

The Impact of Industry 4.0 on Healthcare System Engineering

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Abstract— The introduction of Industry 4.0 vision created huge potentials for many industrial sectors to optimize their operations. Thus they can improve their productivity, cost-effectiveness, reliability, quality, and flexibility. One important sector that can effectively benefit from this vision is healthcare. The Industry 4.0 version of healthcare is named Healthcare Industry 4.0 or Health 4.0 in short. Health 4.0 is based on new technologies to deliver enhanced and value-added healthcare services for patients. Health 4.0 will highly impact healthcare system engineering (HCSE), which applies engineering analysis and design principles to enhance healthcare services. In this paper, we discuss and analyze this impact. We attempt to identify the relationship between Health 4.0 and healthcare system engineering. We also identify the challenges of the different roles in healthcare system engineering and address how Health 4.0 can provide solutions for these challenges.

Keywords- Industry 4.0, Health 4.0, System Engineering, Healthcare System Engineering, Technological Impact

I. INTRODUCTION

There are several challenges facing the healthcare industries including high costs of healthcare services, equipment, and facilities; the difficulty of finding and recruiting the needed healthcare professionals; the increasing demand for healthcare services; the growing demands for high quality healthcare services; and the strong competition among healthcare providers. These challenges make healthcare organizations consider applying new approaches to help address the challenges they face. There are two interesting and promising approaches that can significantly contribute in solving current and future healthcare issues: healthcare system engineering (HCSE) [1][2] and Health 4.0 [3]. The first, HCSE, is an engineering approach to solve healthcare issues, while the second, Health 4.0, is a technological approach to solve these issues. Until now, both approaches are progressing and separately offering promising solutions. However, there are strong relationships between the two as both aim to achieve the same objectives. That is improving and optimizing healthcare services. Looking at both as an integrated approach to improve healthcare services will result in more effective solutions. Health 4.0 can provide many models and approaches that will significantly improve HCSE processes and their outcomes.

In this paper, we investigate the impact of Health 4.0 on HCSE. We identify the roles of HCSE and their challenges. We discuss how HCSE roles and processes can benefit from Health 4.0. We then look at the different issues that may arise when

utilizing Health 4.0 approaches in HCSE processes. In addition, we attempt to answer the question of what are the future perspectives of Health 4.0 based HCSE.

The paper is organized as follows. Section II provides background information about HCSE, its objectives and roles. Section III discusses Health 4.0 and the different components that facilitate it in addition to its benefits for the healthcare industry. The impact and benefits of Health 4.0 on and for HCSE are discussed in Section IV and Section V concludes the paper.

II. HEALTHCARE SYSTEM ENGINEERING

Healthcare systems engineering is a field of study and research in healthcare delivery science that focuses on analyzing and designing reliable, high quality, and cost-effective healthcare systems and processes [1]. Researchers and engineers in healthcare systems engineering aim to improve healthcare efficiency, diminish healthcare and treatment errors, enhance and broaden access to healthcare, and improve the overall quality of healthcare services [2].

HCSE overlaps with many areas in health care and engineering, as shown in Figure 1. These include biomedical engineering, industrial engineering, information technology, law and management. In addition it covers all healthcare sectors and services such as medicine, emergency care, nursing, diagnostics, pharmacy, dentistry, public health, and regulations compliance. The biomedical engineering field emphasizes the design and implementation of different medical products which are the main tools for healthcare and the source for various health support equipment and devices. Industrial engineering responsible for enhancing organizational operations and services procedures, workflow, safety, and cost-effeteness which are essential in the healthcare industry. The main roles of HCSE include:

1. Identifying possible risks and indicators of patients' health and possible complications or problems.
2. Developing principles, procedures, methodologies, and tools to enhance healthcare processes.
3. Enhancing the effectiveness of healthcare staff and teams in healthcare facilities like treatment and operating rooms.
4. Enhancing patients' access to healthcare services.
5. Reducing inconveniences on healthcare staff through improved planning and resource utilization.

