26th Annual INCOSE International Symposium (IS 2016)
Edinburg, Scotland, UK, July 18-21, 2016

Healthcare Facility Commissioning – The Transition of Clinical Services

Riaan van der Watt
Department Engineering and Technology Management, University of Pretoria, South Africa
+27 (82) 823 5503
riaan@reafconsulting.com

Louwrence Erasmus
Integrative Systems Group, DPSS, Council for Scientific and Industrial Research, Pretoria, South Africa
+27 (83) 540 5092
l.erasmus@ieee.org

Abstract. A public multi-disciplinary primary-level hospital delivers clinical services to both in and out patients within its catchment area. A multi-disciplinary hospital is a healthcare facility of which the commissioning or transition into operations is a complex process that can last several months. This paper treats a hospital's clinical services using a systems perspective on healthcare services delivery within the context of the systems hierarchy level definitions used in South Africa to relate the inward and outward commissioning of a hospital to the concepts of systems engineering and services science. A hospital can be viewed as a system of systems containing several tangible and intangible elements identified through the clinical services blueprint that during commissioning can be related to useful systems engineering ideas from large-scale infrastructure projects. The relationship between the clinical services blueprint and the Systems Breakdown Structure (SBS) is very important and must be coordinated with the Work Breakdown Structure (WBS) and Organizational Breakdown Structure (OBS) during commissioning. The concepts put forward in this paper should enable hospital project and commissioning managers to gain insights into the integration of systems from a holistic perspective during design to achieve an integrated and optimized commissioning schedule to achieve overall operational readiness.

Introduction

Commissioning of a healthcare facility, for instance a 200-bed public multi-disciplinary hospital delivering primary level services to both in and out patients, is a complex process that aims to establish a facility, which deliver clinical services apart from other healthcare services to a population that falls within its catchment area. During the commission period which could be anything from 6 to 12 months for this sized facility, the focus is "inwards", on converting a structure of bricks and mortar into a functional facility with staff, equipment, medication, supplies, etc. ready to eventually receive patients who need care and cure. Beyond these tangible elements, there are also many intangibles which are required, e.g. management systems, policies, training, skills, etc. All of these need to link together in order to create a functional entity that is able to deliver clinical services.

"Outwards" there are also links that must be planned, established and maintained in order for the new facility to deliver the intended clinical services. These include links to the emergency services which brings patients in need of emergency care to the facility, links to other healthcare facilities for more specialized care or for continued care and rehabilitation and links to pathology services to report on tests not conducted in-house, to name but a few.

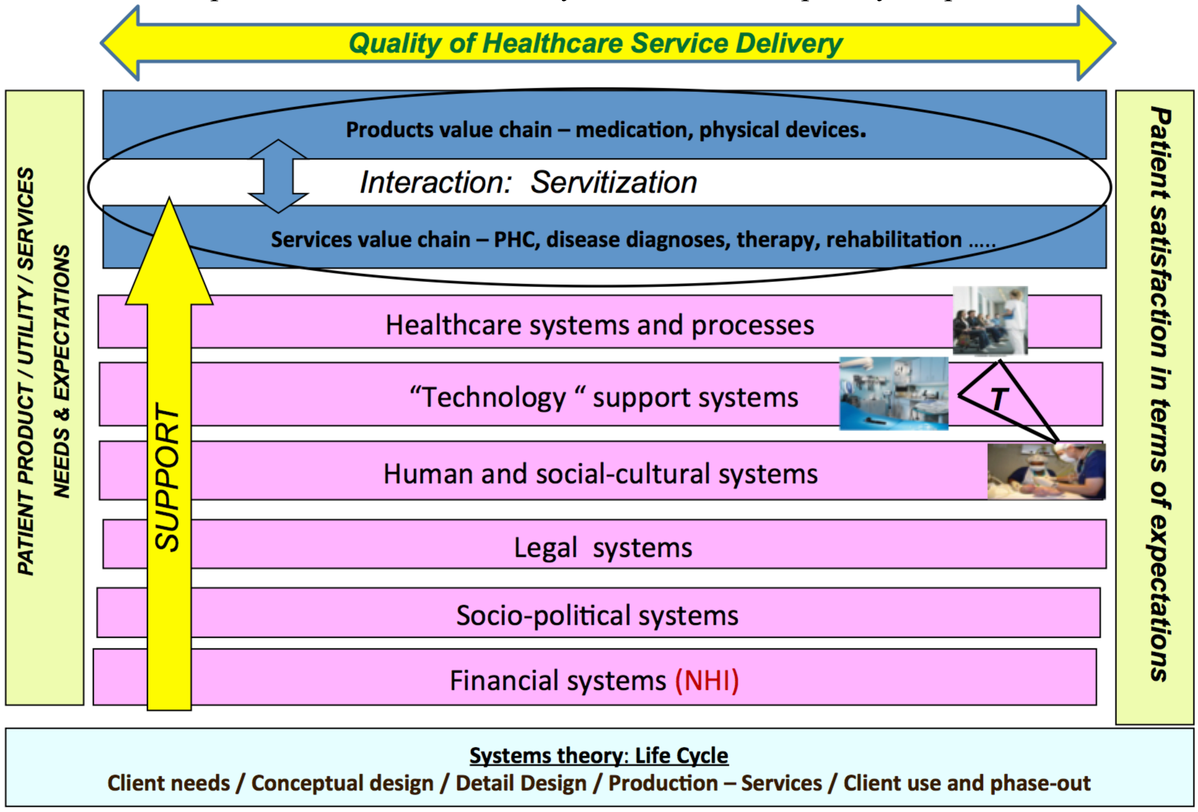
Beyond the healthcare system, there are also connections to and interactions with other entities like the financial systems, the legal environment, the educational environment, and society as a whole. All of these can be seen as systems with their own internal hierarchy and external links, which makes our world function as we know and experience it. In more technical terms, these are various systems of systems interacting with each other to achieve in this paper's case, health care services provision by a multi-disciplinary hospital.

