Hospital 4.0 roadmap: an agile implementation guideline for hospital manager

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Abstract: Social and economic developments, such as the progressive aging of society or rigorous budgetary policies, combined with the latest unforeseen outbreak of the pandemic COVID-19 have shown the fragility of healthcare systems. Today more than ever, concepts like flexibility, agility and efficiency assume significance also for the design of healthcare systems. To increase agility and robustness of healthcare systems, this paper presents an implementation approach for Hospital 4.0 based on a profound analysis of scientific literature about Industry 4.0 and Hospital 4.0 and aims to provide a practice oriented guideline for hospital manager. The proposed roadmap is based on six phases starting with an assessment and ending with the long-term sustainable innovation and development process of future oriented Hospital 4.0 concepts. The main findings of this research is the transfer of Industry 4.0 guidelines to healthcare, leading to a comprehensive roadmap for the development and implementation of Hospital 4.0 strategies.

Keywords: Hospital 4.0; Industry 4.0; roadmap; healthcare system; assessment model; agile systems design.

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1 Introduction

Industry 4.0 was and is still perceived as the digital transformation process in the manufacturing sector capable to enhance the effectiveness and efficiency of industrial entities (Matt et al., 2020). The increasing digitisation and automation level, which triggers naturally the merger of information technology (IT) and production or logistics processes received positive response in enterprises operating in different fields (Culot et al., 2019). The range of applications is not only limited to industrial sectors, since scientists pertaining to non-industrial domains are concerned of transferring Industry 4.0 concepts (Javaid and Haleem, 2019). The industrial phenomenon demonstrated to be a valid possibility to achieve important improvements, even in areas that at first glance seem to be completely unrelated to the manufacturing world. Hospitality and the kindred education sector as well as healthcare are some of them (Aceto et al., 2020; Shamim et al., 2017; Mourtzis et al., 2018). In particular, the healthcare academic field made serious efforts to investigate the applicability of Industry 4.0 concepts relying on the most diverse methodological approaches (Javaid and Haleem, 2019; Aceto et al., 2020).

Social and economic developments, such as the progressive ageing of society or rigorous budgetary policies, combined with the latest unforeseen outbreak of the pandemic COVID-19 have shown the fragility of healthcare systems (Sarkis et al., 2020). Before the Covid-19 crisis, business leaders were focused on gaining competitive advantage, increasing productivity, reducing costs, sustainability and innovation. The main objective was to improve the quality of functioning businesses (Czifra et al., 2020). In the last years, many works have been published on the implementation of lean and agile methods and concepts in healthcare to improve the performance of hospitals and healthcare systems (Mishra et al., 2018; Matt et al., 2015). However, there is a lack of work on agile approaches to introducing modern and innovative Industry 4.0 concepts. With this paper we want to contribute in closing this gap by proposing an agile Hospital 4.0 roadmap to introduce concepts adapted and derived from Industry 4.0.

The paper is structured as follows: after a short introduction, Section 2 reviews the state of the art regarding Industry 4.0 in healthcare. In the following Section 3, we present materials and methods used as a basis for this work. Section 3 reports of a systematic literature review based framework of Industry 4.0 concepts for healthcare. In Section 4, we propose an agile Hospital 4.0 roadmap as core contribution of this work. The six phases of the roadmap are explained in detail before closing with a discussion in Section 5 as well as conclusions and outlook in Section 6.

2 Related works

Healthcare 4.0 is a collective term for concepts derived from Industry 4.0 like data-driven digital health technologies, such as smart health, mobile health, wireless health, e-health, online health, medical IT, telemedicine, digital medicine, health informatics, pervasive health, and the health information system (Buchelt et al., 2020). In-depth analysis of Healthcare 4.0 implications reveals the fact that the effects of the revolution are progressing in two different ways:

i in both medicine itself

ii in the management of healthcare organisations.

The healthcare sector is more digital than in past decades; for example, spreading from x-rays and magnetic resonance imaging to computed tomography and ultrasound scans to electric medical records (Lapão, 2016). Talking about Healthcare 4.0, many works in research focus on the application of technologies induced by Industry 4.0 in the medical field (Jayaraman et al., 2020; Yang et al., 2020). There are only a few works related to the management of healthcare organisations mostly monitoring their influence of hospitals performance (Tortorella et al., 2020). In Unterhofer (2020) Industry 4.0 concepts have been assessed regarding the suitability or need for adaptation for healthcare organisations identifying a list of hospital 4.0 concepts that build a solid ground for further investigation.