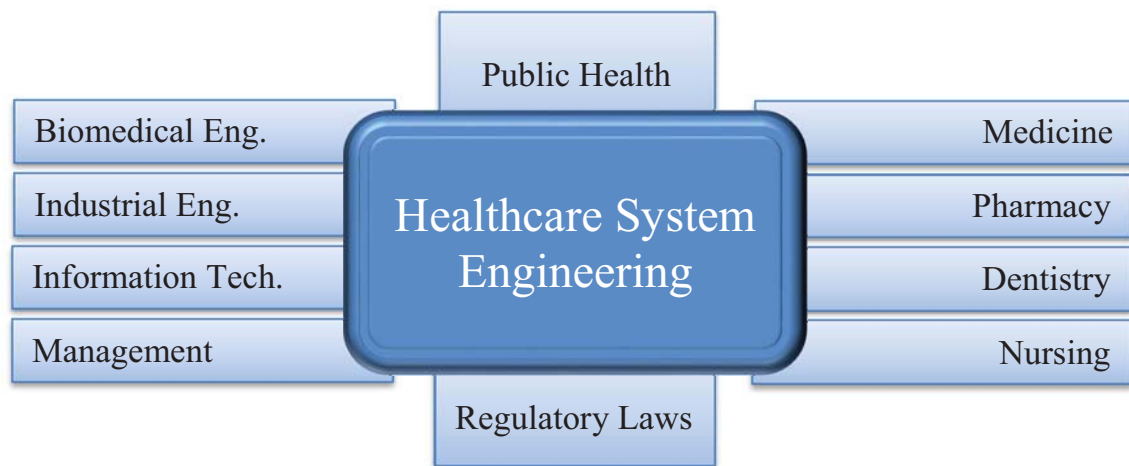


Figure 1. Healthcare System Engineering Overlapping with Other Areas.

6. Improving the safety of healthcare facilities, services and operations.
7. Investigating different healthcare related workloads and staff involvement to suggest improved task executions and outcomes.
8. Improving the operations, utilization, and usability of medical equipment.
9. Improving healthcare related supply-chain management.
10. Monitoring different healthcare processes to offer continuous enhancements.
11. Enhancing cost effectiveness of healthcare services.
12. Optimizing scheduling and resource utilization across healthcare facilities.
13. Conducting capacity planning for future healthcare resources needs.

Although, applying HCSE offers many advantages for healthcare services providers, there are several challenges and obstacles that make it hard to achieve the required objectives. Example of these challenges and obstacles are:

1. Fragmented medical records and health data across multiple divisions within a single healthcare provider and across multiple providers.
2. Unavailability of continuous and fine grain data collection in most areas of healthcare leading to lower capabilities to perform advanced data analytics.
3. Difficulties in managing the sharing and exchange of medical records across multiple health providers and related organizations due to privacy and security concerns and ownership and control issues.
4. Unavailability of effective and efficient automation tools and monitoring services for healthcare records, procedures, and trends.
5. System wide healthcare management processes require more lean approaches and higher reliance on technology to achieve optimized operations and lower costs.
6. Lack of advanced and integrated monitoring tools, services and devices to keep track of operations and

measure the effectiveness of the healthcare staff and procedures.

7. Limited resources and budgets coupled with high costs of healthcare specialists and facilities heavily affect future planning and the capabilities to adopt more advanced approaches.
8. Healthcare is a rapidly changing domain and requires an agile approach to adapt to new methods and technologies for higher effectiveness and lower operational costs.
9. Difficulties in discovering problems in healthcare processes, signs of faults and failures in equipment, and trends in patients' needs.
10. Inefficient value chain integration and management leading to more errors, higher costs and ineffective procedures.
11. Primitive levels of automation and use of technology used in supply chain management and difficulties in optimizing resources and procedures used.