A multi-disciplinary hospital design should start with service blueprinting to capture the standard services packages offered by the facility that includes the prescribed national and local regulations for healthcare services delivery. The services blueprint identifies the physical evidence for the service encounter together with the customer, especially the patient's actions and the line of customer interaction with the onstage contact person, e.g the employees of the multi-disciplinary hospital, especially the healthcare workers (Fitzsimmons et al., 2014:72). The services blueprint also identifies the interactions with the backstage contact persons that acts behind the line of visibility but supports the onstage contact person and also connect over the line of internal interaction with support processes (Fitzsimmons et al., 2014:72). The services blueprint is an important input for the architectural brief for the multi-disciplinary hospital design.

One of the important aspects of health facility design is the servicescape in which the healthcare service will be delivered in a hospital. The physical surroundings have an impact on both the customers, especially the patients, as well as the employees, especially the healthcare workers (Bitner, 1992) and the building communicates, without words, the hospital's values to customers and employees (Fitzsimmons et al., 2014:117). Thus the service should be designed with the "look and feel" that is harmonizing with healthcare service delivery of a multi-disciplinary hospital (Fitzsimmons et al., 2014:116). The services provided by a multi-disciplinary hospital vary between lean and elaborate interpersonal services where both the customers/patients and employees/healthcare workers are involved in delivering the service (Fitzsimmons et al., 2014:116). An example of the lean interpersonal service is the person with the snack trolley selling something to eat and drink to customers in the wards and corridors. An example of elaborate interpersonal services is in the direct interaction between a healthcare worker and a patient where both sides play a major role in making the health care procedure a success for the patient within the hospital facilities.

The servicescape framework has the following dimensions: Environmental Dimensions, Holistic Environment, Psychological Moderators, Internal Responses and Behavior (Fitzsimmons et al., 2014:118). Engineers and architects have a direct influence on the environmental dimensions that consist of the ambient conditions, space/function and symbols, signs and artifacts (Fitzsimmons et al., 2014:118). The factors from other dimensions, which include perceived servicescape, cognitive, emotional, physiological, employee and customer responses, are influenced by the factors of the environmental dimensions. An important aspect which designers must contend with is that the servicescape itself, will change over the life of the facility. This leads to particular challenges for those involved in the Environmental Dimension (architects and engineers) as they need to ensure that their design elements which gives definition to physical spaces must allow for "re-configuration" to accommodate changes in the servicescpe.

Weeks (2012) has developed a systems perspective on healthcare services management, shown in Figure 1, by adapting the Integrated Product And Services Management System framework proposed by Weeks & Benade (2011). The service delivery or servertization where products and services meet within the healthcare servicescape of the multi-disciplinary hospital is shown in Figure 1. This framework is not exhaustive and many other systems that forms part of the multi-disciplinary hospital system of systems are not shown, e.g. hospital engineering system, etc. The important aspect shown by Weeks (2012) is that there is an onstage system supported by several backstage systems that all have lifecycles to implement the services blueprint for a healthcare facility like a multi-disciplinary hospital.



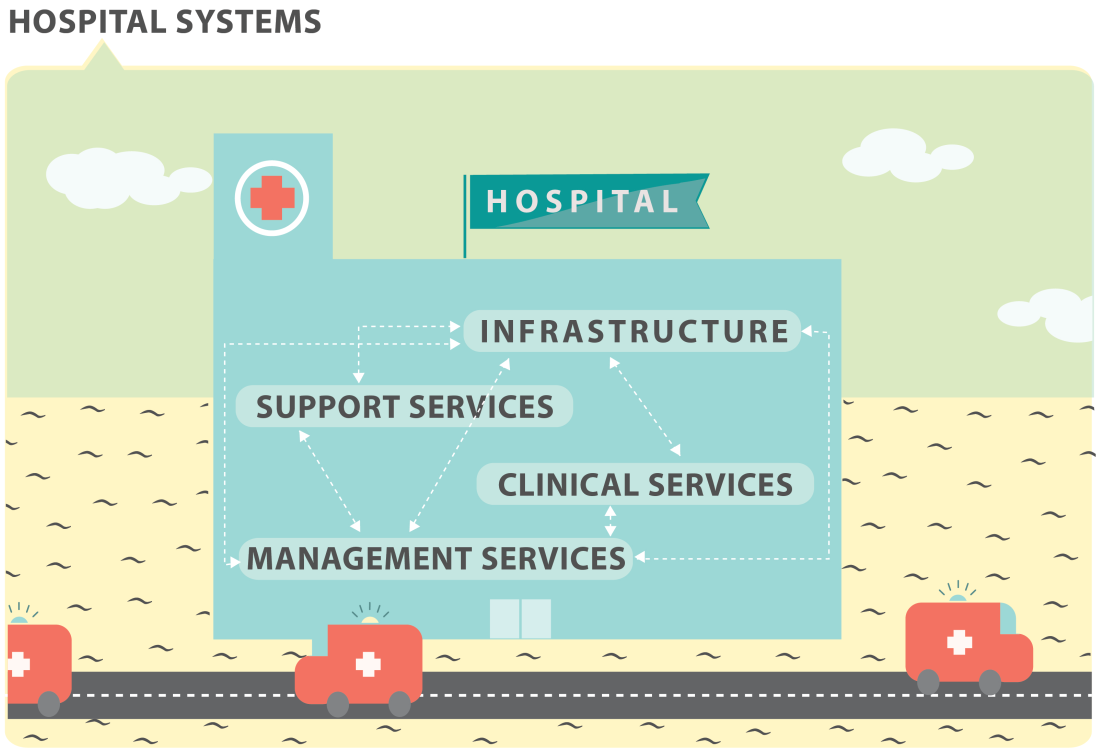
Source: Weeks (2012:385)

Figure1. An Overarching Healthcare Product / Services & Support Systems Perspective

The rest of this paper treats the commisioning (transition into an operational system) of a hospital that consists of a system of systems housed within a facility of bricks and motar and delivering services as defined by the services blueprint from a systems engineering viewpoint.

