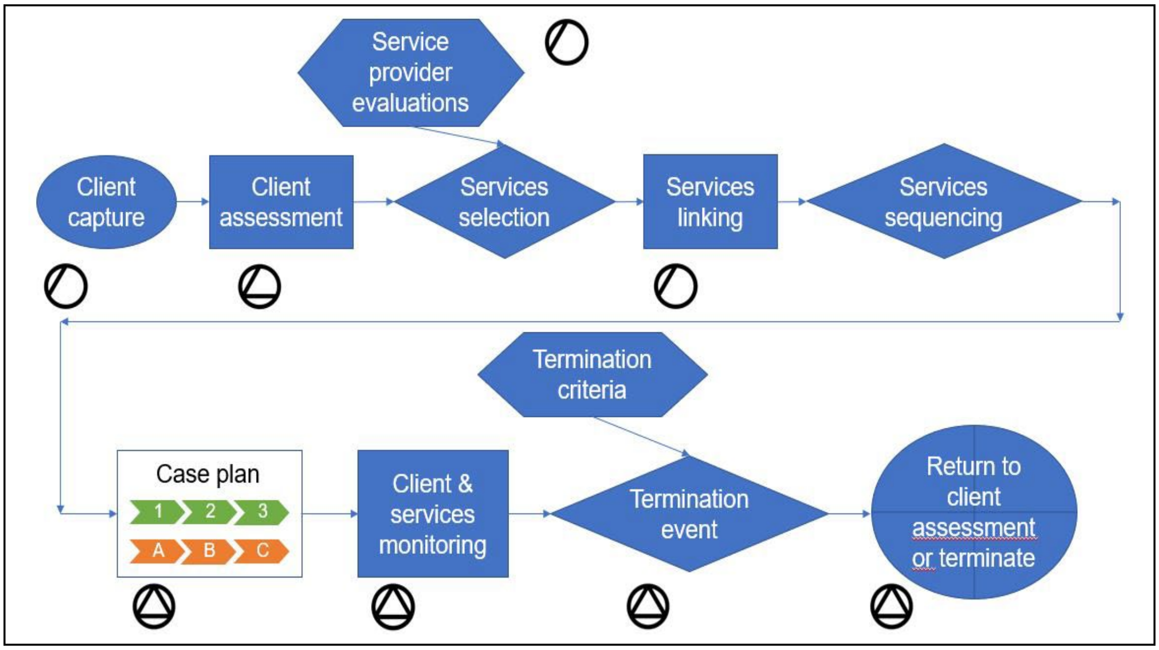


Figure 4. Case management process with communication graphs.

In Figure 4 is revealed that much of the communication in the early stages of the case management process is between Case Management and Service Provider. Even in the assessment stage, where information about Client is transmitted to Case Management, that information is transferred through Service Provider who performed the client assessment.

Figure 4 also reveals that in the latter stages of the case management process, all communication connections become significantly active. This is a reasonable outcome of the case management process. It has been said that essential functions of case management are to link, monitor, and assess (Intagliata, 1982). This necessitates communication with all steps in the process.

The early stages of case management, in contrast, regard linking and assessing. These efforts can be described as discrete: a client assessment is made, then services are selected and linked to the client. The later stages regard monitoring and assessment. These efforts can be described as continual: an updated state of the client, and the delivery of treatment, will be necessary to determine if the client is benefitting from that treatment. Consequently, there will be more communication between all nodes in the latter stages of the case management process.

At this point in model development, it became apparent that a significant component had been overlooked: memory storage and retrieval. A reflection on the model in a real-world context, recommended by TAR, showed first that the volume of data collected required that data storage be made. Next, the "gossip problem" illustrated in Figure 3 *supra*, was instructive. This is the situation whereby information moves along a chain of receivers and transmitters, thereby incurring additional noise and error.

The gossip problem suggested that noise could be reduced by placing the once-transmitted information into a database for retrieval by multiple receivers. This is in accord with Shannon's model of the communication channel, in which he represented that the signal would be retrievable at another "point" in space and time (Shannon, 1953). A common database of client information accessible to the agents of the system could facilitate accurate, coordinated action.

As a result, it was determined that an analysis of the communication to memory storage should be undertaken. The determination that this was occurring at every stage in the case management process was a simple matter. It was revealed thereby that a new node was needed for the model: "Database". One practical implication of this is that an effort to improve case management would do well to consider the mechanisms used for the effective and efficient storage and retrieval of information.

The next step in model development was to identify the most generalizable stations in the case management process. This was necessary in order to ensure that the model being developed would be broadly applicable. It was proposed that the activity at each station should be considered in terms of how domain-driven it was.

For example, it can be readily seen that the activity at Client Assessment will be very domain specific. The assessment of client needs performed at a dentist's office will be very different from that performed at a podiatrist's practice. The training and tools used to make the assessment will also be determined by the domain. As has been shown, the communication involved in performing, reporting, and documenting the assessment is a generalizable feature. However, the weight of domain-specific activity in the assessment process itself, led to the conclusion that this process was non-generalizable.

In reference to Figure 4 above, the following processes appeared to be non-generalizable: client capture, client assessment, service provider evaluations, services selection, services linking, services sequencing, case plan, and determination of termination criteria.

In contrast, the following processes appeared to be generalizable: client and services monitoring; determination of a termination event; and returning to the assessment or full-stop termination. In these stations, domain-specific activities exist, but the generalizable features of communication predominate. It is worth noting that these are the stations at which communication among all nodes are the most active.

The results of model analysis to this point in the investigation were summarized in a table. A blackened triangle icon was used to indicate that the column's condition is true. The result is presented below as Table 4.

Table 4

Results of Model Analysis

CM Events	Generalizable	Communication	CM Memory
Client Capture		SP → CM	▲
Client Assessment		Client → SP → CM	▲
Service Provider Evaluation		SP → CM	▲
Services Selection			▲
Services Linking		CM → SP	▲
Services Sequencing			▲
Case Plan		SP ↔ CM ↔ Client	▲
Client & Services Monitoring	▲	SP ↔ CM ↔ Client	▲
Termination Criteria			▲
Termination Event	▲	SP ↔ CM ↔ Client	▲
Return or Terminate	▲	SP ↔ CM ↔ Client	▲

It must be admitted that although the determination of the cardinal components of the system was reasoned, it was informal. One formal method of deconstructing a complex system is made by counting the number of transmissions between parts of the system, known as Roger Conant's method of structural modeling (Conant, 1980). Conant's method was selected for application. For simplicity and clarity, it was proposed that a comparative scale of 1 to 5 should be used, with 5 representing the most message exchanges between parts of the system.

Reflection on an early version of the model in a real-world context suggested that something significant was missing. It was seen that by counting the frequency of messages, a previously unappreciated node was being overlooked: the decision-maker. This may be explained by illustration. It is a common experience that when visiting a doctor's office, one will have more informational exchanges, and spend more time, with every worker other than the physician. The result is that a Conant analysis will not represent well the importance of the doctor in a doctor's office visit.

This is so because Conant analysis, like communication theory, is agnostic to semantics. The focus is on the transmission of the signal, not the content of the message. Yet the limited exchange with the doctor is full of meaning, and important to the patient's outcome. For example, during a brief encounter with the physician, a determination may be made that surgery is required. It was determined that to capture this important node in the model, a semantic analysis was needed for giving weight to the consequences of the message.

The difficulty in semantics analysis is objectifying the meaning, and such an effort entails the constructs of value, ambiguity, and interpretation. These constructs are notoriously resistant to quantification. It was proposed that an operational definition could be created for the "weight" of communication, and this would be "impact on the outcome for Client".

To simplify matters, the scale would be binary. The semantic value of communication would be considered to be either "light" or "heavy". When this was implemented, decision-makers such as doctor, administrator, and judge made their appearance in the model. This new node was given the label, "Specialist".

Throughout the investigation, a reductionist approach was followed, and semantics were avoided. It had been considered that the "meaning" and "value" of the provisioning of information and services were domain-centric. It had been held that a consideration of such would endanger the goal of a generalizable framework for case management.

It was now proposed that semantics would have to be taken into account. This would be expressed in terms of the impact on the client's need for receiving the services, in other words the client's assessed needs. This extension of information theory and Conant's method increased the model's ability to represent the subject system. It is another example of how the research method's inclination toward benefit-to-client influenced the results.

In Figure 5 below is presented one expression of the revised information-based model of a case management healthcare system. It will be noticed that this model does not represent the process of case management, as did Figures 1 and 4. Instead, it represents the communication channel, as was shown in less developed form in Figures 2 and 3. Additionally, Figure 5 presents the communication channel from a certain point of view, that of Case Management.

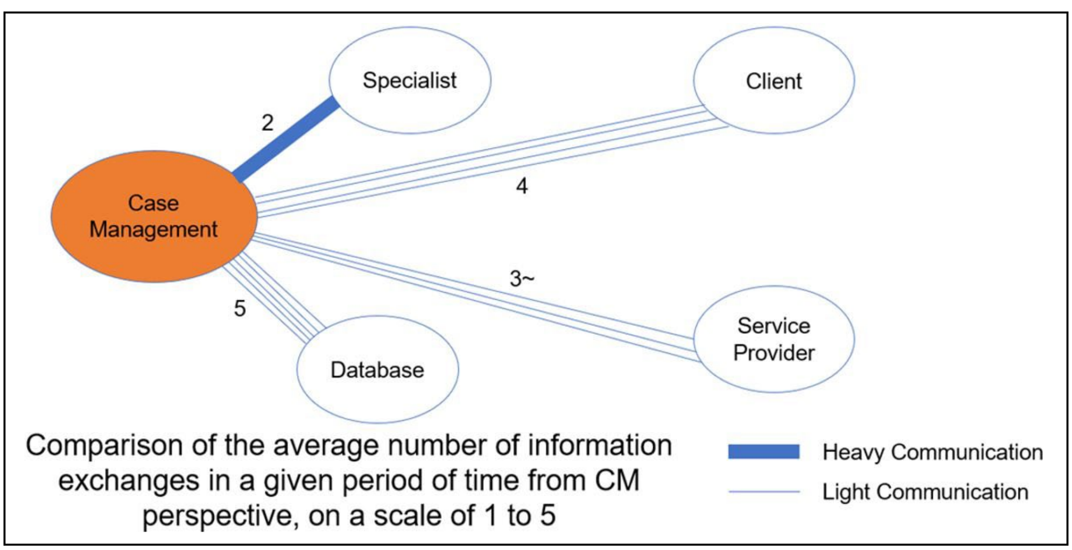


Figure 5. Model of communication in a case management system from the perspective of case management

In Figure 5 are shown the revised cardinal nodes of the case management system: Case Management, Client, Service Provider, Database, and Specialist. Also represented are the comparative values of the average number of information exchanges in a given period of time. The communication exchanges are presented from the perspective of Case Management. Therefore, no connections that do not involve Case Management are shown.

The value of exchanges is made using a scale of 1 to 5. On this scale, 5 represents the most numerous exchanges, comparatively. The number of lines connecting the nodes graphically reinforce the value shown in Arabic numerals.

The exchange value given between the Case Management node and Service Provider node bears the symbol "~", which indicates "highly variable". This is so because interviews with case managers and supervisors indicate that the number of such contacts is highly dependent on the particular service being provided. Even so, it was estimated that the number of contacts between Case Management and Service Provider fell between the number of contacts between Client and with Database.

As represented in Figure 5, Case Management has the most exchanges with Database. The next-most number of exchanges is with Client. This is validated by the fact that in order to perform the functions of link, monitor, and assess, a case manager must document, store, and retrieve documentation about Client and Service Provider. Again, it can be seen that the more difficult the connection to the database is, the more ineffective a case manager's performance may become.

Figure 5 also reveals the impact of the communication exchange between Case Management and Specialist. Because the semantic content is considered to be "heavy", that exchange is represented by a thick line. Heavy, it will be recalled, is one-half of the binary designation of impact-to-client-outcome.

A second model was developed to represent the revised information-based model of a case management healthcare system. Here, the communication channel is shown from the perspective of Client. This model is presented below as Figure 6.