III. HEALTH 4.0

With the recent advances in software, hardware, information and communication technologies (ICT), there are huge opportunities to enhance and develop many applications in different industrial domains. These technological advances motivated the initiation of what is currently referred to as Industry 4.0 [4]. One of these domains is the healthcare industry. The healthcare version of Industry 4.0 is referred to as Healthcare Industry 4.0 or Health 4.0 in short.

The basic principle of Health 4.0 is that by connecting patients, personal medical devices, medical systems, hospitals, clinics, pharmaceutical and medical suppliers, and other medical components; healthcare providers are creating a smart health network along the entire healthcare value chain that can benefit each other by automating and optimizing their operations. This smart health network, as shown in Figure 2, changes healthcare providing models and enables the interactions with value chain.

To consider a healthcare system as Health 4.0 it must be designed such that it includes and supports interoperability, service-orientation, modularity, real-time capabilities and other

advanced functions. Health 4.0 allows advanced software, medical devices, and medical professionals to collaborate effectively to improve healthcare processes and provide numerous capacities to:

1. Automate more healthcare tasks using customizable and adaptive devices and software.
2. Incorporate new healthcare processes, business models, and technologies.
3. Enhance healthcare diagnostics, treatments and monitoring procedures.
4. Offer a foundation for better personalized medicine.
5. Improve response times for different healthcare processes.
6. Elevate healthcare analysis capabilities using the collected data and advanced data analytics models.
7. Continuously collect and store real-time healthcare data.
8. Introduce smart algorithms using available healthcare data to permit some medical systems to make autonomous decisions.
9. Reduce the reliance on humans for healthcare monitoring and decision making.
10. Create a foundation for more reliable and highly available healthcare services.

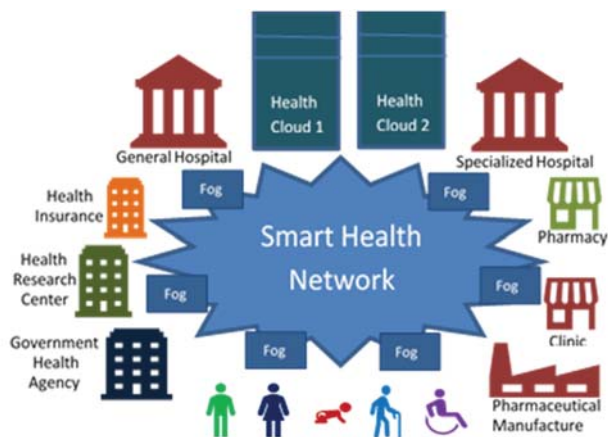


Figure 2. A smart health network utilizes some enabling technologies.

The ability to support these features and capabilities will contribute effectively in realizing the main healthcare goals in improving the quality of healthcare delivery and reducing healthcare costs. With new technologies, new healthcare values and features such as better health predictability and personalized medicine can be generated. These new values contribute in enhancing healthcare services and achieving the main healthcare goals in improving healthcare quality while reducing costs. There are many technologies that can significantly contribute in realizing the objectives of Health 4.0 such as:

1. **Internet of Things (IoT)**, to enable connecting different medical physical devices such as medical sensors used to monitor heart-rate, body temperature, pressure, oxygen levels; and medical actuators controlling devices like infusion pumps and ventilators, and other systems in a network [5].