Healthcare Services System of Systems Commissioning within the Systems Engineering Context

The systems perspective of the overarching healthcare product, services and support in Figure 1 implies that for commissioning of a hospital the commisioning manager is dealing with many systems and sub-systems and the various ways they are interlinked. A system of systems diagram for a hospital is shown in Figure 2.



Source: REAFF Consulting

Figure 2. The Hospital System of Systems Diagram

The commsioning problem can be solved by systems engineering that can be defined as *"... an interdisciplinary approach and means to enable* ***the realization of successful systems****. It* ***focuses on defining customer needs and required functionality early in the development cycle****, documenting requirements, then proceeding with* ***design synthesis and system validation while considering the complete problem****: Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering* ***considers both the business and the technical needs*** *of all customers with the goal of providing a quality product that meets the user needs.*" (Haskins, 2007).

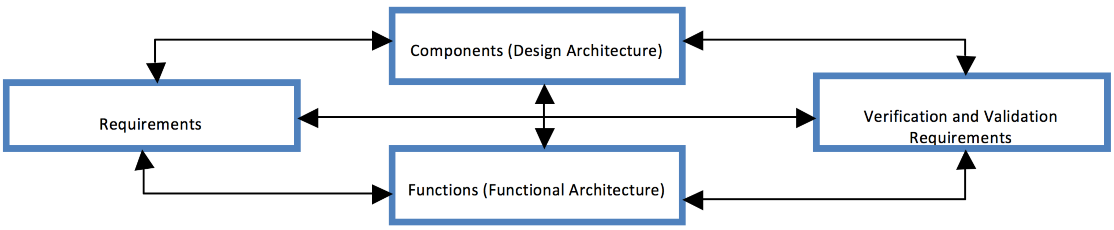
An important characteristic associated with complex systems of systems is that their life cycles often surpass the life cycle of their subsystems and the actors within those subsystems. This result in a dynamic that is much more difficult to contend with than a mere change in requirement over time.

Systems Engineering has been used in many domains from Defense and Aerospace to Software and Infrastructure, see the various topics covered annually by INCOSE conferences. Its adoption in Healthcare is relatively new but from the above discussion, it is clearly applicable. It is specifically the discipline surrounding processes and definitions that offer the most value in applying Systems Engineering to the Healthcare and particularly the Healthcare Infrastructure development domain.

The international standard on System Lifecycle Processes, ISO 15288, identifies several useful processes that can be used in the Healthcare Infrastructure development domain. Specifically, the processes applicable to Healthcare Infrastructure commsioning are (ISO 15288):

- The Agreement Processes that addresses certain aspects of contract management regarding systems engineering through the Agreement Process and Acquisition Process.
- Organizational-Project Enabling Processes that through its six defined processes addresses the Clinical Governace of the systems engineering effort.
- Technical Management Processes that through its eight defined processes addresses the management of the systems engineering effort.
- The Technical Process, specially the Transitioning Process addresses the commissioning of the healthcare facility. The Transition Process is defined as *transfers of custody of the system and responsibility for system support from one organizational entity to another*. In the case of a hospital, it is the transitioning from the Construction Project entity to the Operational entity.

Another useful aspect that systems engineering can contribute to the healthcare facility design fraternity is Model Based Systems Engineering (MBSE). A simple relationship between the four basic information elements that is used in systems engineering is shown in Figure 3 and is implemented by popular systems engineering software tools in industry (Erasmus et al., 2015). Managing to keeping the integrity in place for these four information elements helps to keep the complicated relationships in engineered systems under control, especially to manage the requirements from the original requested set to that of the final delivery set. The final delivery set contains the new requirements, changed requirements, the deleted requirements and the original requirements without the changed and deleted requirements (Haskins, 2010).



Source: Erasmus, et al. (2015)

Figure 3: Basic Information Elements in Model Based Systems Engineering

Context for Healthcare Services Transition Process

The purpose of the Transition Process is to establish an operational capability of the healthcare system of systems to provide healthcare services delivery specified by stakeholder requirements in the operational environment using a healthcare services blueprint. This process is used at each level in the system structure and in each stage of the system life cycle to complete the criteria established for exiting a stage, because the explicitately stated customer requirements rarely contain all the necessary requirements for the success of a project. Therefor, stakeholder identification and needs analysis informs the requirements elicitation activities, and the use-case analyses help ensure that diverse stakeholder needs are accommodated. Ultimately, the Transition Process transfers custody of the system and responsibility for system support from one organizational entity to another. Successful conclusion of the Transition Process typically marks the beginning of the Utilization Stage of the system-of-interest.

In order to understand what is happening conceptually to the different systems in the hospital system of systems in the larger societal context during the transitioning or commissioning process, the South African concept of a Systems Hierarchy Level is introduced.

Systems Hierarchy Levels

De Waal & Buys (2007) discusses the systems hierarchy levels used in the systems acquisition process of the South African National Defence Force and how it is related to General Systems Theory introduced by Boulding (1956). The systems hierarchy levels can be summarized and applied to healthcare context as shown in Figure 4.