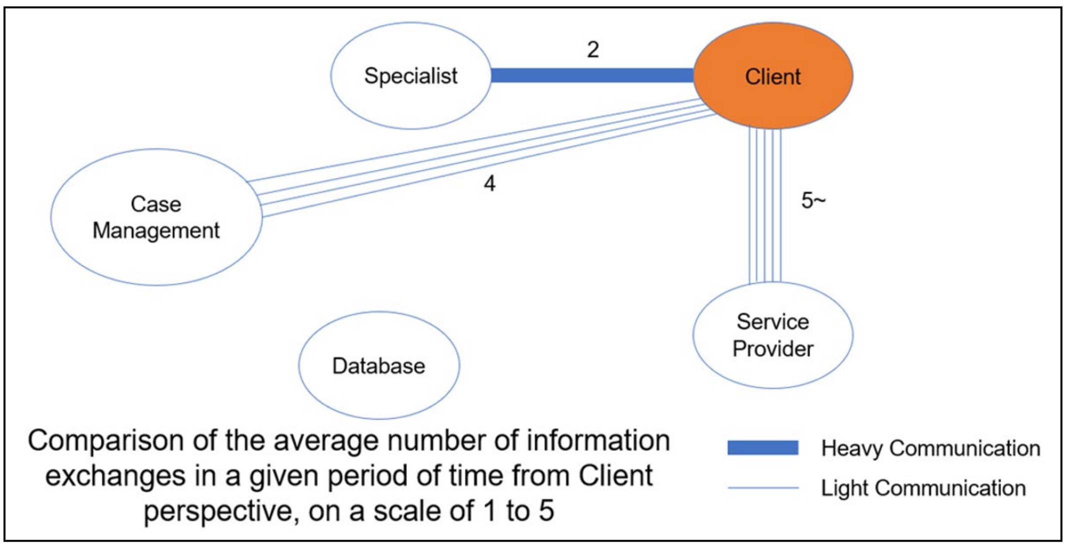


Figure 6. Model of communication in a case management system from the perspective of the client.

As Figure 6 is represents the situation of Client, it can be seen that no connection to Database is shown. The model reveals that Client has more contacts with Service Provider than with Case Management. Also revealed is the impact of the communication exchange between Client and Specialist. Because the semantic content is considered to be "heavy", that exchange is represented by a thick line.

The results of these modeling efforts reveal the importance of effective and efficient communication among all participants in the system. Information will be gathered about the client, treatment providers, assessments, and treatment plans. This information will be documented, stored, and passed along to the participants who need it at one moment or another. This suggests that the storage of gathered information in a database accessible to all participants will be beneficial.

Such a recommendation invites concerns about security, yet there are means available for confronting the challenge. Information transmitted could be encrypted in ways that comply with system, and legal, requirements. Also, access could be limited in predetermined ways using application programming interface (API) technologies. APIs allow applications to exchange information while limiting access through permissions (Date & Codd, 1975). The client, for example, could be given permission to review certain information stored while being denied access to other information. Also, the client could be given permission to input certain information to the database while being denied the ability to input others.

The material presented in this chapter was enlarged upon from a paper submitted and presented by the author at the IEEE Southeastcon 2021 conference (Lipscomb, Alharthi, Alhefdi, & Jololian, 2021).

CHAPTER 4

VALUE-BASED MODELING OF A CASE MANAGEMENT SYSTEM

Introduction

Reflection on the process-based models detailed in the previous chapter revealed that the gathering and transmitting of information facilitated the primary functions of case management. The information-based models, which represented the flow of information through the system, revealed, among other things, the need for a central repository of all gathered information about the status of the client. It was proposed that this information should be accessible by all participants in the provisioning plan, including, at least to some limited degree, the client.

For the next phase of the research, a new modeling technique was employed. This was value-based modeling, a technique often used in the business domain for commercial services development. For this effort, the same real-world system was used as before, that being the CJP.

Value-Based Modeling

Value-based modeling represents actors who are exchanging with each other things of economic value. The actors can be customers and service suppliers. The things of value can be service outcomes and money (Felicia & Jaap, 2019). While often used for commercial service development, it is proposed herein that the term “service outcomes” lends itself to more general application, including healthcare treatment.

In value-based modeling, the terms “value objects” and “value propositions” are used to denote what is being offered and what is being requested in return. Describing the state of the actors in relation to these value propositions is the focus here. In contrast, process-based modeling sets out the tasks whereby the value objects are provisioned. These two complementary approaches may be considered to be the “what” and “how” of the situation under investigation, respectively.

For example, a process model of an internet merchant sale will describe the sequence of tasks required for the customer to receive a product or service and for the merchant to receive remuneration. This approach does not account for the value to the consumer, such as customer satisfaction, fulfillment of a need, or resolution of a problem. Neither does the approach account for the value to the merchant, such as profitability. In other words, the process model simply asks: was the transaction effective and efficient?

A value model, on the other hand, describes the value flow. The focus is on how value objects are offered, accepted, and exchanged in a network. The sequence of the tasks performed to make a transfer is not represented in a value model, neither is the physical movement of value objects. Instead, the elements required for the transfer to take place, the “dependencies”, are shown (Felicia & Jaap, 2019). While process models can be used to improve the operation and sequence of tasks required to exchange objects of value, value models can be used to improve the net value of the exchange. They ask the question: was the transaction worth it?

The elements of a value model can be quantified. This may include, but are not limited to actors, exchanges, transaction costs, resources expended, pricing, time, consumer needs, events, messages, and cash flow. These elements have clear worth for determining whether the effort results in a net gain for the actors.

Several tools exist to assist with this work, including Resource Event Agent (Geerts & McCarthy, 1999), Business Model Canvas (Osterwalder & Pigneur, 2010), e3 value (Gordijn & Akkarans, 2001), and PArchitect (Alshehri, Alharthi, & Tanik, 2019). PArchitect was chosen for the instant research. This software modeling tool grew out of a project with the Brazilian Aerospace Agency for the analysis of highly complex operations (Gattaz, Neto, Catharino, Techima, & Sampaio, 2006). PArchitect was chosen for several reasons, including the fact that it allows for the representation of multiple values, and changes to the state of the value being tracked.

PArchitect is described using tool-specific jargon, with which the user must become acquainted. The main components of the models are called “transitions”, “infrastructures”, and “values”. Transitions are the value exchange events. Infrastructures are the resources that allow exchanges to occur. Values, or value-objects, are subdivided into objects of “input”, “output”, and “reference”. This division allows for the representation of any change to the state of the value object by means of the exchange. In the e3 value method, by contrast, possession and ownership are the only state-changes recognized (Weigand, Johannesson, Andersson, Bergholtz, Edirisuriya, & Ilayperuma, 2007). Reference is that set of instructions for how the transition should occur. That a reference is considered a value and not an infrastructure is an acknowledgement that a value-object can be a service. In a PArchitect model, the status of the value of interest is tracked from its initial state to its final state.

Drug Testing Process

The real-world entity known as Community Justice Programs (CJP) was used for this case study, as it was for the information-based models. It was considered that information gained from the prior effort could benefit the next. It is worth repeating that CJP provides support in addiction recovery and mental health for individuals who have become involved in the justice system as a result of those challenges (UAB Department of Psychiatry, 2021).

One goal for this effort was to create a model with broad applicability. Effort was expended, therefore, to represent value exchanges in such a way that they could apply generally. This design choice was followed up to the point where the modeling of a representative treatment application was required. For this, the drug-testing process of the CJP was selected. The resulting build allows the model to be easily modified to represent another given system by only changing the lowest levels of the model.

Stated succinctly, the drug-testing process involves the client being assigned a color, calling a messaging service each day to determine if their color will test, traveling to the testing site, checking in, then testing. Testing results are reported, and the client's plan of care changes accordingly. The model also represents the preliminary steps of the client entering the system, being evaluated, and being assigned drug-testing as part of the plan of care, as well as the exiting steps from system.

Analysis of the Case Management System

Models built in PArchitect are organized in a tree structure. In this section, the developed model will be presented from the top of the tree down to the representation of the drug-testing process. In so doing, several transitions that were fully modeled will be passed over. These, although interesting for an understanding of such systems, would dilute the impact of the insights obtainable from value-based modeling relevant to the present discussion.

The first model developed for this effort presents the highest level of representation for the system. It also reveals the characteristic way in which PArchitect represents systems. Note that “CJP” stands for “Community Justice Programs”. The shadow around the CJP transition oval signifies that the item can be opened to reveal further tree-structure items. Models of the lower-structure items are hereinafter referred to as being “decompressed”. Figure 7 is presented below.

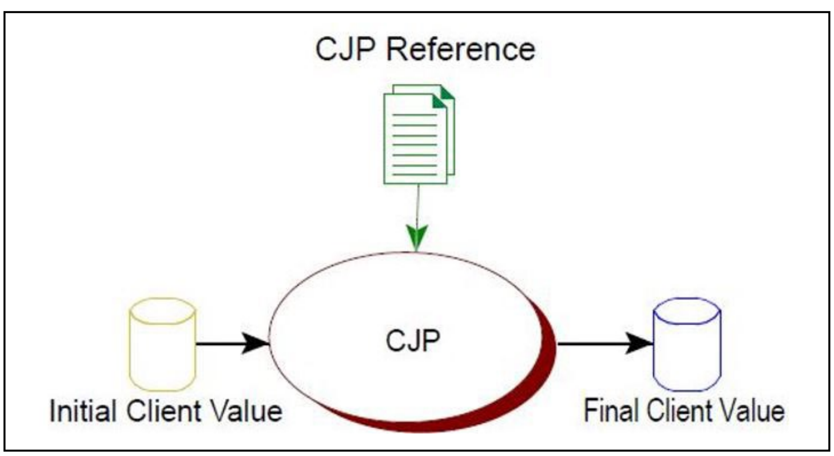


Figure 7. Highest level representation of the case management system.

The state of the initial value of interest is stored in the left-most object, labeled "Initial Client Value". Any suitable value may be modeled and quantified. In this model, a value associated with the client will be tracked, that being the client's relation to the justice system. At this, the highest level, the initial value for the client can be described as "involvement in the justice system". The center object, an oval, is the only transition here and represents a case management system in its entirety, in this case the CJP program. This is where all value exchanges will occur that will affect the initial client value.

When the client exits the case management system, the state of the client's final value will be stored in the right-most object, labeled "Final Client Value". Here, the value can be either "no involvement in the justice system" or "further involvement in the justice system". The initial and final values are meaningful in that a client will enter the CJP program because they have become involved in the justice system. The client will be offered release from the justice system in exchange for completion of the CJP program, among other things (Jefferson County Specialty Court Programs, 2020).

It will be seen that in the PArchitect model, many value exchanges ("transitions") will be tracked. Further, at the level of treatment, several different values will be tracked, all defined by the requirement for an acceptable completion of the task. Yet all of this will converge and contribute to the final value.

The object at the top of the Figure 7 is a reference, which represents that set of instructions for how the transition should occur. No representation of an infrastructure object is shown here for platform reasons of little relevance to the present discussion. Infrastructure objects will appear in subsequent figures. In this, the simplest of model of the case management system, can be seen how value-based modeling prioritizes the tracking of value exchanges.

Next, a model of the "inside" of the CJP transition was developed that reveals the main transitions of the program. Three were identified as being necessary: Capturing, Treatment and Assessment, and Maximum Improvement Decision. Figure 8 is presented below.