Industry 4.0 concepts can be adopted to other fields than only industry like healthcare systems. Possible fields of application for Industry 4.0 technologies can be (Javaid and Haleem, 2019) customisation of implants, digitalisation of hospital processes, smart implants, increase data accuracy of patients, improvement of communication, surgical planning through virtual reality or improved patient monitoring. Industry 4.0 technologies like blockchain may avoid or mitigate the impact of threats related to data storage and management, in general, and to the administration, in particular, of healthcare records

(Faramondi et al., 2019). In health sector, many areas can be improved dramatically, and supply chain management can also be heavily controlled as the data is accessible at every level of manufacturing, production and delivery process (Alloghani et al., 2018). The adoption of internet of things (IoT) in health can significantly improve health services and contribute to their continuous and systematic innovation in a big data environment. However, the resources required to manage this data in a Cloud-IoT environment are still challenging (Silveira et al., 2019). Digitalisation and IoT empower local healthcare clusters also to service patients in their area of residence more effectively to minimise patient referral to their hub hospital (Choosri et al., 2018). Also simulation, as a typical Industry 4.0 technology is used for enabling lean and agile processes (Mutingi, 2013). The use of computational simulation models allows the detection of bottlenecks in hospital workflows. Those blockages can be removed using an improved shift management based on control theory, AI, and telemedicine. This results in an optimisation in the use of the resources and a reduction of the length of stay improving the service quality (Mutingi et al., 2019).

Industry 4.0 technologies do not affect only hospitals, but also the way of living of an ageing society. Ambient-assisted living technologies actually represent an important research area, due to the demographic development, the increasing cost of healthcare and the growing importance that individuals place on living independently. The general goal is to create intelligence systems able to support people with specific demands to live longer in their preferred environment thanks to intelligent, sensitive and responsive devices (Peruzzini and Germani, 2016).

Beaulieu and Bentahar (2021) developed a roadmap for digitalising the supply chain of healthcare systems to effectively support healthcare delivery. In their work they analysed the state of digitalisation in healthcare supply chains and provide digitalisation measures for managing stocks, medical supplies in operating rooms, improve the internal supply chain and make logistics networks more dynamic. Although this work describes important measures towards Healthcare 4.0 its focus is only on logistics and supply chain. Other aspects like organisation, operational workflows and socio-cultural aspects are ignored.

Based on the review of scientific literature, there is a certain lack on original methods and approaches for introducing comprehensive Hospital 4.0 concepts in practice. Due to this lack, we want to focus on this aspect and provide in Section 4 a roadmap for Hospital 4.0.

3 Materials and methods

In this Section we describe the results of a research to identify Hospital 4.0 concepts following (Unterhofer, 2020). These concepts will be used afterwards in the proposed roadmap as a basis for defining the agile approach for their introduction and long-term oriented implementation. Following a systematic literature review approach, in Unterhofer (2020) Industry 4.0 concepts are identified in scientific literature and have been used by the authors as fundamental catalogue for transferring Industry 4.0 concepts to the healthcare sector. The authors used this reference as, at this time, it was the most complete and comprehensive catalogue of Industry 4.0 concepts identified in literature. From 401 identified scientific works, a totality of 41 Industry 4.0 concepts have been extracted performing a qualitative literature evaluation. The authors looked for other works transferring Industry 4.0 concepts to other sectors and subsequently used the concepts-conversion method presented in Rauch et al. (2016) as it showed a similar case where Industry 4.0 concepts were translated to product development. The method was adapted and applied to transform industrial concepts into elements referable to hospitals. Industry 4.0 concepts are categorised into three distinct classes:

1 general

2 non-adaptable

3 adaptable.

Table 1 shows the result of the applied concepts-conversion method. Finally, 38 Hospital 4.0 concepts are defined and classified into two distinct level dimensions, which allow an intuitive correlation to various thematic fields. Table 1 shows the results and Hospital 4.0 concepts from Unterhofer (2020).

Table 1 Hospital 4.0 concepts

No.	*Hospital 4.0 concept*	*II. Level dimension*	*I. Level dimension*
1	Decision support systems	Monitoring and decision systems	Operation
2	Integrated and digital real-time monitoring systems		
3	Remote monitoring of patient		
4	Big data analytics	Big data	
5	Hospital information system (HIS) integration	Care planning and control	
6	Patient flow management		
7	Digital medical product-service systems	Care models 4.0	Organisation
8	Freemium		
9	Digital point of hospital contact		
10	Open innovation	Innovation strategy	
11	Hospital 4.0 roadmap	Strategy 4.0	
12	Sustainable supply chain design	Supply chain management 4.0	
13	Collaboration network models		
14	Training 4.0	Human resource 4.0	Socio-Culture
15	Role of the health-workforce	Work 4.0	
16	Cultural transformation	Culture 4.0	
17	Cloud computing	Big Data	Technology
18	Digital and connected caring stations	Communication and connectivity	
19	E-Kanban		

Table 1 Hospital 4.0 concepts (continued)