<table>
<tr><th>Type</th><th>Level Summary</th><th>Systems Hierarchy Level</th><th>Description</th><th>Type of Capability</th><th>Example</th></tr>
<tr><td rowspan="3">Virtual Systems</td><td>National and International Levels</td><td>Level 9-10</td><td>Multi-government and societal systems</td><td>Regulated Operational Capability</td><td>World Health Organisation (WHO), interministerial committee on health, etc.</td></tr>
<tr><td rowspan="3">Medical Service Delivery Backstage and Support</td><td>Level 8</td><td>Joint Higher Order Organisational Systems</td><td>Coordinated Operational Capability</td><td>National Healthcare System</td></tr>
<tr><td>Level 7</td><td>Operational System</td><td>Operational Capability</td><td>Multi-disciplinary hospital</td></tr>
<tr><td rowspan="4">Physical Systems</td><td>Level 6</td><td>Core System</td><td>Core Capability</td><td>In-patient Service Delivery, training of personnel</td></tr>
<tr><td rowspan="3">Healthcare Technology and Support Facilities and Equipment</td><td>Level 5</td><td>Products System</td><td>Pseudo Capability</td><td>Hospital Building System, Medical Equipment System, Clinical Engineering Workshops, Hospital Engineering Facilities, Training Materials and Facilities, etc.</td></tr>
<tr><td>Level 2-4</td><td>Products</td><td></td><td>Medical Gas sub-system consisting out of a compressor, Cathlab system consisting of an X-ray system, etc.</td></tr>
<tr><td>Level 1</td><td>Raw Material</td><td></td><td>Surgical stainless steel, etc.</td></tr>
</table>

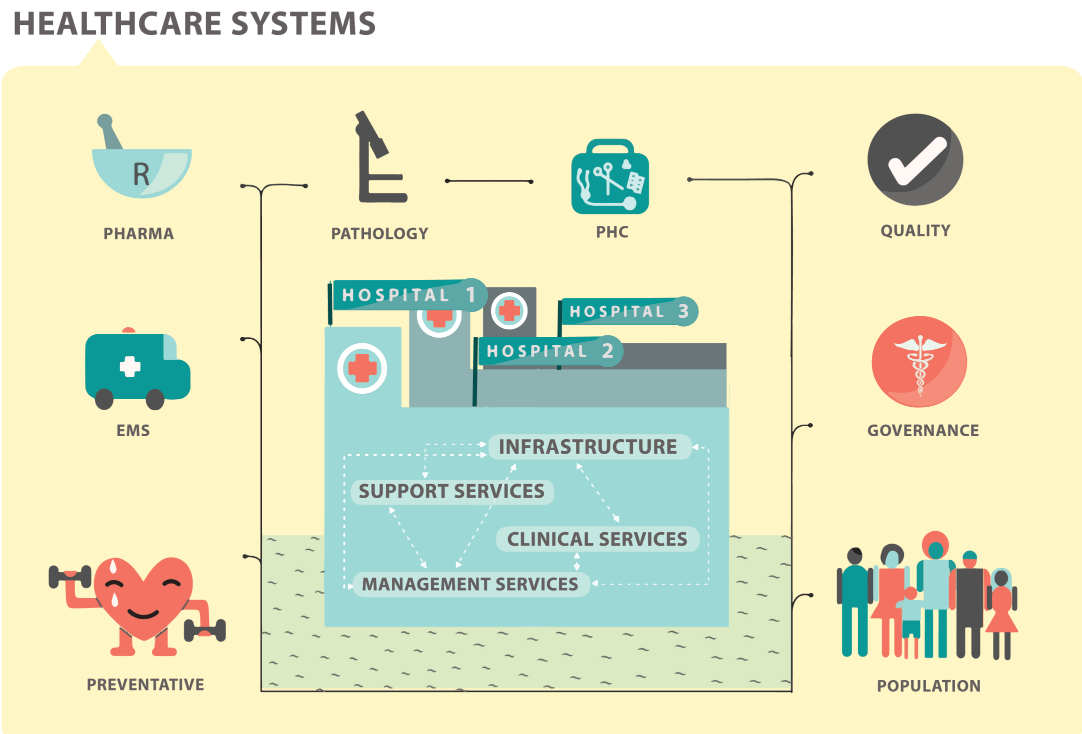
Source: Adapted from De Waal & Buys (2007)

Figure 4. Systems Hierarchy for Healthcare

Systems Hierarchy Levels of Healthcare Services

The organization delivering the Healthcare Services is the hospital (as an organization) that functions on Systems Hierarchy Level 7 (it is a Level 7 System). This is the required Operational Hospital shown in Figure 2 as a system of systems. It should be noted that the hospital building (the physical facility) is a Level 5 System though.