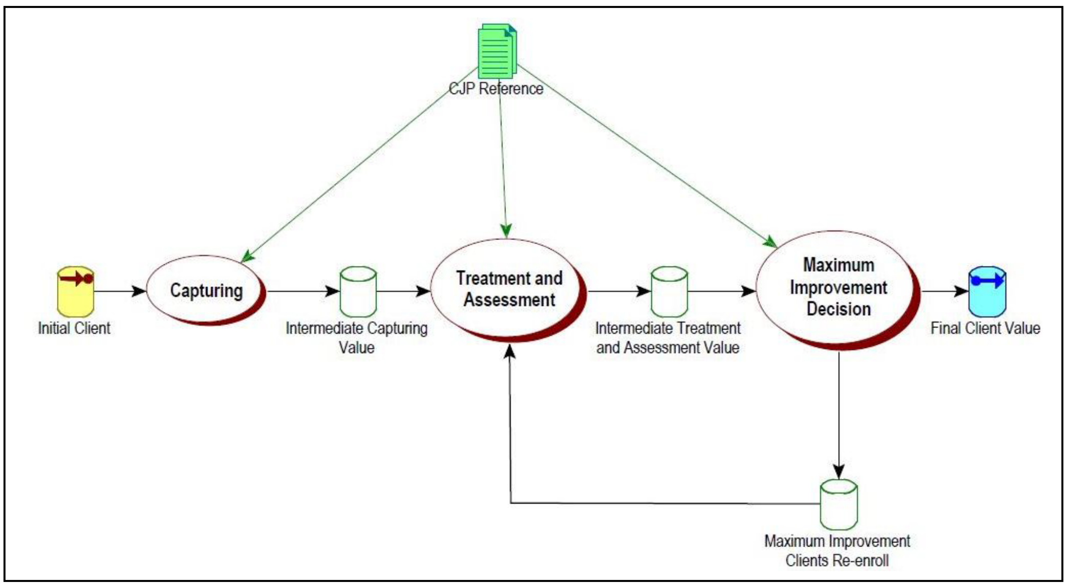


Figure 8. Decompressed model of the case management system.

Capturing is the transition wherein the client is brought into the case management system. Treatment and Assessment is the transition wherein the client is assessed, receives treatment, and completes plan requirements. Maximum Improvement Decision is the transition wherein the decision is made to release the client from case management. In this expression of the model, release from the CJP is not necessarily concomitant with release from the justice system as the client may be placed on probation or sent to prison (Jefferson County Specialty Court Programs, 2020).

Each one of these transitions was decompressed and modeled to provide greater detail. In many cases, the resulting models were themselves decompressed. An elaboration of the Capturing transition is not of relevance to the present discussion and is not presented here.

Next, a decompressed model of the Treatment and Assessment transition was developed. Two value transitions were identified as being necessary: Assessment and Plan, and Treatment Tasks. Figure 9 is presented below.

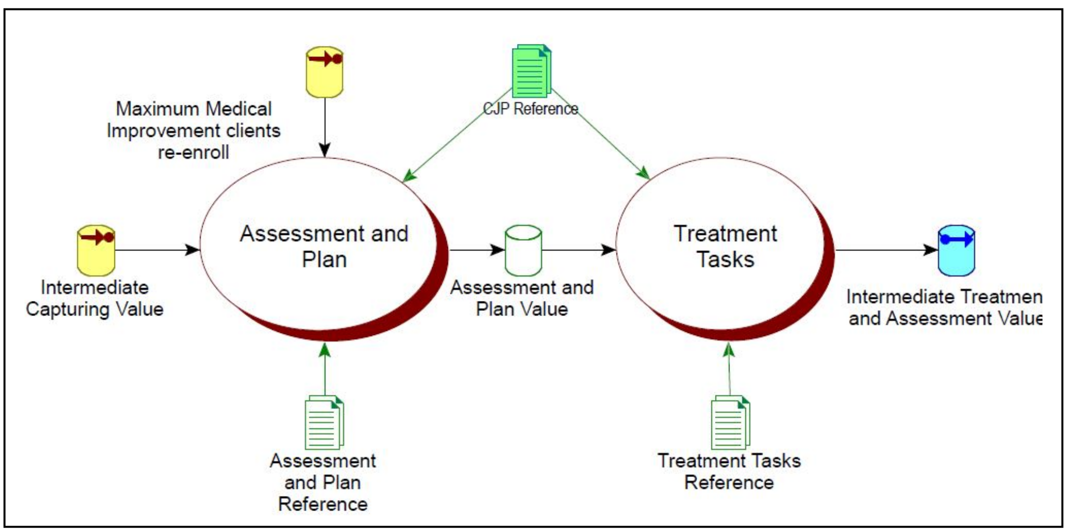


Figure 9. Decompressed model of treatment & assessment.

Because the focus of the present discussion is on the treatment of drug-testing, an elaboration of the Assessment and Plan transition will not be given. It should suffice to say that Assessment and Plan regards the value transfers that occur as the client's needs are assessed and a plan of care is created. Note that the plan of care may involve a set of treatments and requirements arranged in a sequence line. Termination criteria will be defined to determine when a client may stop one task and begin the next. Multiple sequence lines may run in parallel.

The Treatment Tasks transition is of greater relevance to the present discussion. This is where the client will perform the tasks that lead up to and include the receipt of treatment. For this discussion of the CJP, the main treatment is drug testing.

This transition was decompressed and modeled. Three transitions were identified as necessary: Linking to Services, Attend Plan Requirements, and Intermediate Treatment Decisions. In this model can be seen most readily the primary functions of case management, which are to link, monitor, and asses (Intagliata, 1982). Figure 10 is presented below.

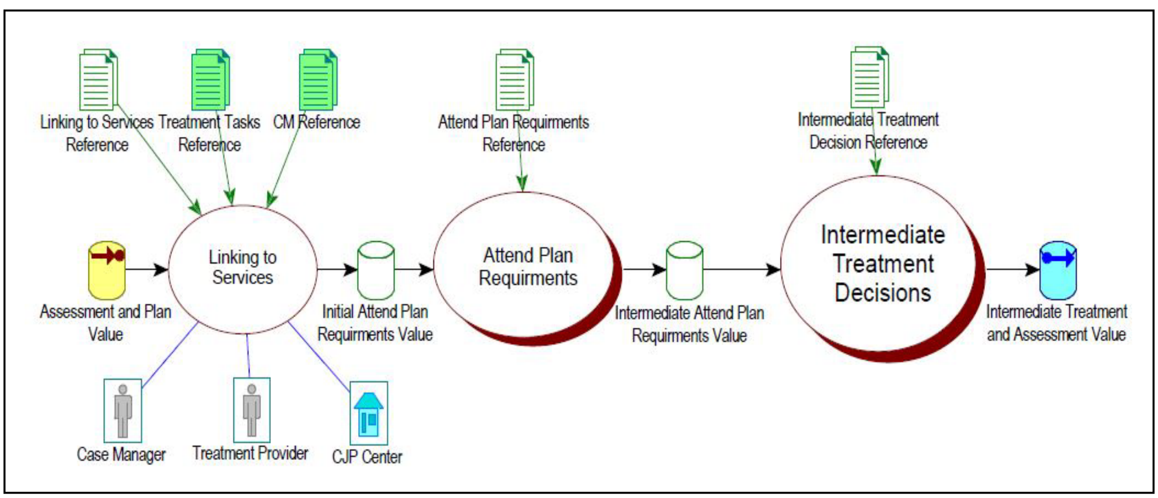


Figure 10. Decompressed model of treatment tasks transition.

The Linking to Services transition involves the case manager connecting the client to treatments and plan requirements as an outcome of the Assessment and Plan transition, which was represented in Figure 9 *supra*. This linking could be as simple as providing the client the name and contact information of the service provider, or as involved as completing all enrollment and appointment-making tasks for the client. Any remaining administrative tasks will be completed by the client in the Attend Treatment transition as presented in Figure 12 *infra*.

The center-most transition in Figure 10 above is Attend Plan Requirements. This represents the client engaging with those treatments and requirements that are part of the plan of care. This transition was decompressed and modeled, and will be shown in Figure 11, *infra*.

The right-most transition in Figure 10 above is Intermediate Treatment Decisions. Here, decisions will be made as to whether individual services and requirements should continue or terminate. Each task will have its own value that will be tracked as part of monitoring. Value exchanges will alter the tracked value. A periodic assessment will be made to determine if the task value is such that the client may stop the subject task and proceed to another. For example, in the drug-testing task, the initial task value may be "no consecutive clean drug tests". The final value that signals completion may be "twelve consecutive clean drug test results".

Next, a decompressed model was developed for the Attend Plan Requirements transition, originally shown in Figure 10 above. Within this transition are many elements. It is, therefore, difficult to present graphically. Yet the figure does demonstrate PArchitect's ability to represent complexity. It should be noted that at this level of the

PArchitect tree structure, the constructed model becomes less generalized and more specific to the CJP program. Figure 11 is presented below.

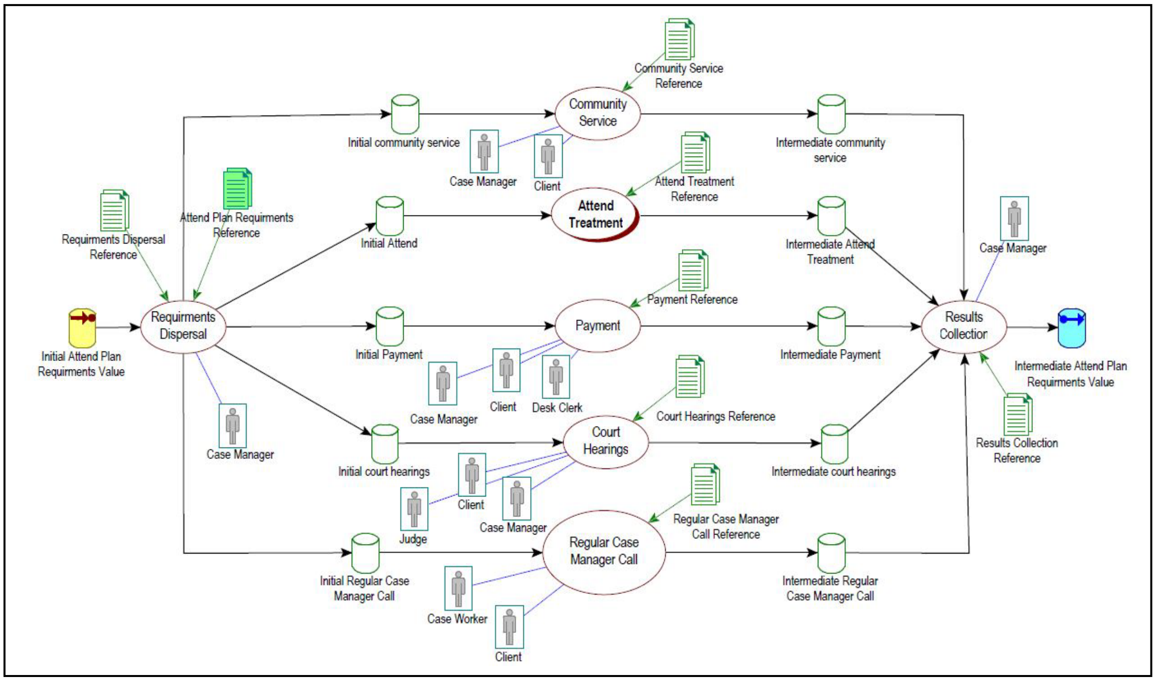


Figure 11. Decompressed model of attend plan requirements transition.

The left-most and right-most transitions shown, those being Requirements Dispersal and Results Collector, are platform requirements of PArchitect and do not model any real-world system. Between these two is shown a column of transitions. These represent the fact that a plan of care for the client may involve multiple sequence lines running in parallel. At this level of the model, typical treatments and requirements of a CJP plan of care are represented. These are Community Service, Attend Treatment, Payment, Court Hearings, and Regular Case Management Call. Except for the Attend Treatment transition, these transitions are of little relevance to the present discussion and will be passed over.

Next, a decompressed model was developed for the Attend Treatment transition, originally shown in Figure 11 above. This model is generalizable to case management systems. Four transitions were identified as necessary: Appointment Process, Client Action, Registration Process, and Treatment. Figure 12 is presented below.