2. **Internet of Everything (IoE)**, to provides intelligent connections for not only physical objects but also for people, processes, and data [6]. In healthcare IoE allows intelligent connectivity among people, (patients, doctors, nurses, and other healthcare staff), processes (diagnostics, treatments, health-related scheduling, and health insurance), data (electronic health records (EHR)), real-time health monitoring data, lab results and imaging data), and things (medical devices, wearable medical devices, doctors' diagnostic and treatment tools, and medications).
3. **Internet of Service (IoS)**, to enable providing services for different health-related systems and organizations via the Internet. These services can be used by their owners and other health systems and organizations that may need them [7].
4. **Medical Cyber-Physical Systems (medical CPS or MCPS)**, to facilitate useful interactions between the cyber world and the patients to offer continuous health monitoring and treatment services [8].
5. **Health Cloud**: to provide scalable computation, data storage, and other advanced services for different health-related applications [9].
6. **Health Fog**: to provide low latency support, real-time control, location awareness, better mobility and security support, and streaming and real-time support for healthcare applications [10].
7. **Health Data Analytics**, to offer tools for intelligent analysis and decisions based on gathered health and healthcare data for enhancing healthcare services and management [11].
8. **Blockchain**, to enable secure and fair collaboration among healthcare providers, to maintain patient's privacy, and to enable negotiations, transactions, and smart contracts across the healthcare value chain [12][13].

The idea of Industry 4.0 is created based on six design principles that are also very appropriate for Health 4.0. These design principles provide a general foundation to the main requirements of Industry 4.0. However, these are discussed here with specific references to the healthcare industry.

1. **Interoperability**: the ability of different medical CPS and other medical devices and systems along with the patients, healthcare providers, healthcare producers, and insurers to connect and communicate via a well-established network such as IoT and IoS.
2. **Virtualization**: the ability to monitor different healthcare producers, providers, and receivers processes such that virtual copies can be created for these processes. These virtual copies can be utilized for future enhancements of different healthcare processes. One example is to virtualize a specific treatment procedure (e.g. administering a specific medication through a connected IV at specific times or based on specific monitored conditions) such that medical CPS can be used to automate that procedure.
3. **Decentralization**: the ability of different medical CPS and other medical systems to make decisions on their

own. This design principle requires avoiding the use of centralized controls. Although, medical CPS and medical systems can benefit from other facility systems such as health cloud and health fog, they still need to be able to make their own decisions to effectively continue their operations.

4. **Real-time Capability:** the ability to immediately collect and analyze health data such that the right actions can be effectively conducted. This ability enables discovering erroneous medical treatments, faulty medical CPS, sudden changes in a patient's condition, etc.
5. **Service Oriented:** The ability to present the functions features and devices in the healthcare system as services. These services will represent healthcare producers, providers, supporters, and medical devices and systems and will be accessible over the IoS to participants. These services can be provided both internally within the same organization and across multiple organizations.
6. **Modularity:** the flexibility of changing, expanding, and enhancing individual modules to fit new requirements in existing healthcare processes or building new processes.

IV. THE IMPACT OF HEALTH 4.0 ON HCSE

Health 4.0 advanced technologies can be used to support the healthcare industry in many ways. To begin, the deployment and use of IoT, IoS, and medical CPS components will significantly increase the amount of healthcare data collected. This data can be used in different ways to achieve various number of goals. In real-time, we can gather data directly from patients' monitoring devices, analyze it and initiate remedial actions when necessary. In addition, real-time data about resources in use, staff schedules, activates in progress and a lot more, can be used to streamline operations, direct staff to where they are needed most, optimize equipment operational schedules, and enhance patients' flow across the different departments within the healthcare facilities. With a little extra time, it is also possible to automatically create a patient's visit profile and prepare the procedures and items needed. For example, as a nurse measures and records vital signs and get initial information about the visit's purpose, the needed doctor is identified and tagged to be available for the patient. During a doctor's visit with the patient, information regarding tests, lab work, medication is directly streamed to the relevant departments and get prepared or scheduled for the patient. By the time the patient leaves, the examination room, specific instructions are available for the next steps.