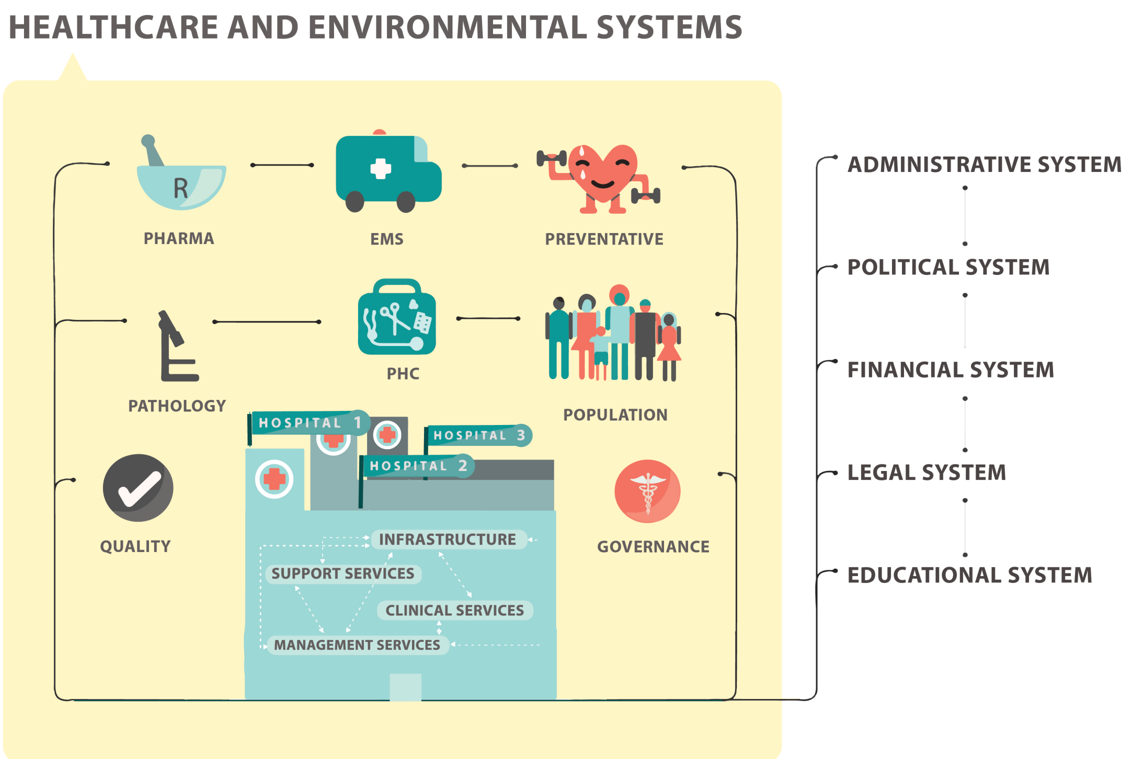
The Operational Hospital has interaction in the National Health System (Level 8 System) as shown in Figure 5 with, amongst other entities, Emergency Medical Services (EMS), Pharmacy (Pharma), Pathology, Primary Health Care (PHC), Preventative Care, Healthcare Governance, Quality of Healthcare and the general Population.



Source: REAFF Consulting

Figure 5. Level 8 National Healthcare System Context for an Operational Hospital

On a national level (Level 9 System), shown in Figure 6, the National Healthcare System has interaction with the Government Administrative Systems, Political System, Financial System, Legal System, Educational System, etc.



Source: REAFF Consulting

Figure 6. A National Healthcare System within a Level 9 System Context

The Operational Hospital is achieved through the integration of several Core Healthcare Capabilities (Level 6 Systems) identified through services blueprints and using Figure 1.

The services blueprints and Figure 1 is also used to identify the product systems that are configured into a core system to enable a specific core healthcare capability.

The Level 5 systems are all the healthcare technologies (Level 4 System Products) together with all necessary support equipment, special tools, information, facilities, training material, ICT systems, etc. (product systems) used or consumed in the different Core Healthcare Capabilities.

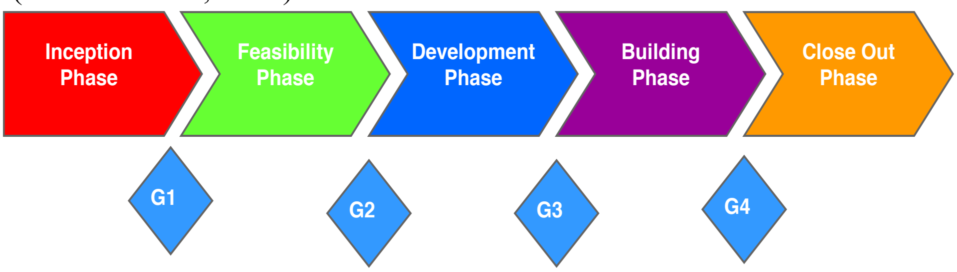
Level 4 System is usually the level on which tenders for the acquisition for various Products are placed at vendors. The level 1 to 4 systems are also the concern of the various vendors, with the necessary information made available to designer/integrators on Level 5 Systems.

The different dynamics and response times of System of System constituents at different systems hierarchy levels is another important factor to consider. For example: Device and procedures are developed with a specific clinical objective however, the impact on clinical practice might be so radical that it takes many years for the new idea to find it's way into regular use. The result maybe inappropriate equipment or design elements which only come to the for during facility commissioning.