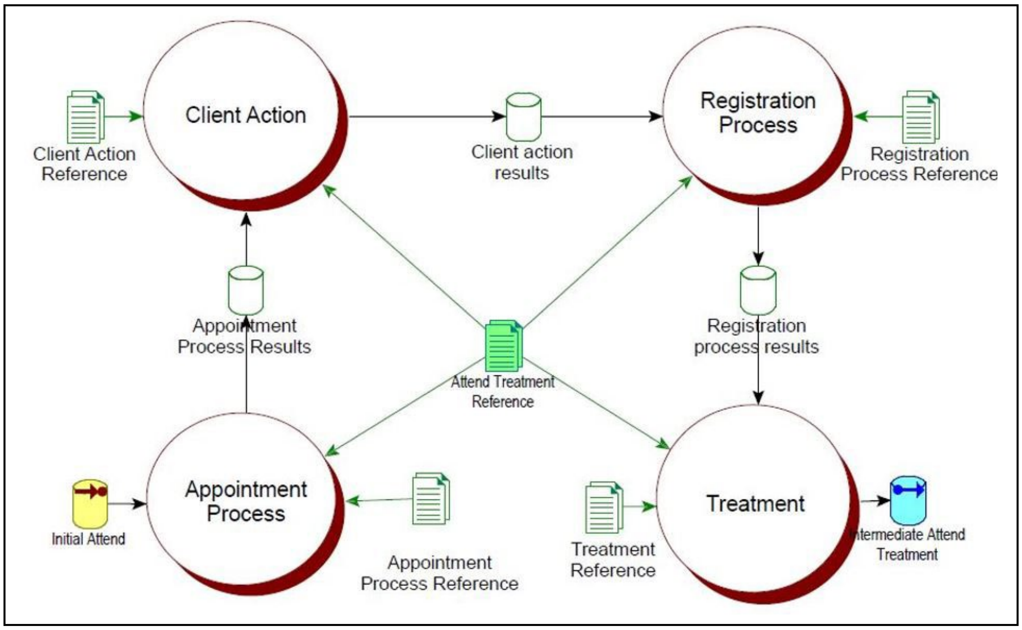


Figure 12. Decompressed model of attend treatment transition.

The Appointment Process transition involves the client's actions for resolving any remaining requirements to finalize an appointment for treatment. The Client Action transition involves the client deciding whether to attend the treatment appointment. It was decided that this decision was significant enough to the treatment task value to warrant its own representation. The Registration Process transition involves the client presenting for treatment and making any necessary payments or administrative documentation. The Treatment transition involves the client receiving treatment.

Next, a decompressed model was developed for the Treatment transition, originally shown in Figure 12 above. Three transitions were identified as necessary: ID Verification, Reject and Report to Supervisor, and Therapeutic Treatment. Figure 13 is presented below.

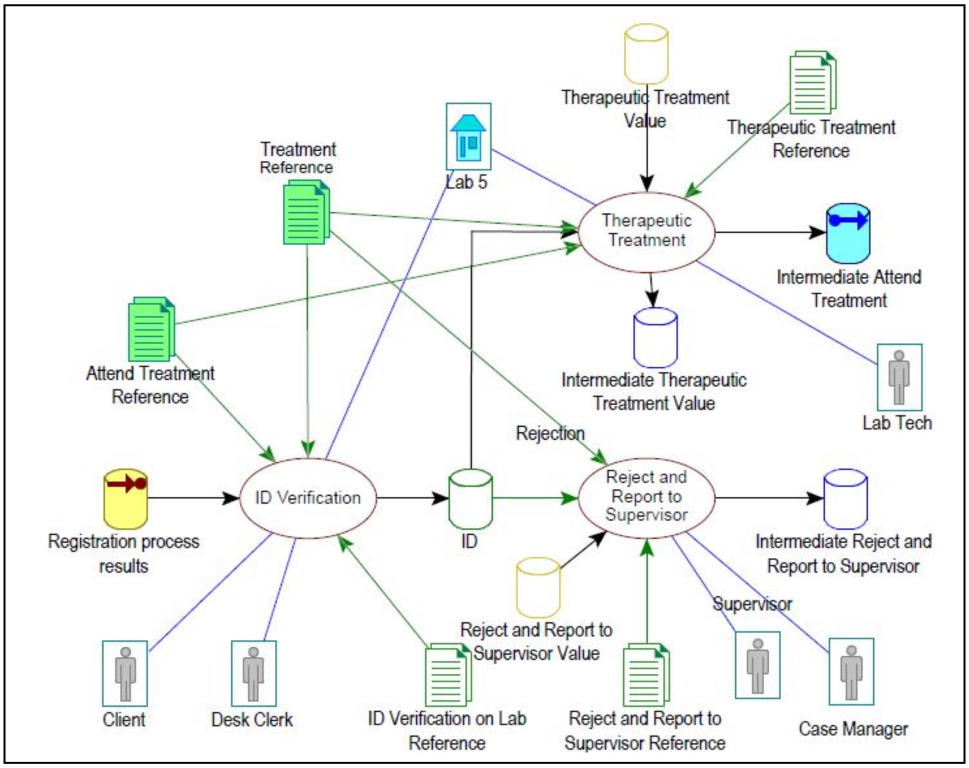


Figure 13. Decompressed model of treatment transition.

The ID Verification transition represents the fact that even though the client has already been identified in the Registration Process transition, as shown in Figure 12 *supra*, an additional verification will be made immediately prior to the providing of treatment. In the case of drug testing, this means that the lab technician will verify that the sample is coming from the proper individual.

The Reject and Report to Supervisor transition models the event in which a misidentification is made, or an imposter presents as the client. In the case of drug testing, the presence of an imposter would have meaningful consequences for the client. In terms of value-based modeling, the activation of this transition would cause a significant change to the Client Value. This transition reveals one benefit of tracking changes to client value rather than simply elaborating the process.

The Therapeutic Treatment transition represents the event in which a value-object exchange, here a treatment service, occurs. In the case of drug testing, this involves the client giving a sample, the lab technician testing or having tested the sample, and the results being reported to the CJP system. This is another significant value-object exchange for the client. The resulting modification to the Client Value will accumulate to help determine whether the client is required to continue the treatment.

The progress of the Client Value has now reached the point of the Intermediate Treatment Decisions transition. This transition is “up” in the tree structure and was presented in Figure 10 *supra*. Intermediate Treatment Decisions involves the case management team deciding whether the client should continue a particular treatment or plan requirement. The decision will be based in part on the Intermediate Attend Plan Requirements Value that exited the Treatment transition and then entered the instant transition.

The decisions that occur in the Intermediate Treatment Decisions transition are considered intermediate because the client may need to continue the given treatment. Alternatively, the client may need to terminate the existing treatment and start the next one in the sequence line. At some point, the Client Value will accumulate to a threshold level indicating readiness to proceed to the next major transition.

Next, a decompressed model was developed for the Maximum Improvement Decision transition, originally shown in Figure 8 *supra*. This transition exemplifies the case management function of assessment. Figure 14 is presented below.

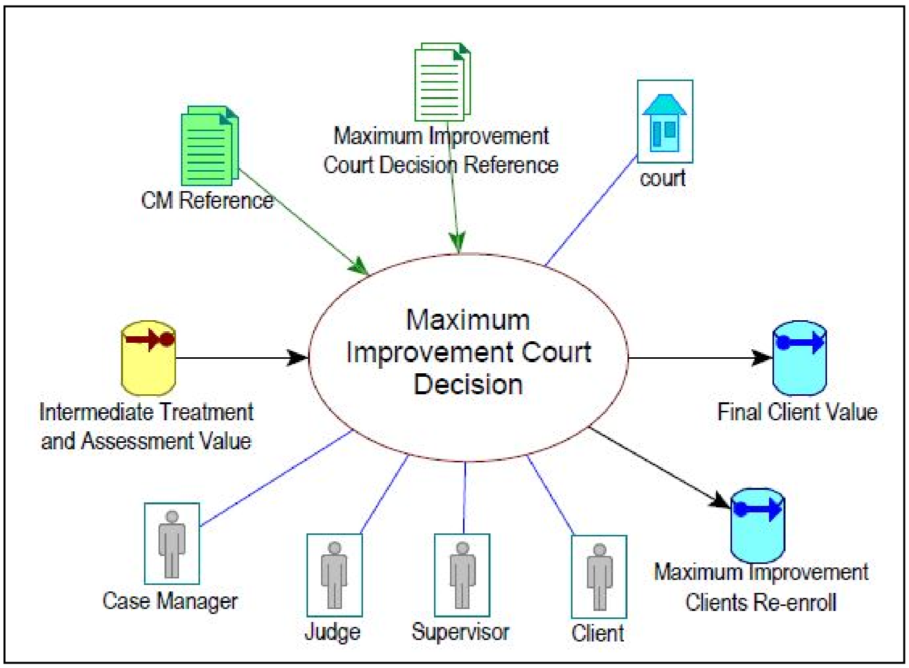


Figure 14. Decompressed model of maximum improvement decision transition.

The Maximum Improvement Decision transition contains only one transition, and one that is specific to the CJP: Maximum Improvement Court Decision. Such a construction is not efficient for modeling purposes, as a single transition within a transition is not necessary. Yet this was done so that the overall model could be adapted for a specific situation as simply as possible. Built in this way, the model can be adapted to the specifics of a given case management situation by only making changes at the lowest levels.

In the case of the CJP, the Maximum Improvement Court Decision transition will involve a subjective decision. This will be made by the judge who oversees the client's involvement in the justice system. The judge will render this decision based in part upon the Client Value that flows into the transition. The judge will also receive input from the human infrastructure elements represented: Client, Case Manager, and the Supervisor. These specific values, references, and infrastructures are specific to the CJP. However, it is proposed that there is something generalizable here: that graduation from a plan of care may be based upon Client Value, human inputs, and subjective decisions.

Discussion

Client Value had been modified along its journey from Initial Client Value to Final Client Value. The highest-level representation of this transformation was presented in Figure 7 *supra*. For purposes of the CJP case study, the Initial Client Value was "involvement in the justice system". The Final Client Value was either "no involvement in the justice system", meaning that the client would no longer be required to interact with the justice system, or it was "further involvement in the justice system", meaning that the client would still be required to interact but in some different way.

The value-based approach placed a spotlight on changes to Client Value that led to the final result. A process-based approach can encourage the modeler to focus on the administration of a system. Of interest will be how efficient and effective the process is. A process model of package delivery, for example, will reveal ways for improving delivery time. A process model, however, will not reveal the value of the process. These could be questions like “was it profitable?”, or “did it increase customer satisfaction?” Such is the benefit of value-based modeling.

The process-based model and value-based model built for this research may be compared and reflected upon in a real-world context, as recommended by TAR. By such effort, it may be seen that certain processes and events are of no value or are of detrimental value to the client. It is proposed that the client has the potential to gain value toward a desired final value in every step of the process.

The client can gain value in the early steps because these are potentially increasing the client’s access to needed services. The term “access to services” describes a situation in which services are available, relevant & effective, and utilizable by a client (Gulliford, Figueroa-Munoz, & Morgan, 2002). In the present context, utilization by the client is the focus. An implication from this is that anything present in the steps that hinders access to services will reduce client value.

If the client is physically injured in the Client Capture step, for example, it will hinder access to the services that were needed before the injury occurred. Such an outcome is not unforeseeable in a criminal justice context. An example would be a client being injured during the Client Capture step. Further, if the client is required to navigate difficult and idiosyncratic administrative processes in the steps that lead to the presentation for treatment, the client’s access to services will be reduced.

It might be argued that the most important process step for purposes of the client gaining value is the Client Services & Monitoring step, shown in the process model of Figure 1 *supra*. Here, the client receives needed treatment per the plan of care. This event was given value-model treatment in Figures 11-13, *supra*. Even here, it could be conceived that many factors might reduce the value gained by the client. Value-based modeling can be used to draw attention to such factors.

This analysis may be compared with one found in education. In that domain, there exists the concept of "course alignment", the details of which are beyond the scope of the present discussion. Succinctly stated, course alignment is the admonition that all content presented in the classroom to students should contribute to achieving course learning objectives (Blumberg, 2009). In terms of value-based modeling, it could be said that only value-objects that increase Client Value should be exchanged. The term "process alignment" will be used herein to describe the design of a provisioning system whereby only value objects that benefit the client are exchanged.

Another reflection upon the value-based model is that the case management system may not provide an objective threshold value for determining the outcome. Instead, a human subjective decision may make the call. This would frustrate attempts to construct an automated case management system.

A first step toward that effort is presented in the next chapter. There, a framework for a mobile health digital application is set out. Whereas the modeling of the CJP system brought attention to the value exchanges in the stages leading up the point of treatment, the modeling of the mobile health app invited consideration of the constraints to value-exchange at the point of treatment.