No.	*Hospital 4.0 concept*	*II. Level dimension*	*I. Level dimension*
20	Internet of things and cyber-physical systems		
21	Cyber security	Cyber security	
22	Artificial intelligence	Deep learning, medical machine learning, artificial intelligence	
23	Patient self-alert		
24	Identification and tracking technology	Identification and tracking technology	
25	Additive manufacturing (3D-Printing)	Additive manufacturing	
26	Predictive maintenance	Tele-support	
27	Tele-maintenance (for medical devices)		
28	Tele-assistance (for patients)		
29	Automated storage systems (for medical material)	Robotics and automation	
30	Automated transport systems (for patients)		
31	Automated transport systems (for medical material)		
32	Automated patient care		
33	Collaborative robotics		
34	Smart medical assistance systems		
35	Patient lifecycle management	Patient lifecycle management	
36	Interoperability	Standards 4.0	
37	VR and AR	Virtual reality, augmented reality and simulation	
38	Simulation		

Source: Unterhofer (2020)

Relying on this theoretical framework from Unterhofer (2020), the so-called Hospital 4.0 roadmap is presented in the following Section 4.

4 Hospital 4.0 roadmap

The proposed Hospital 4.0 roadmap relies on the standards determined by the Project Management Institute (PMI) in the reference book "A Guide to the Project Management Body of Knowledge (PMBOK Guide)" (P.M. Institute, 2017). As apparent from Figure 1, the roadmap frame comprises six-phase, which are respectively represented by (0) assessment,

1 initiation
2 planning
3 execution
4 monitoring and control
5 innovation and development.

Figure 1 Structure of the conceived Hospital 4.0 roadmap (see online version for colours)

Each phase is described in detail in the subsequent sections by presenting outcomes and deployed tools.

4.1 Phase 0: Hospital 4.0 assessment

The phase zero focuses on the assessment of the current as well as desired target Hospital 4.0 maturity level. Based on a structured Hospital 4.0 assessment model, the 4.0 readiness of the hospital is determined. For the quantification of the maturity level we propose a 5-stage Likert-scale (1 lowest maturity level and 5 highest maturity level). The following five parameters are measured in this assessment:

1 Hospital 4.0 score
2 Hospital 4.0 target score
3 relevance for the evaluated hospital
4 hospital gap to target and finally
5 weighted gap.

Commencing with the Hospital 4.0 score, the intent is to present the current situation with respect to a Hospital 4.0 concept. To determine which maturity level the hospital manager desires to have in future, the Hospital 4.0 target score is established. Since none of the two presented parameters transmit the importance of the evaluated concepts, the third parameter denominated as relevance is identified through the assessment of the hospital management. Also, in this case we propose a 5 stage Likert-scale (1 low relevance and 5 high relevance). With the objective to prioritise the Hospital 4.0 concepts the following parameters can then be computed.

Equation 1: Hospital deficiency to target.

$$Hospital\ deficiency\ to\ target = Hospital\ 4.0\ target\ score - Hospital\ 4.0\ score \quad (1)$$

Equation 2: Weighted deficiency.

$$Weighted\ deficiency = \frac{Hospital\ deficinecy\ to\ target * relevance\ for\ evaluated\ hospital}{Maximum\ value\ of\ relevance\ for\ evalauted\ hospital} \quad (2)$$

While the first quantifies the gap from the desired target maturity level, the weighted gap offers precious help for healthcare managers as capable of signalising which highly relevant Hospital 4.0 concepts must be tackled with urgency.

To facilitate the understanding and in a second step the execution of the assessment a six-phase model comprising

1 instruction

2 comprehension

3 current maturity level

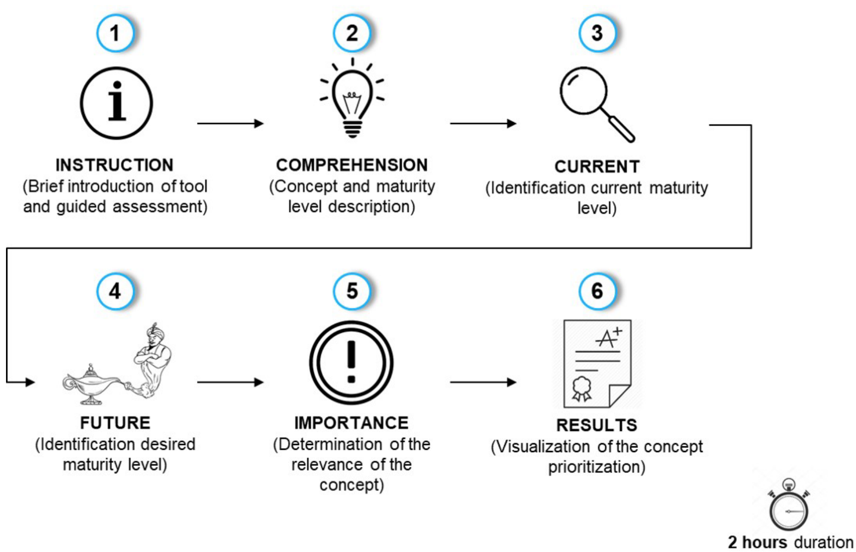
4 future maturity level

5 identification of the importance and finally

6 results, is recommended, as shown in Figure 2 (see also Rauch et al., 2020).