Healthcare Facility Commissioning

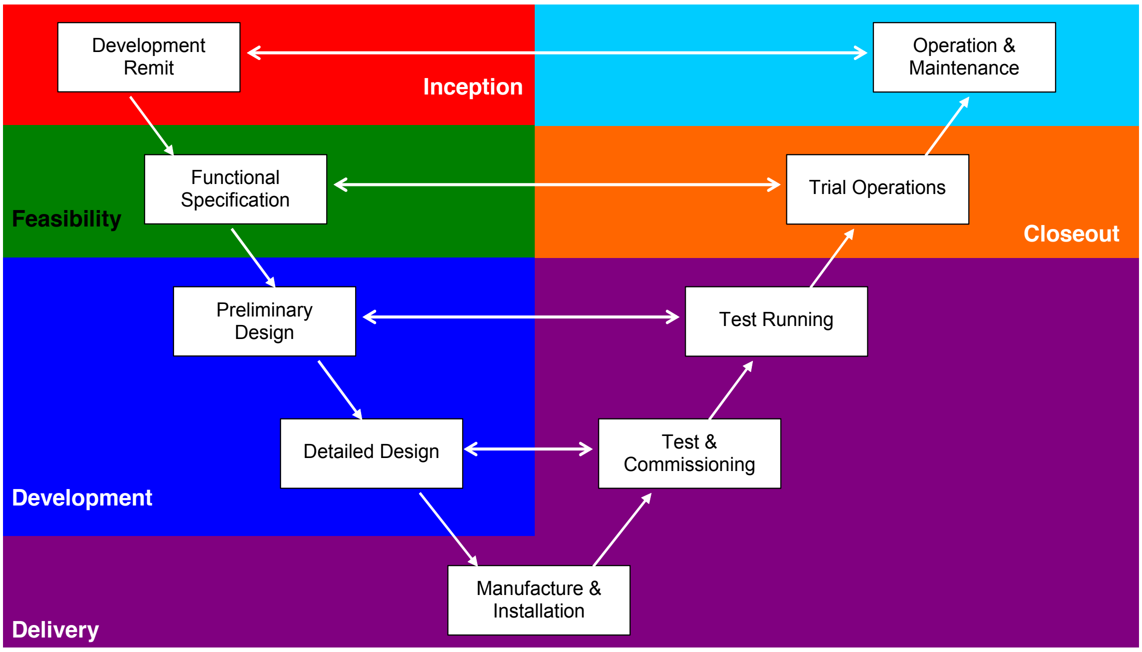
In essence, during commissioning a building containing all the necessary services and equipment is transitioned into an Operational Hospital. This transition is from Level 5 Product Systems into Level 6 Core Capabilities. The integration of these different core capabilities is needed to achieve an Operational Healthcare Services Capability within a nurturing and caring servicescape.

This process can be illustrated through the work by the INCOSE IWG NETLIPSE in Figures 7 and 8 showing the Lifecycle for Large Infrastructure Projects where the systems in the System of Systems are separated in space and time. In a hospital these two dimensions are less of a problem but because some of the systems behaves as they are virtually separated in other dimensions. Figure 7 shows only a partial system life cycle and if compared to the systems life cycle treated by Erasmus et al. (2011), only Development, Manufacturing, Construction, Installation & Implementation, and Commissioning phases are treated. The Operations & Support and Decommissioning phases (Erasmus et al., 2011) are not shown. For sustainable design, all the lifecycle phases should be considered during the Development Phase (Erasmus et al., 2011).



Source: INCOSE – IWG NETLIPSE

Figure 7. Lifecycle for Large Infrastructure Projects



Source: INCOSE – IWG NETLIPSE

Figure 8. V-Model showing the Mapping of Lifecycle for Large Infrastructure Projects

The delivery phase should deliver the various Level's of systems as shown in Figure 4. It is also during this phase that the inward and outward commisioning of the healthcare facility is taking place.

Inward Commissioning

During inward commissioning intangible and tangible elements of Level 5 to 7 systems are analyzed, audited, inspected, demonstrated or tested in the context of the applicable systems level before they are transitioned for utilization in the next higher level. Test Running during the Delivery phase of the project is done on Healthcare Capabilities with Core Systems (Level 6 Systems). Test & Commissioning is done on the Product Systems (Level 5 Systems) to transition them for use in Core Systems (Level 6 Systems).

Tangibles. These are things like building, equipment and medication and they are constituting the Level 5 Product Systems.

Intangibles. These are the management, policies and skills of employees that constitute part of Level 5 Product Systems and the Core Systems for the Level 6 Healthcare Capability. Further, the servicescape encountered on Level 7 Operational Hospital also consists of some of these intangibles.

Outward Commissioning

Outward commissioning uses the Level 7 System (Operational Hospital) within the larger National Healtcare System (Level 8 System) and Level 9 System. Trial Operations during the Closeout phase of the project is when this should be finalised.