The material presented in this chapter is enlarged upon from a paper submitted by the author and to be presented at the IEEE Southeastcon 2022 conference (Alharthi, Alhefdi, Lipscomb, & Jololian, in press).

CHAPTER 5

VALUE-BASED MODELING FOR MOBILE HEALTH APPLICATION DEVELOPMENT

Introduction

The lessons learned in the previous steps of the research plan were applied to a new effort: an attempt to build a framework for a mobile health digital application (hereinafter "app"). The intended purpose of the app was to increase a client's access to health services. Access to services, it was said, describes the situation in which services are available, relevant & effective, and utilizable by a client (Gulliford, Figueroa-Munoz, & Morgan, 2002). Stated succinctly, the use-case of the proposed app would be for the client to self-monitor a given health condition, then report the data to their treatment provider by means of an internet-connected device.

PArchitect was used again for this effort. Knowledge gained from prior work described herein revealed that the tool was flexible enough to model the proposed app as well as the provisioning system it would embody. More specifically, PArchitect was employed to understand what architectural structures would be needed to construct a working app, and to reveal what hindrances to positive value exchange might exist in the proposed system.

A central tenet of use-inspired basic research is that research should be done with a real-world application in mind (Roco & Bainbridge, 2013). In the field of digital application development, an accepted method is the production of conceptual models

(Mylopoulos, Borgida, Jarke, & Koubarakis, 1990). A literature review of this use of modeling revealed that it can facilitate communication with stakeholders, allow for semi-automated analysis, and can be employed to avoid some of the pitfalls of natural language (Weigers, 1999). The use of natural language for requirements specification is accompanied by known risks such as ambiguity, contradiction, overspecification, the inclusion of irrelevant information, and the omission of valuable information (Meyer, 1985). As such, modeling was again revealed to be a reasonable tool for the job.

The goals of the instant phase of research were two-fold. First, apply value-based modeling to a straightforward mobile health app design. Second, use the insights provided by the model to improve the design. A discussion of the impetus for the work follows.

The Saudi Proposal

A funding proposal supplied the opportunity to put value-based modeling into practice. This was a call for proposals by the government of Saudi Arabia to develop means for improving access to health services (Prince Faisal Bin Fahad Award for Sports Research, 2021). The initial idea for the proposal was simple: the client would self-monitor a health condition and report the results to a medical service provider by means of internet transmission.

Stated more precisely, the proposal was to develop a customizable procedure to identify, collect, and analyze individual health data variables using smartphone technology for data capture; Cloud computing for data storage and analytical processing; and a user dashboard to access information to support patient care. The essential components were straightforward: client, digital mobile device, digital software application, health monitoring device, internet access, Cloud-based data base system, big data analytics subsystem, machine learning subsystem, medical services provider, data-summarizing dashboard, and process management tool.

For this proposal, case management was not a factor. Even so, the lessons learned from process-based, information-based, and value-based modeling performed on case management systems were of benefit to the present work. The results of this effort and reflections on the results are presented in the following sections.

Mobile Health Application Case Study

By use of the PArchitect tool, a model of the proposed app system was generated. The first model developed signifies the highest level of representation for the system and contains only one transition, the app system itself. Figure 15 is presented below.

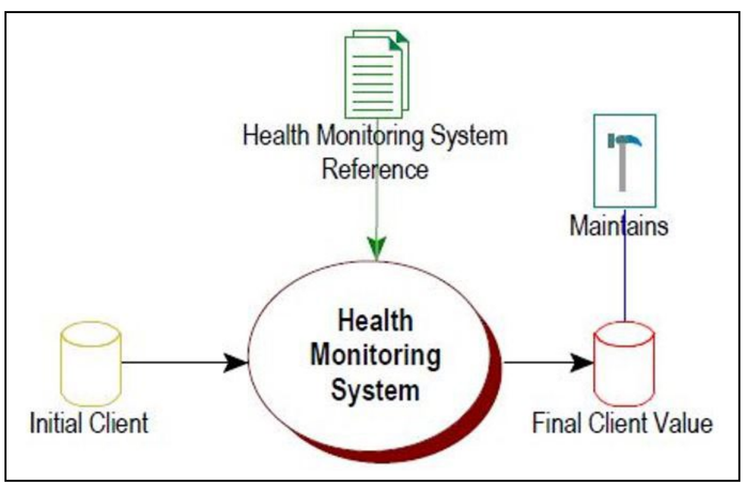


Figure 15. Highest level representation of mobile health monitoring system.

The state of the initial client value is stored in the left-most object. In a value-based model, any suitable value may be selected for tracking. Here, a value associated with the client has been chosen, that being the client's relation to a health condition. The initial client value is "unsatisfactorily managed health condition". The center object, an oval, is the only transition here and represents the health monitoring system in its entirety. This is where all value exchanges will occur that will affect the initial client value.

When the client terminates all use of the app, the final value will be stored in the right-most object, labeled "Final Client Value". This value is described as, "independent management of health condition". This state would mean either that the client has exited the plan of care against recommendation or has reached a health status for which the monitoring system is no longer recommended.

As will be shown, many value exchanges, or transitions, will be tracked in the model. In some instances, several different values will be tracked at once. Yet all values, and all changes to values, will converge to the final value.

The objects at the top of Figure 15 are, from left to right, a reference and an infrastructure. A reference represents that set of instructions for how a transition should occur. An infrastructure represents an item needed to facilitate an event. A detailed understanding of these particular objects is not necessary for purposes of the present discussion.

Next, a decompressed model was developed for the Health Monitoring System transition, originally shown in Figure 15 above. It reveals the structures "inside" the previous transition. Four main transitions were identified as necessary here: IoT (internet of things) Enterprise System, IoT Information Center, Health Monitoring, and Health Assessment. Each of the transitions was modeled, or decompressed, to provide greater detail. In some cases, the resulting models were further decompressed. Figure 16 is presented below

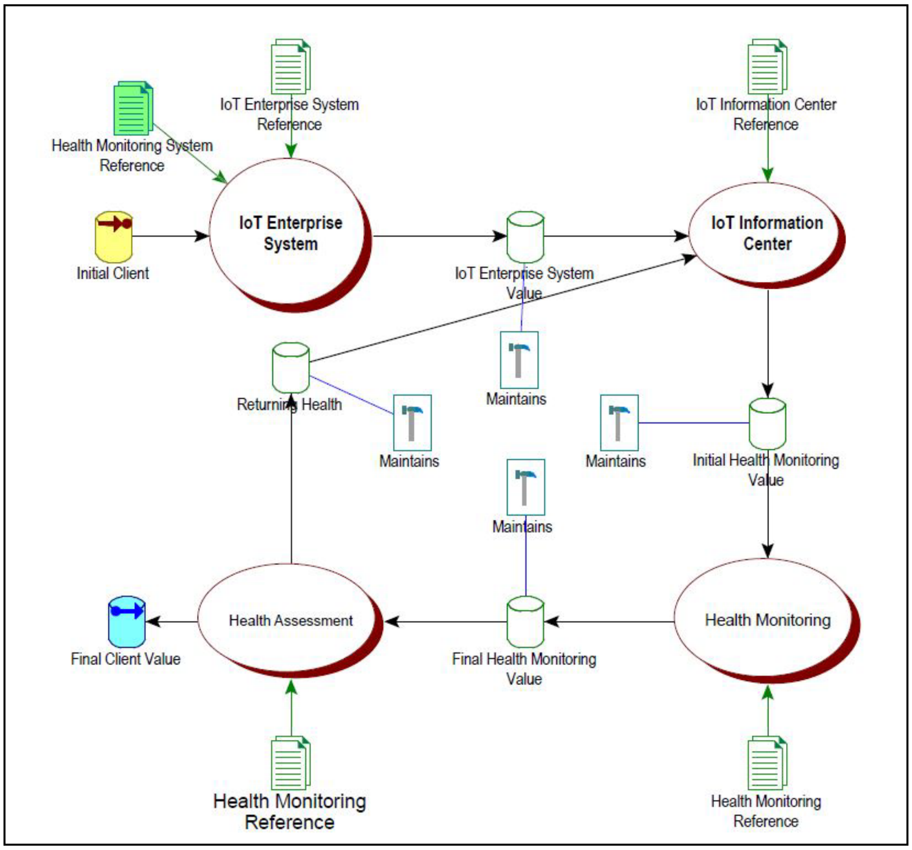


Figure 16. Decompressed model of the mobile health monitoring system.

IoT Enterprise System represents the transition and software structures involved in a user's access to the system, as well as the structures responsible for the system's access to needed Cloud services. The Cloud is a term referring to a network of remote servers that supply software and services (Ray, 2017). Moving clockwise, the IoT

Information Center transition contains the software structures responsible for the system's ability to collect, categorize, and clean the data received. The Health Monitoring transition represents the structures that allow the client to use the app to transmit health-monitored data to the system in the Cloud. The Health Assessment transition represents the structures that allow the treatment provider, or an automated decision process, to respond to data received with a change to the plan of care.

Two values exit the Heath Assessment transition: Final Client Value and Returning Health. As previously stated, the final client value is the status the client will attain when leaving the system. Where, however, the client will continue to use the system, the tracked value will return to the IoT Information Center for processing, and the cycle of monitoring and assessment will continue. Thus, the client recirculation behavior discussed in chapter 3, identified as being an agent of complexity in provisioning systems, appears again.

Next, a decompressed model was developed for the IoT Enterprise System, first presented in Figure 16 above. Two value transfers were identified as necessary here: Enterprises and Network. Figure 17 is presented below.

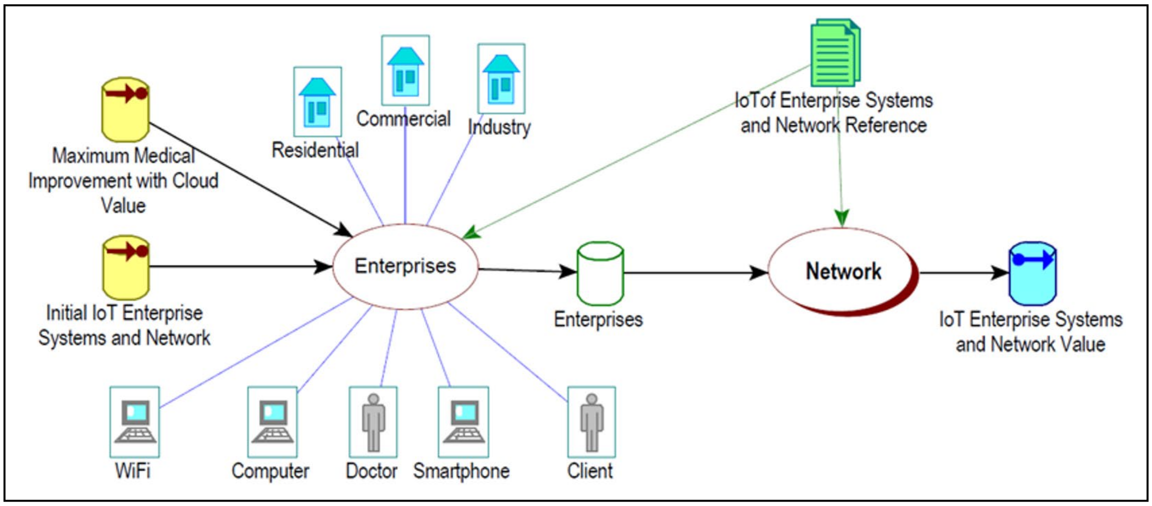


Figure 17. Decompressed model of IoT enterprise system transition.

For purposes of the present discussion, a detailed explanation of the Enterprises transition will not be necessary and will be passed over. The Network transition represents the activity of users accessing the system. The software structures of this transition must be robust to fulfill the use-case of the app, as explained below.

A decompressed model was developed for the Network transition, first presented in Figure 17 above. Five transitions were identified as necessary here: Access Control, Secure Gateway, IoT Cloud Services, IT (information technology), and Login. Figure 18 is presented below.