Tests in a local hospital have shown that such an assessment needs at least two hours.

Figure 2 Six-phase model for the guided assessment approach (see online version for colours)



Once the prioritised Hospital 4.0 concepts from Unterhofer (2020) have been assessed, the results in form of the weighted gap for the dimension (process-driven technologies, data-driven technologies, socio-cultural concepts, organisational concepts, operational concepts) can be visualised as illustrated exemplary in Figure 3.

4.2 Phase 1: Hospital 4.0 roadmap initiation

Having accomplished the Hospital 4.0 assessment allows to initiate the proper roadmap. On the one hand the administrative burden is overcome by developing the roadmap charter, and on the other hand the involved staff for the implementation are brought on board through specific trainings, which aim at raising awareness for the upcoming transformation process. The contents of phase 1 as well as the expected outcomes are shown in Figure 4.

Figure 3 Result of the Hospital 4.0 assessment (see online version for colours)

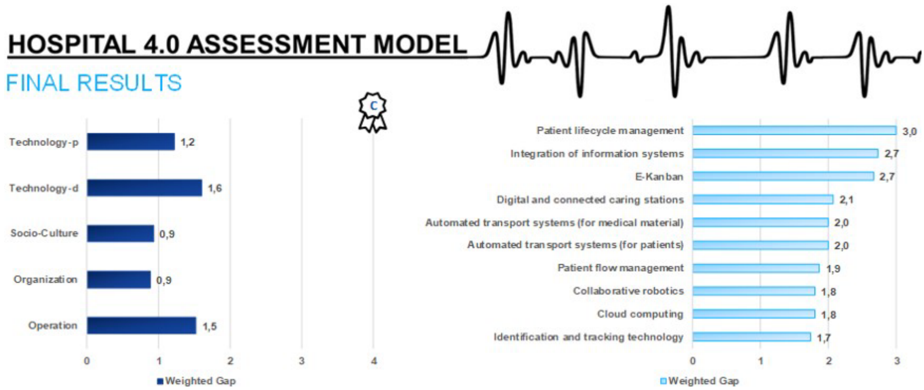


Figure 4 Content and output of phase 1 (see online version for colours)

In parallel to the awareness-raising measure, the roadmap charter that formally authorises the start and existence of the Hospital 4.0 roadmap, is edited. Apart from satisfying the bureaucratic necessities, the charter specifies the Hospital 4.0 project boundaries. Figure 5 shows all the included elements that are represented by

1 name

2 purpose

3 objectives

4 brief description

5 constraints

6 assumptions

7 core team members

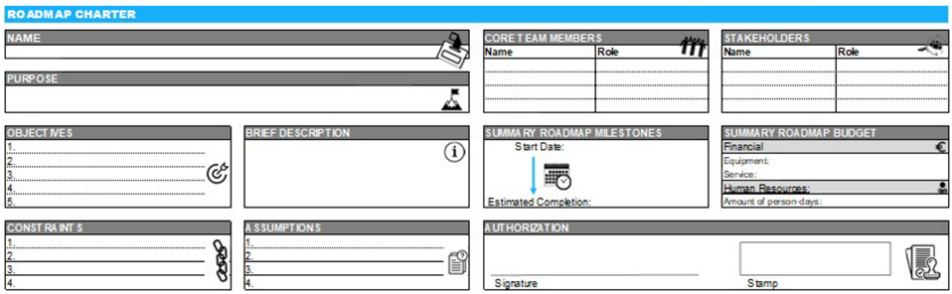
8 stakeholders

9 summary roadmap milestone

10 summary roadmap budget and conclusively

11 authorisation to commence the program.

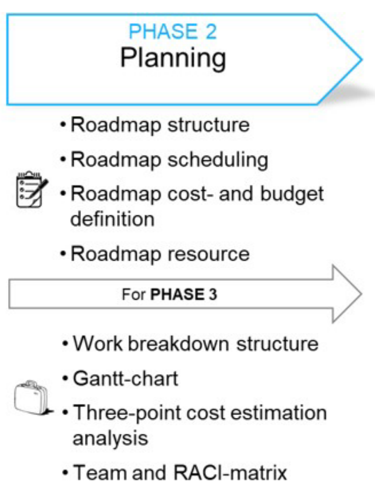
Figure 5 Excerpt sample roadmap charter (see online version for colours)



4.3 *Phase 2: Hospital 4.0 roadmap planning*

The formal actualisation of the program allows to initiate the planning phase, which contributes decisively to the implementation success of the Hospital 4.0 project. Considering the volatile and uncertain environment in which hospitals are operating, the planning process beyond doubts must be designed as "iterative and ongoing activity". Besides functioning as precious guide for the project team, the documentation of the planning phase establishes a common understanding of the stakeholders. Figure 6 shows the content and output of phase 2.