On the long run all the data being collected can be further processed, analyzed and deeply assessed to create a proactive action plan for the healthcare industry. Recurring issues will be easy to identify and study, problems with equipment, facilities and procedures can be identified through careful analysis of data collected over long periods of time. Patterns can be found and accordingly enhancements can be made more easily and effectively. Maintenance work can be scheduled in proactive manner and with minimum disruption to regular work procedures. One example here can be a long term analysis of operating rooms and equipment utilization. Gathered data over extended periods like months or years can be scrutinized to find utilization patterns, possible peak demand points, and hidden areas of inefficiencies and use all of this information to create

more efficient scheduling schemes. Moreover, when all the organizations and entities involved in or related to the healthcare sector are integrated through a complete value chain, collected data across all sectors can help optimize information flow, resources utilization, and access to required services. Patterns and trends can be identified and HCSE can capitalize on these findings to further enhance the services. At the same time, better integration along the entire healthcare value chain will provide various opportunities to create smart features to automate many of their operations.

The collected data about patients and illnesses can also be analyzed over a long term to benefit specific patients or the general public. For example, patterns of viral infections spreading in specific areas can be used to optimize vaccinations and offer better health safety guidelines for the public. Aggregate information about a specific disease can help identify risk groups, best treatment procedures, and enhanced diagnostics methods for patients who have the disease or at risk. Furthermore, collective data analysis for a specific patient can be very useful in providing personalized treatments and better ways to understand and treat illnesses.

To achieve all these goals, IoT and medical CPS components will need access to more facilities such as cloud and fog computing, advanced analytics software and smart AI solutions. Collectively, introducing Health 4.0 capabilities to support HCSE tasks will lead to highly efficient healthcare systems. Looking at the goals and roles of HCSE (Section II), we can identify direct connections where Health 4.0 will be extremely beneficial. Several of the HCSE goals and roles rely on information. Figure 3 depicts the main goals in the healthcare industry (improved healthcare quality, improved patient access to healthcare services, higher cost effectiveness, and improved competitive advantage). These goals can be achieved if the roles of HCSE are effectively and efficiently developed and achieved. This requires having some software tools to help HCSE professionals efficiently conduct their roles. These tools are enabled by Health 4.0 technologies and values.

With Health 4.0 services and capabilities HCSE can get access to more detailed data about every aspect of the healthcare system that is connected to the Health 4.0 applications. With that data and the analytics capabilities in Health 4.0, HCSE will improve quality through the ability to:

1. Enhance patient scheduling, treatment and monitoring operations through faster and better access to all patient data.
2. Improve staff scheduling through more detailed analysis of current and historic operations and staffing needs.
3. Incorporate automated equipment and smart solutions to reduce the reliance on humans for mundane or repetitive tasks and reduce the possibilities for error.
4. Create more accurate operational procedures and policies based on the collected data and identified problem areas.
5. Analyze data gathered about the equipment and tools used over time to create more proactive maintenance schedules and have better predictions of future needs. Thus, reducing the probabilities of service interruptions or delays.
6. Create long term and strategic plans for resources utilization, acquisition, and distribution. This includes facilities, equipment, materials and human resources to achieve more timely and effective healthcare services.