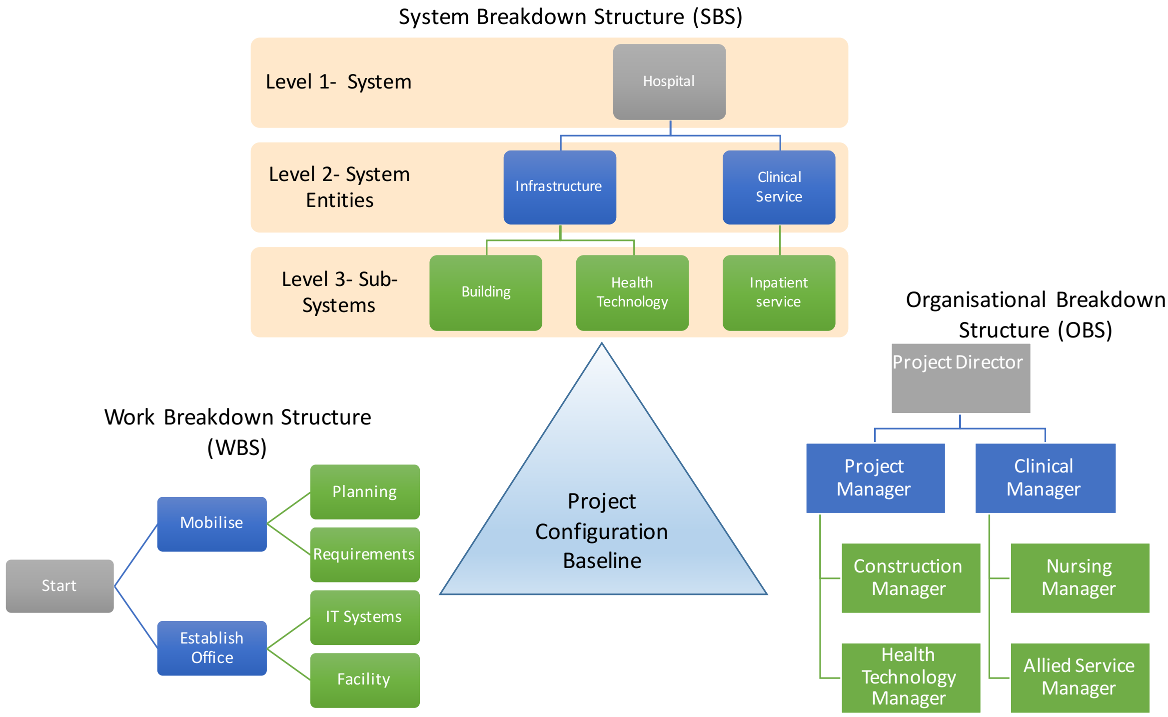
Inside the Health System. Within the Health System a range of interfaces between the new hospital and the components of the Health System need to be established. In terms of the Emergency Medical Services (EMS) which operate within the geographic area, protocols for admission of patients need to be established. It would be undesirable for the EMS provider to communicate with the new facility regarding their ability to accept and treat a specific emergency case while they are already transporting the patient during the emergency event. The exact capability of the facility to accept emergencies must be clearly agreed upfront. In terms of in-patient referral, similar protocols need to be establish. No facility is ably to treat every kind of conditions. The new facility needs to discuss with the facility's delivering service both at a lower and a higher level of care compared to them, the terms on which intra-facility transfers will take place. This interface is much more complex than that which relate to EMS as the facilities to which and from which they might transfer might be geographically quite distant. For example radiation oncology to treat certain cancers are deliver in highly specialised facilities which are only found in major centres. If such a service is needed, a patient might be transferred to a facility hundreds of kilometres away. These interfaces needs to be established upfront.

Outside the Health System. Interfaces between other systems also need to be established. For example the financial system needs to be engaged in order for transaction to be able to take place. The new facility must open bank accounts in order to trade. It needs to establish a company or other vehicle through which it can function as an entity to enter into contracts, or pay taxes. In terms of communication, it needs to establish voice and data services in order for both business and clinical service communication to take place.

Bringing the Project Management, Systems Engineering and Commissioning Together

One of the special application areas of Systems Engineering is in what is called Large Infrastructure Projects (LIP) (INCOSE IWG NETLIPSE, 2012). These are projects that involve the design and construction of new railway or power generation and distribution capacity. Planning, design and construction can span years and even decades. Hospital development does not usually qualify as a LIP due to the fact that the construction takes place in one location and not multiple sites with vastly diverse project timeline. But, due to the complexity of interfacing many new systems related to the new facility as well as interfacing with many existing systems, combined with the common elements of large scale construction, many of the special conditions defined in LIP apply. The common element of large scale construction include; complex building services coordination, significant amount of statutory compliance needed in order to obtain certification to occupy the building, long and complicated construction project planning and execution, to name but a few.

One such LIP condition which apply is the particular focus on the relationship between System-, Work- and Organisational Breakdown Structure captured in the Project Configuration Baseline as shown in Figure 9.



Source: INCOSE – IWG NETLIPSE(adapted)

Figure 9. Coordinating of the SBS, WBS and OBS through the Project Configuration Baseline

Every element and sub-system in the System Breakdown Structure (SBS) of the Operational Hospital (tangible and intangible elements) has a life cycle (INCOSE IWG NETLIPSE, 2012; Erasmus et al., 2011). It is important to understand how all these life cycles relate to each other and how they align with the Work Breakdown Structure (WBS) and the Organisational Breakdown Structure (OBS). The WBS refers to the project schedule of activities required to establish the infrastructure system and each of the other systems, which constitutes the Operational Hospital Level 7 System. The OBS refers to the relationship between organisation, departments and individuals who need to ensure that the systems are developed, constructed and operated.

The major engineering grouping of roles are systems engineer, designer, construction manager and commissioning manager. During the Project Lifecycle Phases, the intensity of activities for each role changes as shown in Figure 10.

Conclusion

This paper discusses how aspects from systems engineering combined with that of services management can enable hospital project and commissioning managers to improve their project results through improved up-front integration of systems and functions from a holistic perspective to better ensure that sub-optimization is avoided. This occurs during initial development of a hospital's design, considering the various factors involved in the transition of healthcare services into the operations phase of a hospital's lifecycle. Commissioning of the health facility is defined as the transition process through which custody of the healthcare system is transferred from the construction project owner to the operational system owner. All the definitions, processes, documentation requirements, etc. designed to ensure the successful establishment and operation of a system is available through the Systems Engineering discipline.