Figure 6 Content and output of phase 2 (see online version for colours)



The roadmap structure is defined by the work breakdown structure (WBS). Each project, whose aim consists in realising the targeted Hospital 4.0 maturity level of a specific concept, comprises three core elements enclosing

1 the analysis of framework conditions

2 the concept design and conclusively

3 the validation as well as pilot project.

Considering time as a critical success factor for the implementation of the roadmap, the scheduling of the Hospital 4.0 projects is executed utilising the Gantt chart model. The established project management tool visualises not only the executed projects and their durations, but also important achievements also denominated as milestones.

Building on the so far developed planning base, the cost structure exploiting the three-point estimating methodology is delineated. As a rule, at the beginning of a project the determination of the exact arising cost is perceived as complicated undertaking so that merely an estimation can be performed. In this light, the rough order of magnitude (ROM), which indicates the preciseness of the evaluation, exhibits an important variance coefficient that can vary from –25% to +75%. Nevertheless, advancements of the Hospital 4.0 project facilitate the information collection of the project team, so that the variance can be lowered to –5% to +10%. To ensure the adoption of an all-encompassing approach, each resource contributing to the success of the implementation of the Hospital 4.0 roadmap is taken into consideration. PMI adduces that five elements, which are respectively represented by

1 labour

2 materials

3 equipment

4 service, and conclusively

5 facilities, must be included in the calculation (P.M. Institute, 2017).

The three-point estimating methodology offers the possibility to consider variegated scenarios, including the most likely costs (cM), the optimistic (cO) and the pessimistic costs (cP). Exploiting the formula of the triangular distribution, the cost estimate is detected.

Equation 3: Cost estimate through triangular distribution.

$$cE = \frac{(cO + cM + cP)}{3} \quad (3)$$

To complete the second roadmap phase, the human resources framework is developed. In respect thereof, three distinct methods, respectively represented by

1 organisational chart

2 the responsibility chart

3 the role description are presented.

The organisational chart delineates the command structure, which preferably should be represented by a small project team characterised by a flat hierarchy. Despite the manageable size, the responsibility assignment matrix (RAM) is required and deployed to specify the assignment of human resources to the Hospital 4.0 project. Exploiting the capabilities of the responsible, accountable, consult, and inform (RACI)-matrix, which is considered to be one of the most efficient RAM by the PMI, clarity with respect to the field of competence related to each project is provided. In conclusion, the roles and responsibilities of each project team member are specified through a fact sheet explicating

1 role

2 authority

3 responsibility

4 competency (Stark, 2020).

4.4 Phase 3: Hospital 4.0 roadmap execution

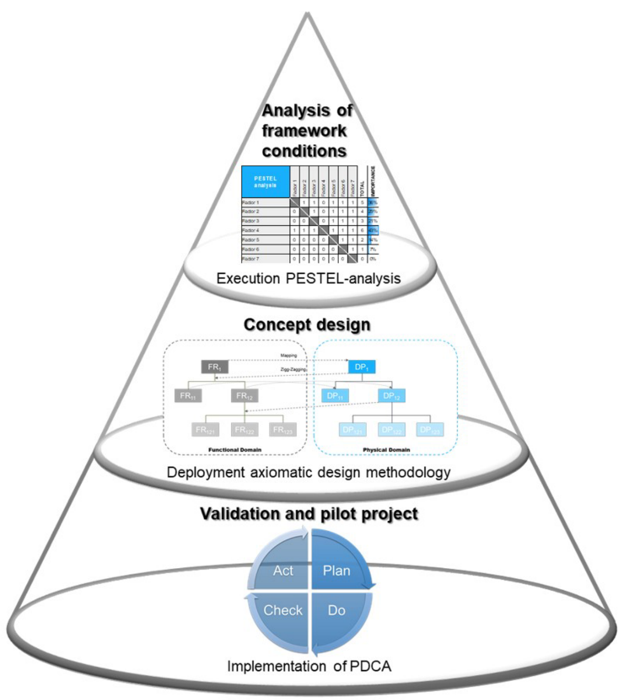
The completion of the planning framework paves the way for the Hospital 4.0 roadmap execution, which rests upon the three-level model developed by Rauch (2013). As shown in Figure 7, three passages, namely

1 the analysis of framework conditions

2 the concept design

3 the validation and pilot project, are performed to ensure the implementation of Hospital 4.0 concepts.