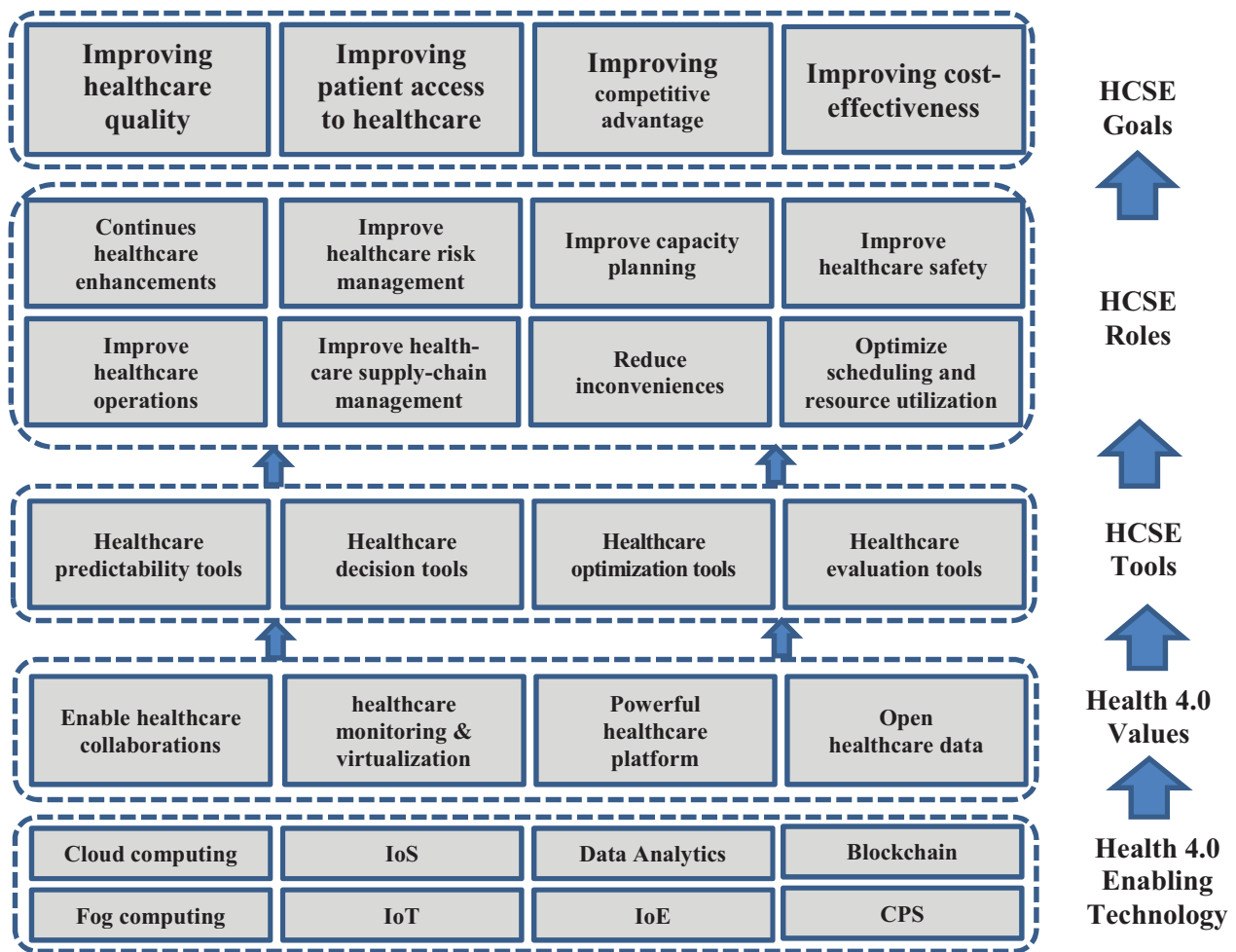


Figure 3. An impact architecture of Health 4.0 on healthcare system engineering.

Another area where HCSE will highly benefit from applying Health 4.0 solutions is the increase in cost effectiveness of different operations and processes.

1. Proactive maintenance enabled by constant monitoring and measurements, will reduce costs of maintenance, improve equipment operational efficiency and reduce the number of unscheduled repairs.
2. Analysis of a patient's complete health records over a long period of time will help improve diagnostics and reduce the need for excessive tests and lab work and can also optimize medication use.
3. Collective data about all patients' in the system will provide good basis for analytics that will allow for better allocations of needed resources, more accurate estimate of necessary equipment in each location, better scheduling for facilities, equipment and operational staff based on realized patterns of use over time.
4. Equipment supported by medical CPS components and smart decision making features will help automate various processes and reduce staffing needs, thus reducing costs.
5. Smart algorithms can be used to create a knowledgebase for all sectors involved in healthcare that allows them to

investigate spending trends, redundancies, and operating procedures to design leaner more efficient procedures.