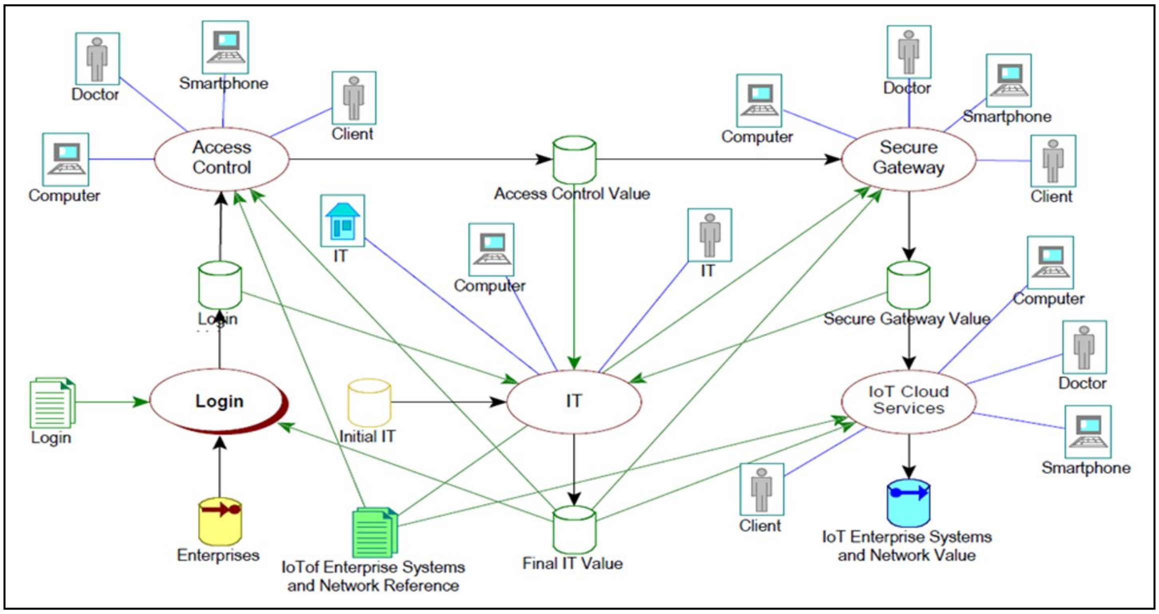


Figure 18. Decompressed model of network transition.

The first four transitions, beginning at top left and moving clockwise, were not individually modeled. Access Control represents the system component responsible for authentication and verification such that no unauthorized users or devices can gain access. Secure Gateway represents a method of connecting protected resources to Cloud resources. IoT Cloud Services represents the activities of Cloud computing. IT represents the activities of network maintenance and upgrades, firewalls, security, interface analysis, operating system maintenance, server maintenance, and software deployment. Login represents the activity of a user accessing the system.

Next, a decompressed model was developed for the Login transition, first presented in Figure 18 above. Six transitions were identified as being necessary here: Invalid Login, Valid Login, Successful Login, Login System, and User Settings Display. The individual workings of these structures are not relevant to the present discussion and will be passed over. It can be said that, taken together, these structures enable the client to access the functionality of the application software. This model is presented below as Figure 19.

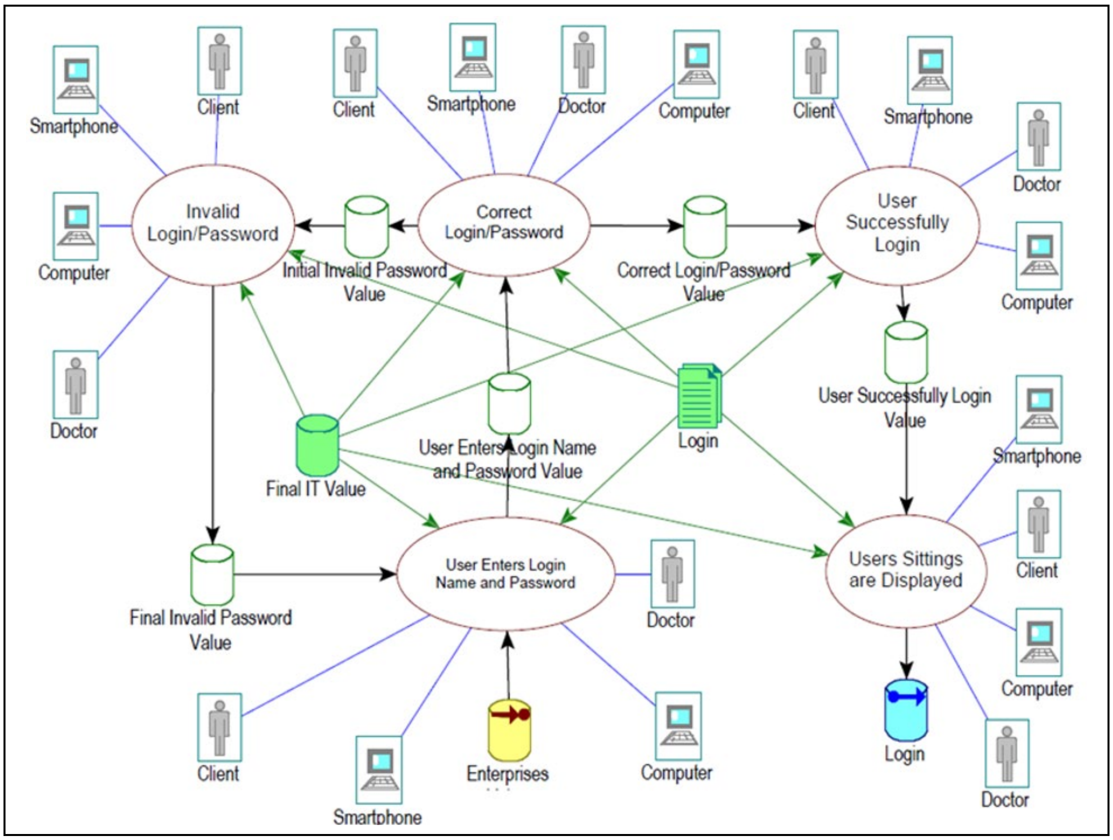


Figure 19. Decomposed model of login transition.

At this point, it will be helpful to return attention to the overview model of the app system, which was presented in Figure 16 *supra*. In that model, the first major transition decompressed and modeled was the IoT Enterprise System, as detailed above. The next major transition decompressed and modeled was the IoT Information Center as will be discussed. Four transitions were identified as necessary here: Data

Synchronization, Anomaly Behavior Analysis, Classification, and Data Structure. The IoT Information Center model is presented below as Figure 20.

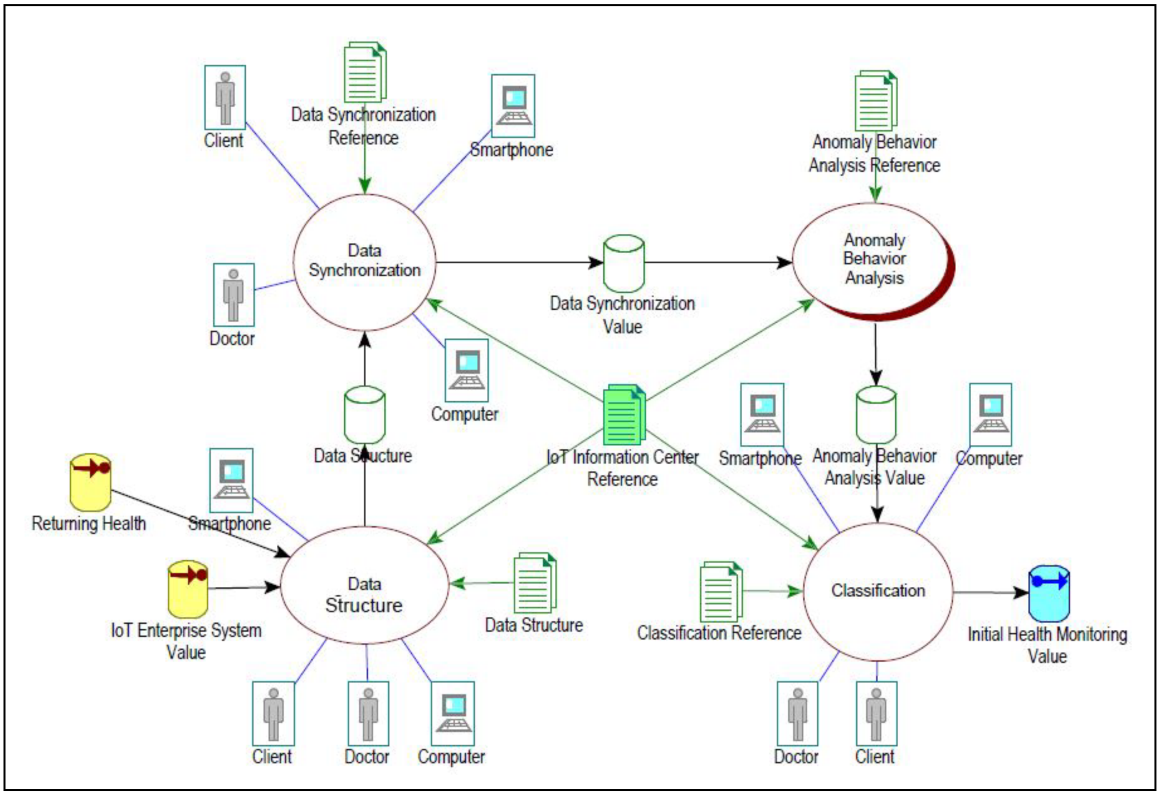


Figure 20. Decompressed model of information center transition.

This transition contains the software structures responsible for collecting, classifying, and cleaning data received by the system. The system establishes the handshake between the client, the client's device, and the system. This means that the system determines what kind of health data the client is reporting, and by means of what device and operating system. In decentralized systems in which the client owns and maintains the input device and inputs their own data, the importance of this transition is significant. If, for example, the client manually inputs the temperature 987° instead of 98.6°, the app system will need to be able to detect and respond to that error.

Beginning with the top-left transition and moving clockwise, Data Synchronization represents a method of organizing and accessing data. Anomaly Behavior Analysis represents the component responsible for analyzing, correcting, validating, or rejecting data input to the system. This transition was decomposed and modeled and will be presented below. Classification represents a method of categorizing data according to data set requirements. Data Structure represents the component responsible for the systematic formatting, managing, storing, and retrieving of data.

Next, a decompressed model was developed for the Anomaly Behavior Analysis transition, first presented in Figure 20 above. Within this transition, three transitions were identified as necessary: Database, Data Mining, and Decision Making. The Anomaly Behavior Analysis model is presented below as Figure 21.

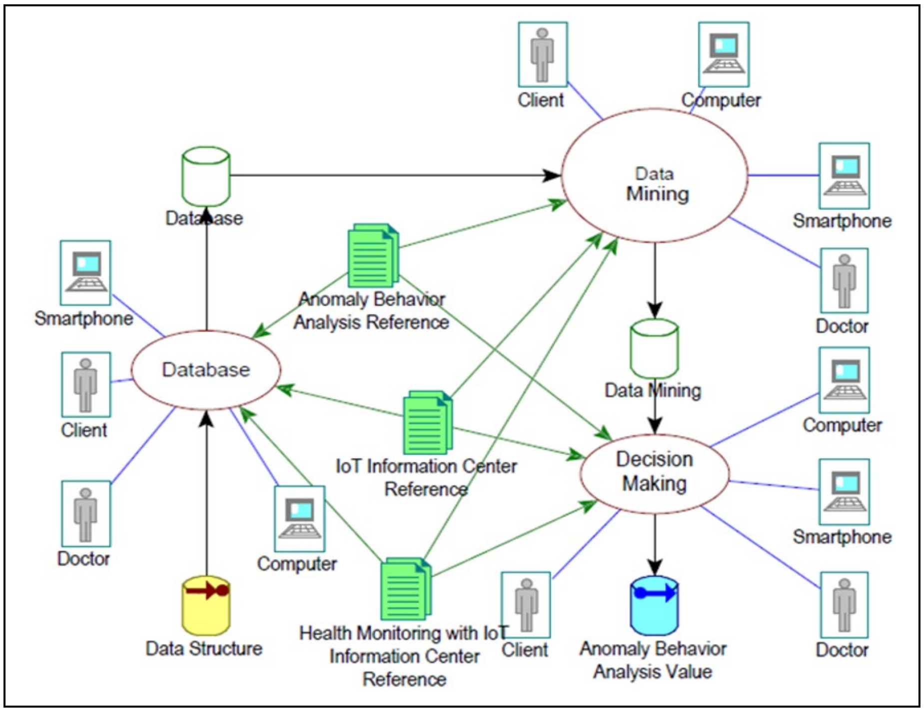


Figure 21. Decompressed model of anomaly behavior analysis treatment transition.