Figure 7 Three-level model (see online version for colours)



Source: Adapted from Rauch (2013)

The first step focuses on the screening of framework conditions, such as environmental and situational issues, through the PESTEL-analysis. As the acronym reveals, six core investigation areas respectively represented by

1 political

2 economic

3 social

4 technological

5 ecological

6 legal, are considered in detail.

Having identified elements capable of exerting negative influence on the project realisation, the method of the pairwise comparison, is employed to determine their relevance. The so-called PESTEL-ranking is established. With the intent to provide a transparent procedure, the pairwise comparison matrix (PCM) is adduced. Exhibiting an *n x n* structure, the PCM permits to ascertain the importance based on a binary evaluation approach, in which 1 signifies *"is more relevant than"* and 0 epitomises *"less important than"*. The deployed PCM must be characterised by the following clauses to hold true.

Equation 4: Pairwise comparison matrix.

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{n1} & 1/a_{n2} & \cdots & 1 \end{bmatrix}, \tag{4}$$

where $a_{ii} =||$ and $a_{ij} = \frac{1}{a_{ji}}$ for $i, j = 1, 2, \ldots\ n$.

By summing up the established values of each row, the score utilised to rule the ranking is deduced.

The second level of the model deals with the concept design. Based on a scientifically acknowledged methodology known as axiomatic design (AD), the systematical transformation of customer attributes (CA) into functional requirements (FR), design parameters (DP) and finally into process variables (PV) is realised by means of so-called mapping processes, as shown in Figure 8 (Arcidiacono et al., 2017).

Over the course of each mapping process the user must keep in mind two fundamental axioms. According to the first or independence axiom, the design ideality is provided if each DP is merely related to a single FR and does not exert influence on another functional element, while the second or information axiom, reminds the designer to choose the solution with the lowest information content.

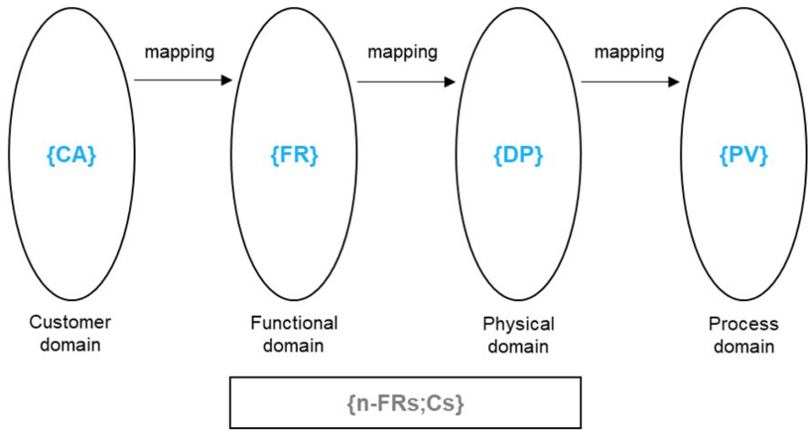
The linking of FR and DP is accomplished by means of the so-called design matrix (DM), which handles the involved axiomatic elements like vectors.

Equation 5: Design matrix.

$$\{FR\} = [DM]\ \{DP\} \tag{5}$$

To comprehend how the user is supported over the course of the mapping process, the composition of each element is explicated as follows (Rauch et al., 2019).

Figure 8 Axiomatic design domains (see online version for colours)



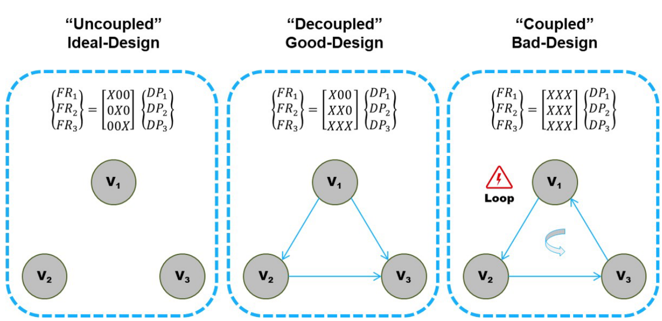
Source: Adapted from Arcidiacono et al. (2017)

Equation 6: Design matrix affiliated to the axiomatic design procedure.

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ \vdots \\ FR_n \end{Bmatrix} = \begin{bmatrix} a_{11}a_{12}\ldots a_{1n} \\ a_{21}a_{22}\ldots a_{2n} \\ \vdots \\ a_{n1}a_{n2}\ldots a_{nn} \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ \vdots \\ DP_n \end{Bmatrix} \tag{6}$$

Observing the DM and in particular its format, whose consistency is conferred by the components (*aij*) capable of assuming the value '*X*', in case an interdependency between a FR and DP subsists, or '0' otherwise, the system complexity as well as quality is derived. In respect thereof the DM can be (1) 'uncoupled', representing a good system design, (2) 'decoupled', signalising an acceptable system design or (3) 'coupled', which shows a bad system design. Figure 9 shows possible DM-results (Arcidiacono et al., 2017).