6. Simulation environments can be created using collected data, which will allow the applications and staff to explore the feasibility and benefits of possible actions or procedures before actually investing in them.

These are some benefits of utilizing the technologies and approaches in Health 4.0 to support the HCSE activities. As technologies advance, more data is collected, and smarter software features become available, more benefits will be possible. Highly intelligent healthcare services will be created, where machines, staff and patients will seamlessly collaborate for better services. Several currently manual procedures and activities, will be automated and will use smart equipment and decision making software to operate independently. Scheduling, optimization effective execution, and capacity planning will be greatly enhanced by the wealth of historic and real-time data made available. Table 1 provides a summary of the impact and benefits of utilizing Health 4.0 for HCSE.

Table 1. The impact and benefits of Health 4.0 on HCSE Roles.

#	HCSE Role	How can Health 4.0 Help?	Potential Impact/Benefits
1	Identifying possible risks and indicators of patients' health and possible complications or problems	- Better access to patients' data within one and across multiple collaborative healthcare providers. - Integrated services to support and automate the process of identifying potential risks and issues.	- Fast and more accurate detection of possible healthcare risks - Reduced potential for negative consequences of healthcare risks. - Reduced costs of responding to healthcare risks.
2	Developing principles, procedures, methodologies, and tools to enhance healthcare processes	- Introduction of automated healthcare processes - More healthcare data can be collected for analysis and future development - Better measurements for healthcare processes	- More efficient healthcare processes - Better management of healthcare processes - Fast decision-making related to different healthcare processes
3	Enhancing the effectiveness of healthcare staff and teams in healthcare facilities like treatment and operating rooms	- Introduction of the possibility to develop and use new medical devices such as medical robots to increase the effectiveness of healthcare staff - Enabling integrations across different devices and processes for better operations and management	- Better healthcare effectiveness - Enhanced use of available human resources with the support of automation
4	Enhancing patients' access to healthcare services	- Introduction of services to monitor and estimate patients' needs - Incorporating optimization, evaluation, and analytics services to help manage the limited healthcare resources	- Better patients' access to healthcare services - Better healthcare resources utilizations
5	Reducing inconveniences on healthcare staff through improved planning and resource utilization	- Enabling innovative new technological services to help reduce inconveniences for healthcare staff - Facilitating better planning, scheduling and resources utilization approaches	- Better productivity - Enhanced staff satisfaction
6	Improving the safety of healthcare facilities, services and operations	- Offering real-time monitoring for healthcare processes and medical equipment to maintain good safety levels - Enabling the sharing of data and services related to the safety of healthcare across the value chain - Enabling new innovative services across the value chain to help improve healthcare safety	- Reduced unwanted healthcare incidents - Better quality and safety of healthcare services
7	Investigating different healthcare related workloads and staff involvement to suggest improved task executions and outcomes	- Providing better mechanisms for estimating healthcare workloads - Helping in creating performance profiles for each staff member - Providing data analytics tools to help improve healthcare task executions and outcomes	- Better healthcare tasks executions and outcomes - Better utilization of healthcare resources - Reduced operational costs
8	Improving the operations, utilization, and usability of medical equipment	- Enabling better integration between medical equipment and systems - Enabling optimized maintenance schedules and procedures for medical equipment and facilities - Enabling better monitoring of medical equipment - Allowing multiple providers to share expensive medical equipment - Enabling innovative services to manage medical equipment	- Increased utilization of medical equipment - Reduced cost of accessing expensive medical equipment
9	Improving healthcare related supply-chain management	- Enabling better estimations for healthcare supply chain needs - Enabling communication, negotiation, and contract automation with suppliers using blockchain and smart contracts	- Increased efficiency and reliability of healthcare supply-chain management - Reduced human errors - Lower costs
10	Monitoring different healthcare processes to offer continuous enhancements	- Providing better measurements for different healthcare processes - Providing tools for monitoring healthcare processes in real-time - Providing data analytics tools to help in continuous enhancements	- More efficient healthcare processes - High degree of adaptability of healthcare processes to match new healthcare requirements - Improved performance and enhanced recognition of successes and issues
11	Enhancing cost effectiveness of healthcare services	- Enabling better management for healthcare recourses - Enabling better cost measurements for different healthcare services - Enabling collaboration among healthcare providers to enhance cost effectiveness - Enabling better estimations of healthcare needs	- Better cost effectiveness of healthcare services - Reduced healthcare costs for patients - Enhanced competitive advantages - Opportunities to offer new healthcare services
12	Optimizing scheduling and resource utilization across healthcare facilities	- Enabling better measurements for workloads and resources capacities - Providing data analytics tools to help in achieving optimized scheduling and resources allocation - Enabling the creating and use of simulation tools to evaluate proposed scheduling and resource utilization methods.	- Better healthcare resources utilization - Reduced operational costs - Enhanced knowledge of current and future scheduling and resources needed
13	Conducting capacity planning for future healthcare resources needs	- Enabling collecting accurate data about healthcare services - Enabling developing new services to detect future trends in illnesses - Enabling developing new services to estimate the future trends in the number and needs of patients - Providing different data analytics tools to help in conducting capacity planning and future healthcare resources needs.	- Enhanced planning for future expansions and allocations of healthcare resources - Cost effective introductions of future services based on accurate analytics and predictions