Beginning with the left-most transition and moving clockwise, Database represents the activity of collecting all patient data to the database. Data mining represents the activity of extracting data from the database. Decision Making represents the machine learning component of the system.

Returning attention to the overview model presented as Figure 16 *supra*, the next major transition modeled was Health Monitoring. This represents the activity of a client monitoring and reporting health conditions. The transitions housed within serve those conditions about which a client might report. For this model, three health metrics were represented: Blood Pressure, Blood Sugar, and Weight. The decompressed model of the Health Monitoring transition is presented below as Figure 22.

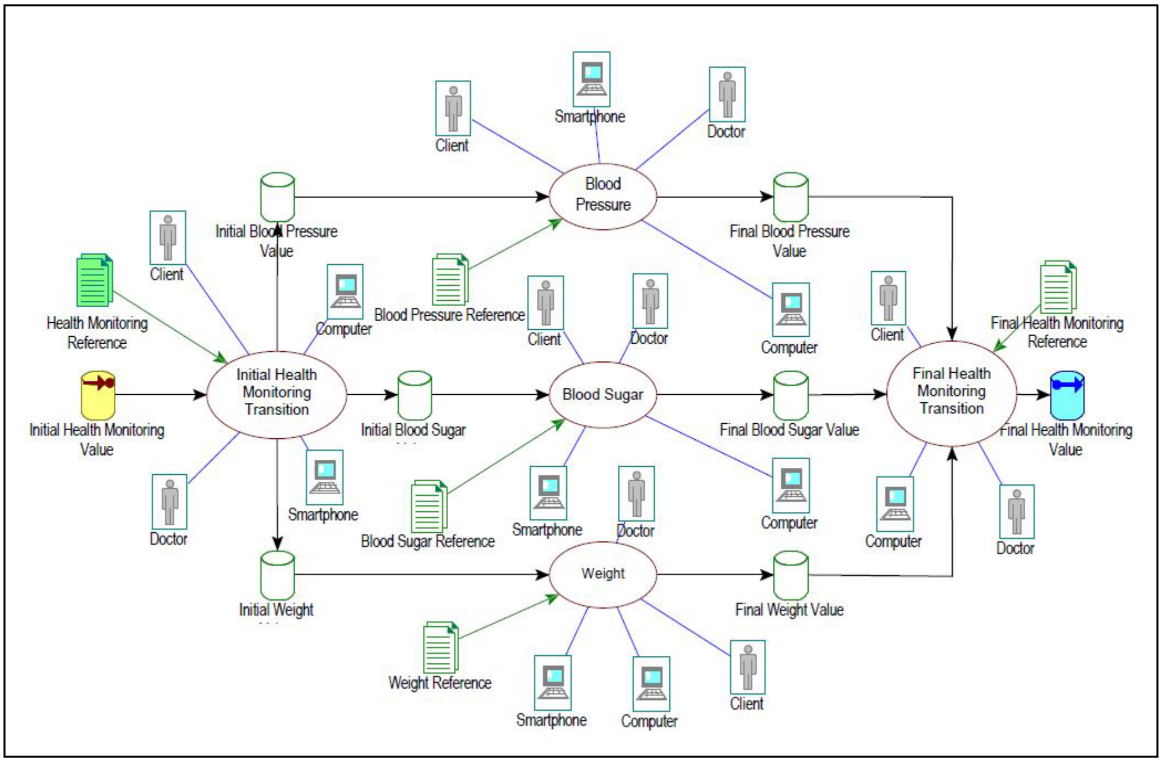


Figure 22. Decompressed model of health monitoring transition.

In Figure 22 can be seen the way in which the tracked value can be split into sub-values. Several health conditions can be tracked. Thereafter, the values will converge to exit the transition and proceed to the next one. During the Health Monitoring transition, the client will employ a health monitoring device and self-report the results to the app system. If the device is internet-connected and has been synchronized with the app, the pushing of data can be automated. If the device is not internet-connected, the client must manually enter the data into the app system.

Returning to the overview model presented as Figure 16 *supra*, the last of the four main transitions was modeled: Health Assessment. Two transitions were identified as necessary here: Manual Decision System and Health Improvement Decision. The Health Assessment Model is presented below as Figure 23.

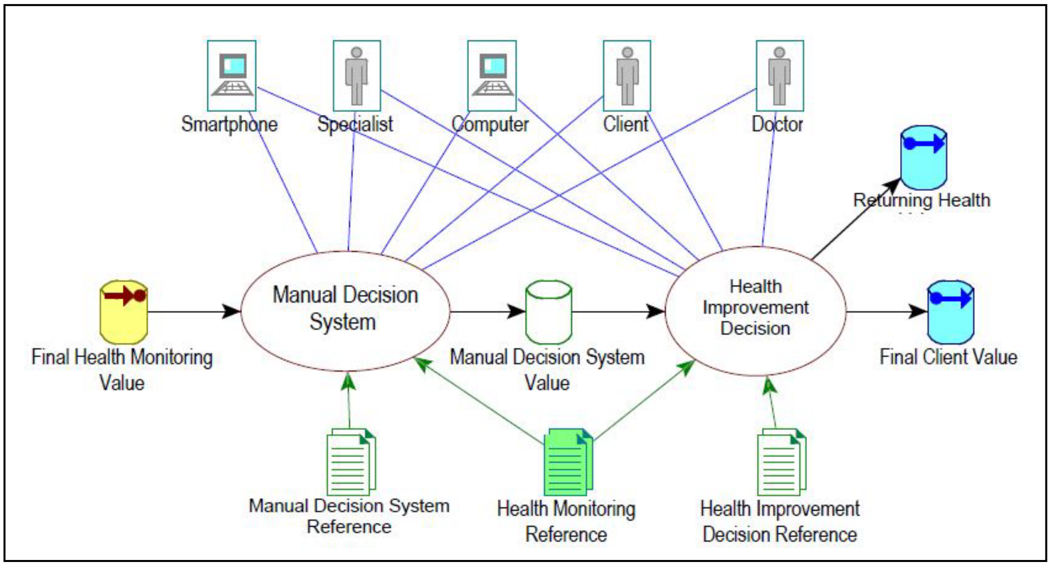


Figure 23. Decompressed model of health assessment transition.

In Figure 23 is represented the way in which actions are taken on client-reported health data. Here, the treatment provider reviews, on a dashboard-type display, a summary of the client's self-reported data. The treatment provider will decide whether to alter the plan of care. If the decision is not to make a change, the treatment provider will have a second decision to make: whether to continue or terminate the client in the system.

If the client does continue, the client value will exit the transition as shown by the Returning Health value, and the cycle of monitoring and assessment will go on. If the client does not continue, the client value will exit the transition as shown by the Final Client Value and will thereafter exit the entire system. If upon review the treatment provider decides that a change to the plan of care is warranted, the treatment provider will manually enter that change into the app system. The revised plan will then be pushed to the client via the app system.

Not shown in Figure 23 is the involvement of the Anomaly Behavior Analysis software component. This was represented in Figures 20 and 21 *supra*. As discussed above, corrupted data from the client's monitoring device or errors in manual entry must be dealt with before the health data is presented to the treatment provider.

Discussion

When the case management system was modeled, the results reflected the modeling tools used. Process modeling emphasized the importance of efficient task completion. Information modeling emphasized the importance of efficient and reliable communication. Modeling of the Saudi app system followed the trend: value modeling emphasized the importance of effective value exchanges.

The instant results revealed a limitation on the value exchange at the point of treatment. This was related to the constraints of time, cost, and responsibility. Such a situation can be illustrated through descriptions of two major methods of healthcare delivery: one-to-one and one-to-many.

In the one-to-one event, the treatment provider interacts with the patient in an individual-focused meeting. Here, the treatment provider gathers health condition information from the patient. Laboratory or other objective data may be captured in addition to the patient's subjective report and self-assessment. The information gathered will be the basis for an assessment, and the assessment will be used to create or modify the plan of care.

There may be significant time gaps between treatment events. As a result, the number of data packets collected from the patient will be limited by the number of treatment events. An illustration of this would be a patient who visits the doctor once every six months. During these visits, the patient's blood pressure is measured. In this case, the doctor has only two blood pressure measurements per year from which to make an assessment, suggest a plan of care, and make an adjustment to treatment. It is proposed that a more informed image of the patient's health care condition could be achieved by increasing the number of data packets received.

One method to do this would be to increase the frequency of appointments. This, however, may be constrained by several factors including cost, insurance coverage, the patient's ability to travel to appointments, and the medical care provider's time availability. Another method for increasing the transmission of patient information would be to facilitate self-reporting by the patient between treatment events.

This might occur in two ways. First, the patient could use some traditional method to manually self-report. The patient could take their own blood pressure, for example, then call the doctor's office to report the results. Second, the patient could use a digital monitoring device that would automatically perform the reporting task. The act of self-monitoring could itself be automated. An illustration of this would be a cell phone app that counts the user's footsteps.

This is a straightforward and sensible view of how digital tools and communication can improve healthcare delivery. However, there are constraints to the actionability of the resulting volumes of data: time and money. Assuming an idealized situation in which a patient can continuously stream relevant data to a healthcare provider, it is probable that the provider will not have the time or the ability to bill for reviewing the data and making a response.

A different situation is presented by the one-to-many treatment event, but constraints to the value exchange still exist. Here, the treatment provider interacts with a group of patients simultaneously, administering treatment and gathering data from the patients. The treatment provider can use the information gathered to adjust how treatment is being provided to the group.

An advantage of one-to-many delivery is savings. It will cost less money and save time for the treatment provider to meet with a group compared with a series of individual appointments. Consequently, a patient may have more encounters with a treatment provider in a one-to-many setting than in a one-to-one setting.

Even so, responsibility will be a constraint. This may occur because, from the operations standpoint, it may not be a focus of the job to perform individual assessments of clients' needs. Instead, job requirements may focus on delivery, reporting of results, and patient satisfaction. As a result, assessments may suffer in the category of one-to-many treatments. Although the same information can be gathered in both forms of treatment, the information may be less actionable in a one-to-many setting given the role constraints of the provider.

A comparison may be made from this scenario to education. The situation of an instructor lecturing to a classroom full of students appears to be a time efficient manner for the delivery of educational material. Yet the instructor will be hard-pressed to perform individualized assessments of each student's needs and to make recommendations for individual adjustments. It is certain that managing a group requires a different skill than managing an individual. Classroom instruction job duties will likely focus on delivery, reporting of results, and student satisfaction.

The need for tutor services is an obvious the result of this constraint on value exchange. The tutor performs a one-to-one service whereby the described loss of value is addressed. However, just as with the one-to-one medical provider situation, the constraints will again be time and money.

The value-based model of the proposed healthcare app highlighted the constraints to value exchanges. This, and the final TAR step of reflecting on the model in a real-world context, made the above analysis possible. This was responded to by proposing an improvement to the design. The improvement consists of developing an automated decision-making subsystem within the machine learning component of the app system. The rules of decision-making could be based on protocols established by the treatment provider.

The proposed healthcare app system would transmit and process the patient's self-reported data. It is proposed that there is a category of assessments that can be performed based on this data. These assessments could be automated, based upon protocols established by the treatment provider. These automated assessments would lead to adjustments to the plan of care, which would also be done according to established protocols.

An expected clinical impact of such a practice is improved management of chronic conditions that require frequent treatment protocol adjustments to avoid exacerbation into acute phases. While improved health status from improved treatment management is a desirable clinical outcome, there should be associated financial benefits as well for the patient and for the health system, as acute care costs exceed chronic care costs at both levels.

Automated adjustments would be within a smaller range than those made by a treatment provider during a one-to-one treatment event. Anything falling out of this range would require direct intervention from the healthcare provider. However, such between-visit, micro adjustments would represent a more agile response to the patient's changing needs. Further, the lessons learned from the value-based modeling are responsive to the challenges to access to services. The improved design is presented below as Figure 24.