Figure 9 Typologies of DM and the relation of the single elements (see online version for colours)



Source: Adapted from Rauch et al. (2019)

The lowest level of the three-level model focuses on the validation and concretisation of the designed concept. In this regard a double inspection is performed firstly at the conceptual level and secondly at the practical level through the proper actualisation of the pilot project, which allows to highlight systematic defects without negatively impacting the patient experience. To provide a structured proceeding for the implementation of the improvements, the plan-do-check-act (PDCA) or Deming circle is recommended.

4.5 Phase 4: Hospital 4.0 roadmap monitoring and controlling

Once Phase 3, the Hospital 4.0 execution, is completed, the fourth roadmap phase is initiated, in which the compliance check with predefined cost-, quality- and time-parameters takes place. In fact, three different monitoring methods, respectively represented by

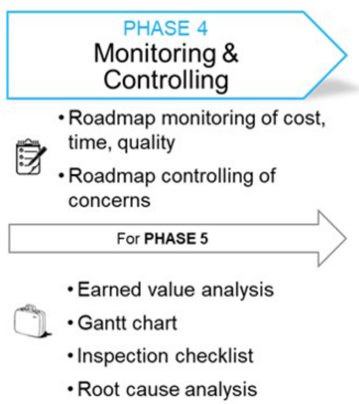
1 earned value (EV) analysis for the cost supervision

2 Gantt chart for the time surveillance

3 inspection checklist, and one controlling tool, namely the root cause analysis (RCA), are put into practice.

Each method headed in Figure 10, is described.

Figure 10 Content and output of phase 4 (see online version for colours)



Considering the complexity in surveilling Hospital 4.0 projects, the EV-analysis is presented as one of the most effective and widely utilised tools for accomplishing the task. Based on three key parameters represented by the

1 determined value (DV)

2 earned value (EV)

3 actual cost (AC), the technique provides clarity related to cost.

With the purpose to extract valuable performance information, the scheduling performance index (SPI), which signalises the planning efficiency, as well as the cost performance index (CPI), which informs about the cost effectiveness, are presented as follows (Zohoori et al., 2019).

Equation 7: Formula of the scheduling performance index.

$$SPI = EV/PV \tag{7}$$

Equation 8: Formula of the cost performance index.

$$CPI = EV/AC \tag{8}$$

Since the presented formulas offer insights related to current project evolutions, further indicators, such as the estimate at completion (EAC), budget at completion (BAC) and the to-complete performance index (TCPI), are explicated due to their forecasting ability. The formulas are presented as follows (Zohoori et al., 2019).

Equation 9: Formula of the estimate at completion.

$$EAC = PV/\mathrm{CPI} \tag{9}$$

Equation 10: Formula of the to-complete performance index.

$$TCPI = \frac{BAC - EV}{BAC - AC} \tag{10}$$

Especially the outcome of the TCPI indicates problems related to the project completion if the result assumes a value greater than one.

Having implemented the cost monitoring, the consideration of time and quality is tackled. In respect thereof, the Gantt chart and the inspection checklist are proposed. Starting with the time monitoring, and therefore the Gantt chart, the alinement of milestones exhibiting the scheduled macro-activity completion dates and the progression bar allow to evaluate the temporal evolution of the project. Pursuing the target to examine the qualitative standards demanded by patients, each functionality of the realised Hospital 4.0 concepts is verified through the so-called inspection checklist, which by means of the terminology 'non ok' indicates the presence of a main issue.

Passing from the monitoring to the controlling activity of the fourth phase, the root cause analysis is described. Known as effective problem-solving methodology, this kind of analysis enables an in-depth scrutiny capable of discovering the proper issue or root cause by applying a four-step approach including

1 the determination and brief description of the concerns

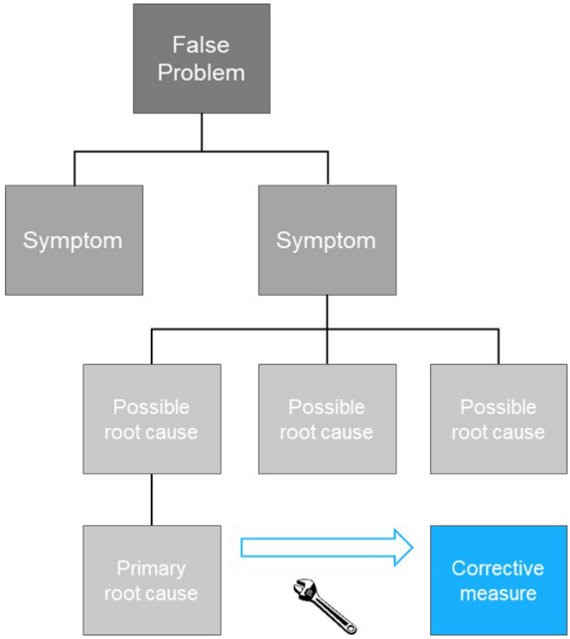
2 the classification of the established issues

3 the hierarchical structuring of the concerns

4 the definition of corrective actions.