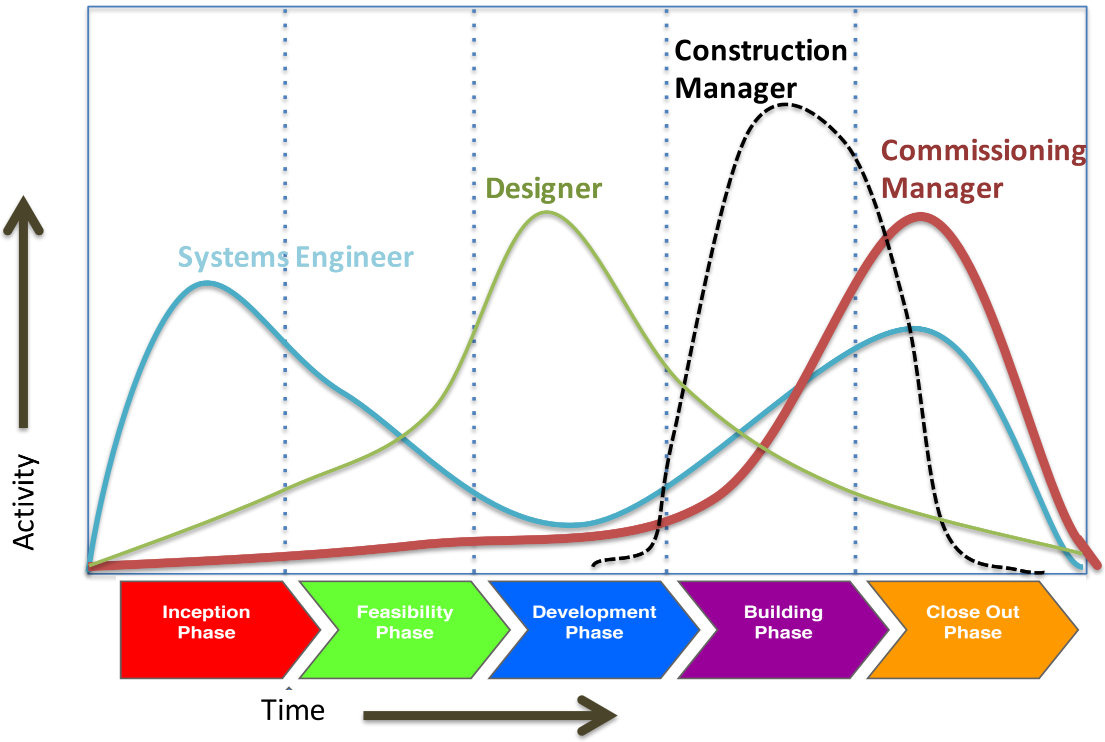


Figure 10. Activity of Various Role Players throughout the Project Life Cycle

The results from this paper can also be used in identifying tools from systems engineering and how to integrate it with project management in helping commissioning healthcare facilities in a more cost effective and operational effective manner. Further exploration of the application of Systems Engineering to Hospital development offers significant potential towards an improved outcome.

References

Bitner, M.J. 1990. "Evaluating service encounters: The effects of physical surroundings and employee responses." *Journal of Marketing*, 54:69-82.

De Waal, J. and Buys, A. 2007. "Interoperability and Standadisation in the Department of Defence: An Exploratory Study." *Journal of Industrial Engineering*, 18:175-190.

Erasmus, L.D. and Doeben-Henisch, G. 2011. "A Theory for System Engineering Management." in *1st International Conference on Industrial in Engineering, Systems Engineering and Engineering Management for Sustainable Global Development*, Spier, Stellenbosch, South Africa: ISEM.

Erasmus, L., Du Plooy, N., Schnetler, M. and Yadavalli, S. 2015. "Engineering Logistics of Personnel and Computer Resources of a Command and Control Centre: Desk Study," in *11th INCOSE SA Conference - Systems Engineering: Shifting the Barriers*, 16 - 18 Sep 2015, Pretoria, South Africa: INCOSE South Africa Chapter.

Fitzsimmons, J.A., Fitzsimmons, M.J. and Boroloi, S.K. 2014. *Service Management: Operations, Strategy, Information Technology*, 8th ed. Boston: International editors McGraw-Hill.

Haskins, C., ed. 2007. *Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities.* Version 3.1. Revised by K. Forsberg and M. Krueger. San Diego, CA (US): INCOSE.

———. 2010. *Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities.* Version 3.2. Revised by M. Krueger, D. Walden, and R. D. Hamelin. San Diego, CA (US): INCOSE.

INCOSE IWG NETLIPSE. 2012. *Guide for the Application of Systems Engineering in Large Infrastructure Projects*, Version 1, Document # INCOSE-TP-2010-007-01, San Diego, CA (US): INCOSE.

ISO (International Organization for Standardization). 2015. ISO/IEC/IEEE 15288:2015. Systems and software engineering–system life cycle processes. Geneva, CH: ISO.

Weeks, R. 2012. "Healthcare services management: A systems perspective." *Journal of Contemporary Management*, 9:382 – 401.

Weeks, R.V. and Benade S.J. 2011. "Service science: A servitization systems perspective." In *1st International Conference on Industrial in Engineering, Systems Engineering and Engineering Management for Sustainable Global Development*, Spier, Stellenbosch, South Africa: ISEM.

Biography

Riaan van der Watt has been working in the Health Technology field since 1995. He has worked for two of the three large private hospital groups as hospital engineer, clinical engineer and as group technical manager. He has served as member of the National Council of the Clinical Engineering Association of South Africa. He holds a Bachelor's degree in Mechanical Engineering, a Honours in Biomedical Engineering and a Masters in Engineering Management, all from the University of Pretoria. In June 2007 he founded Rho Consulting, an independent Health Technology Consultancy focusing on Clinical Engineering and Health Technology Management. In 2011, REAF Consulting is formed as a JV between Rho Consulting and Axi Health.

Louwrence Erasmus worked for more than 20 years in academia, national and international industries. He is a Principal Systems Engineer at the CSIR and part-time senior lecturer at the Graduate School for Technology Management, University of Pretoria. His interest is the underlying formal structures in systems engineering using constructivist philosophy of science and their practical implications in practice. He graduated from the Potchefstroom University with B.Sc., B.Ing., M.Sc. degrees in 1989, 1991 and 1993 and a Ph.D. in 2008 from North West University, Potchefstroom. He is a registered professional engineer with ECSA and a senior member of IEEE and SAIEE.