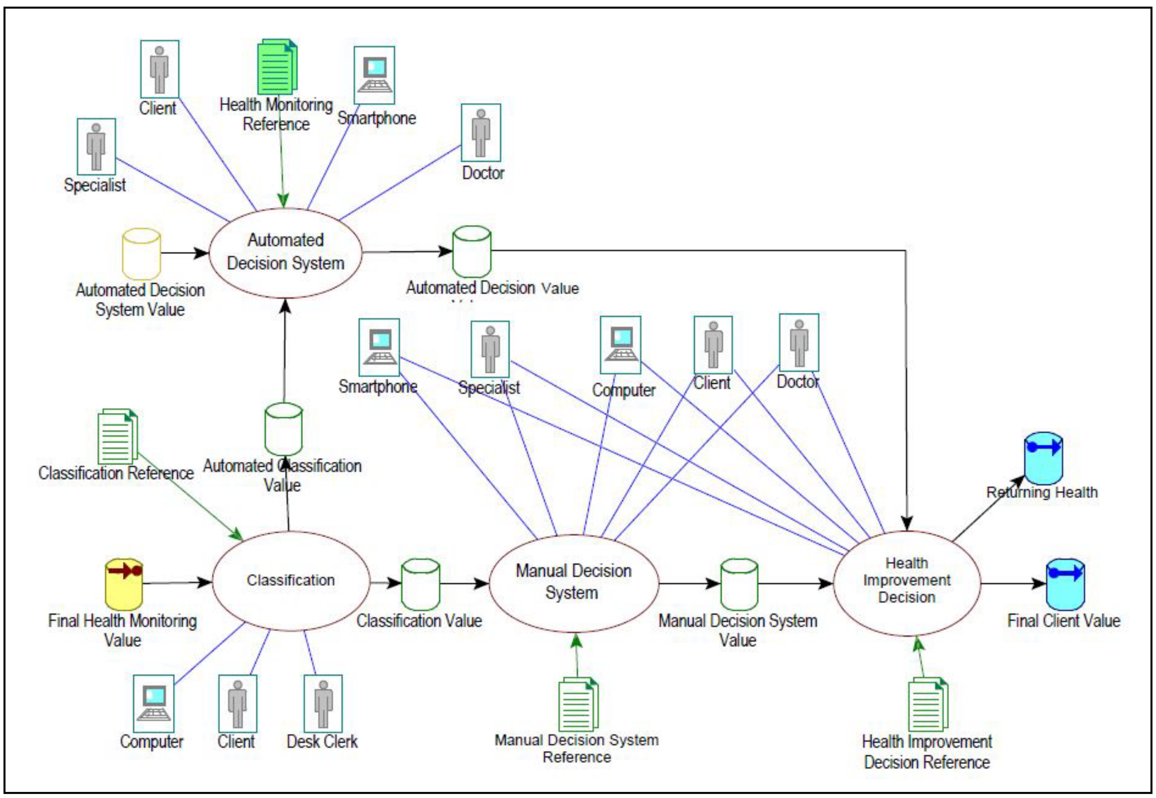


Figure 24. Decompressed model health assessment transition with automation.

In Figure 24, the client's self-reported health data is shown to enter the Health Assessment transition and proceed to the sub-transition, Classification. Here, a determination is made as to whether the data reported falls within the range set by the treatment provider. The Classification Reference provides this set of instructions to the transition. If the health data falls within the range, a protocol set by the treatment provider will be triggered.

This value will next travel to the Automated Decision System transition. Here, the Health Monitoring Reference will provide instructions as to how the decision should be made. It may be that the health data reported requires no change to the plan of care, or that some change is indicated. In the case of the later instance, a change to the plan of care will be pushed to the client via the app. As with the operation of the Manual Decision System, the client value that leaves the Automated Decision System will travel to the Health Decision System transition. There, the decision will be made as to whether the client will remain in the health monitoring system or leave it.

The material presented in this chapter was enlarged upon from a paper submitted by the author and published in *mHealth*, an international, open access, peer reviewed journal (Lipscomb, Alhefdi, Alharthi, & Jololian, advance online publication).

CHAPTER 6

CONTRIBUTIONS, LIMITATIONS, AND FUTURE WORK

The goal of the foregoing research was to develop a framework for the improvement of information and value exchanges toward process alignment in complex, decentralized provisioning systems. Process alignment was described as the state of a provisioning system whereby all value exchanges are of benefit to the client. This research plan included five tasks: investigate interdisciplinarity, select methods, identify generalizable features and activities, build models, and design a model of a proposed app. Based on the lessons learned from these efforts, a framework for improvement was developed. This is presented below as Figure 25.

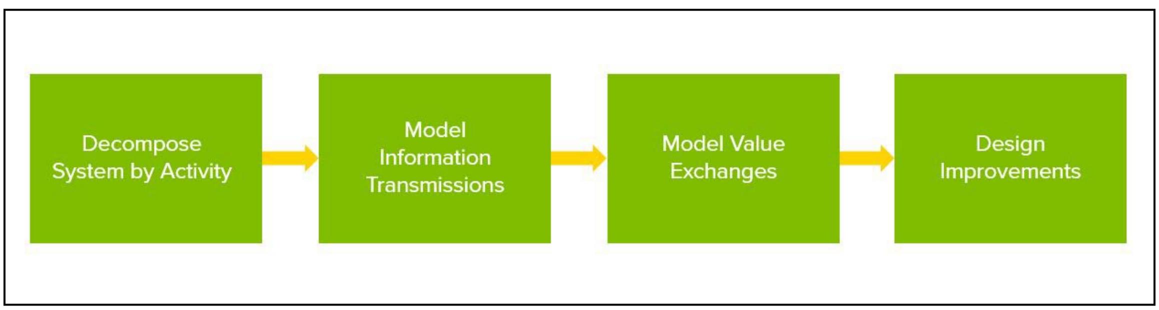


Figure 25. Framework for Process-Alignment.

The framework process begins by describing the system under investigation in terms of its activities and processes. A flowchart was used for this step in the instant research. The framework process continues by modeling the system's information exchanges, followed by its value-transitions. Shannon notation and a value-based modeling tool were used for these steps in the instant research. Finally, the information gained is employed to design improvements to information and value exchanges toward process-alignment. A model of a digital application was made to demonstrate the final step for the instant research.

The framework represents an integration of engineering design and scientific modeling whereby a complex system is rendered more understandable by decomposition and abstraction. The framework is a tool for managing bounded rationality. It can be employed to improve information access, provide computational aid, and reduce decision-making time.

The framework embodies two instances of knowledge reengineering, or the transformation of preexisting knowledge into a form more suitable for a different use (Hoekstra, 2010). The first occurs through the development of process, information, and value-based models. The second occurs through reflection on the knowledge gained by multidisciplinary modeling toward the design of improvements to the system.

The following are the proposed contributions of the research:

1. Engineering design was recommended as a common language and organizational tool for interdisciplinary research groups.
2. The communication channel was identified as a generalized feature of complex, decentralized provisioning systems.
3. Management techniques used for dealing with decentralization were recast as error correction according to the mathematical theory of information.

4. Conant’s method of structural analysis was adapted to include semantic representation of the impact on client outcomes.
5. The presence of an accessible database was identified as important for effective and efficient transmission of information.
6. A strategy termed “process-alignment” was proposed, which holds that only value-objects that increase client value should be exchanged.
7. Client self-reporting was recommended for facilitating an extension of the point of provisioning.
8. A model was presented of the partial management of adjustments to provisioning by automated processes.
9. A framework was presented for the improvement of information and value exchanges toward process alignment in complex, decentralized provisioning systems.

The research has three main limitations. First, only human-based systems were considered, to wit, systems with human agents providing things of value to other humans. This is not a restriction on provisioning systems generally, as one system may provide things to other systems while not involving humans directly. Consequently, for the present research, many of the system tasks described involve subjective decision-making. Further, the bounded rationality of the participants is a factor in the success of outcomes.

It would not be difficult to conceive that the stated contributions of the work could apply to other systems. Items important to a human-based provisioning system might also be important to one that is not: the communication channel, error correction, Conant’s method, an accessible database, process-alignment, self-reporting, automation, and a framework for improvement. Even so, case studies would have to be performed on non-human-based systems to fully understand the results of the framework on them.

Second, the research methods employed, particularly TAR, call for an examination of the results in a real-world context. Yet these methods do not require an implementation in the real-world. As a result, this was not done for the instant research.

Lastly, all case studies were performed within the context of the medical treatment domain. No case study was done for the application of merchant package delivery, for example. Although the models were built to be generalizable within the category of the defined systems, case studies would have to be performed outside the domain of healthcare to fully understand the results of the framework on them.

The proposed future work is a response to the limitations expressed. First, a case study could be performed on a non-human-based provisioning system. Second, a real-world implementation could be performed by building a working digital system for healthcare self-reporting and treatment adjustment. Third, case studies could be performed on domains other than healthcare.

In *Our Knowledge of the External World*, Bertrand Russell detailed the approach of mathematical logic for gaining understanding of the perceivable world (Russell, 1914). He posited that the sciences and mathematics move toward complexity whereas philosophy moves toward simplicity. Philosophy, he said, begins with common knowledge and then generalizes them into “the simplest statement of abstract form that can be obtained by logical analysis” (Russell, 1914).

The instant research has certainly followed this course – moving deliberately from the concrete and specific to the abstract and general. Yet the differences between disciplines can be overstated. An interdisciplinary perspective reveals that although the many rational disciplines have different ends, they all employ tools for rendering the world more understandable and actionable. It is in this spirit that the foregoing dissertation is offered.

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GLOSSARY

Abstraction – A design technique that groups together several subsystem components by means of a generalization of the interfaces between them.

Access to Services – Describes a situation in which services are available, relevant and effective, and utilizable by a client.

Adjustment Subjectivity – Refers to the tendency for decision-making to be subjective when the system is complex, decentralized, and designed for human clients.

Application Programming Interface (API) – A set of programming code that allows applications to exchange information while limiting access through permissions.

Bounded Rationality – The idea that decision-making is limited by three factors: access to information, the decision-maker's cognitive ability, and the time available for the decision to be made.

Case Management – A management technique benefiting clients in a provisioning system such that a continuum of care is provided.

Client Recirculation – Refers to the tendency, in complex and decentralized systems, for the client to repetitively move through provisioning steps in a circuit.

Cloud – A metaphor for a network of remote servers that supply software and services.

Complexity – Describes an object of interest that is difficult to understand.

Convergence – A problem-solving approach that focuses on integrating the life sciences and medicine on the one hand, with the physical sciences and engineering on the other.

Decentralized – Describes a system in which agents are not regulated by a single set of procedures, motivations, and goals. They act independently, but for some parameter of interest, attempt to act cooperatively with other agents.

Decompressed – When used to refer to a PArchitect model, it refers to a value exchange transition that has been “opened” to reveal lower levels of the tree structure.

Decomposition – The reduction of the number of details in consideration by dividing the space into partitions.

Design – The devising of a system or process for the improvement of an existing situation.

Design Science – The scientific study and creation artifacts built to solve problems.

Gossip Problem – The situation whereby information moves along a chain of receivers and transmitters, thereby incurring noise and error.

Interdisciplinarity – A research effort to integrate knowledge and tools from two or more disciplines toward a common goal.

Knowledge Reengineering – The transformation of preexisting knowledge into a form more suitable for a different use.

Modeling – The process of representing a system in terms of a parameter of interest in a consistent manner and described in terms of the modeling language.

PArchitect – A commercial digital platform for value-based modeling, computation, and emulation.

Process Alignment – The design of a provisioning system whereby only value objects that benefit the client are exchanged.

Provisioning – The act or process of providing something of value to another entity.

Technical Action Research (TAR) – A research method that involves identifying a problem to be solved, proposing a solution, applying the solution, and reflecting on the solution in a real-life context.

Use-Inspired Research – A research method in which basic research is performed with a real-world application in mind.

Value Objects (value propositions) – The objects being exchanged by participants in a provisioning system.