The future holds more benefits and capabilities in all the fields of technology feeding the Health 4.0 areas. As a result, HCSE practices based on these technologies will also improve significantly. Solutions enhancing the different healthcare services, optimizing resources management and responding to needs on demand will further improve the healthcare industry. The main Objectives of HCSE will be highly driven by technology and will be achieved faster and become more effective. Imagine a complete healthcare system managed and operated seamlessly and efficiently with minimum human interactions. Supply chain activities, for example, automatically scheduled at optimized levels, negotiated and completed at the moment they are needed. Disease information flowing around the world across research and treatment facilities with boundaries managed and controlled instantaneously between all organizations involved, leading to faster and more efficient controls, management and treatments. High quality healthcare services made available at low cost to all patients at any facility anywhere with experts having access to records and resources to provide these services without being physically present at the same location. HCSE practices will be extremely efficient, highly available and very agile. Allowing for fast and effective changes to happen in response to the changing needs and developments in the healthcare industry.

V. CONCLUSION

In this paper we outlined the main goals and characteristics of two important aspects that can significantly improve healthcare systems. One is healthcare system engineering, which has evolved over time from the solid engineering principals and approaches. This allows for optimizing and streamlining services and requirements in healthcare to achieve optimal operations efficiency, quality and cost effectiveness. The other is Healthcare Industry 4.0 or Health 4.0, which has been adapted from the general vision and principles defining Industry 4.0. Health 4.0 calls for integrating various technologies and capabilities with the humans and current operational procedures to automate and optimize healthcare services. IoT, IoS, medical CPS, Cloud computing, Fog computing, and any devices, systems and equipment used in healthcare will be integrated through reliable and smart infrastructure. Thus, adding intelligent and autonomized capabilities in the healthcare environment. We then discussed how Health 4.0 can become a significant contributor to better healthcare system engineering. By offering vast access to sensed and collected data using the Health 4.0 technologies, healthcare system engineers can do a better job optimizing and streamlining operations. Access to automated equipment, real-time monitoring and control systems and highly intelligent software services will enhance resources management and utilization and overall increase the cost effectiveness of all healthcare operations. Collectively the main beneficiary will be the patients as they will have better access to higher quality healthcare services at lower costs.

This vision needs to be further investigated and refined to achieve these goals. Approaches, models, algorithms, tools and many other components, that can utilize Health 4.0 technologies and values for improving healthcare system engineering need to be investigated and developed.

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