The problem determination step is supported by the five whys technique, which allows to detect reasons for the malfunction. Once the list of issues is finalised, the classification is initiated. The first and rougher distinction comprises the establishment whether the issues is interpretable as root cause, more specifically in a secondary or primary root cause, or as causal factor, which can classified into a false problem or a symptom of an issue. As Figure 11 shows, through the hierarchical outline the degree of concreteness grows in correspondence to the bottom level. To complete the executed analysis, concrete and actable countermeasures are determined and step by step put into practice.

Figure 11 Excerpt sample of the root cause analysis (see online version for colours)



4.6 *Phase 5: Hospital 4.0 roadmap innovation and development*

The fifth and final phase, which compared with the previously roadmap stages exhibits a diverse orientation centred on the roadmap continuity, is presented. Following the purpose to trigger the innovative initiative, the fifth phase reconciles the project nature of the roadmap with the keynote of the 4.0 phenomenon. As shown in Figure 12, the innovation and development phase assumes strategic and creative connotations owing to the innovation map on the one hand, and the strategic alliance plan on the other hand, which both promote the 4.0 consolidation within the hospital culture.

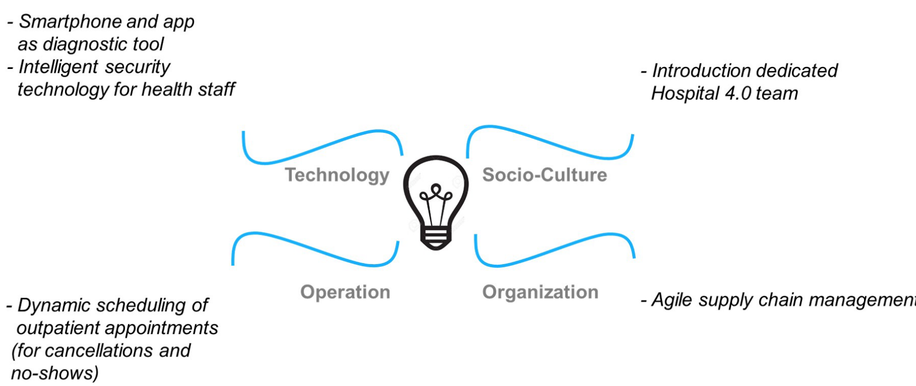
Figure 12 Content and output of phase 5 (see online version for colours)

With the purpose to include novelties in the Hospital 4.0 roadmap implementation, innovation workshops are executed. A straightforward three-phase approach is proposed, in which through a professional moderation the innovative as well as creative spirit of the participants are aroused. Exploiting the capabilities of the brainstorming technique, the free and open environment is established with the intent to promote the idea generation process. Each thought is put on paper by means of pen and cards, and clustered according to the thematic affiliation respectively represented by

1 technology
2 socio-culture
3 operation
4 organisation.

Subsequently, the translation of the cluster into actable concepts is executed, which are concretised through the realisation of an innovation map (Brem, 2019). Figure 13 shows a sample of the innovation map.

Figure 13 Excerpt sample of the innovation map (see online version for colours)



In parallel to the innovation process, the development of strategic alliances is undertaken. A diligent exploration of possible cooperation partners, which can be beyond the borders of the healthcare domain, is performed. The objective is to generate a close-knit network capable of generating added value for the hospital structure.

Conclusively, the core element of the innovation and development phase must be stressed. The continuity of the roadmap must be guaranteed to comply with the 4.0 fundamental idea. In fact, the phase zero of the roadmap implementation procedure, whose substance has been ameliorated through the content of the innovation map and the result of the systematic literature review focused on identifying new Hospital 4.0 concepts, is restarted.

5 Discussion

Our study aims at conceptualising an agile implementation guideline for hospital managers. Based on a systematic literature review, Industry 4.0 concepts are identified and transposed to hospital realities. Hospital 4.0 concepts are than integrated in an assessment model offering the possibility to systematically identify deficiencies in hospitals, which are ought to be eliminated or minimised implementing the Hospital 4.0 roadmap. The structure of the assessment model, which covers the most representative areas of a hospital, facilitates the conduction of a comprehensive analysis.

Compared to the work in Beaulieu and Bentahar (2021) providing a roadmap for healthcare supply chains our approach is more comprehensive and includes all perspectives of a hospital including operational, organisational, socio-cultural and technological aspects. Both works, the work in Beaulieu and Bentahar (2021) and ours use a literature review as a basis. While in Beaulieu and Bentahar (2021) the authors undertake an umbrella review (analysing other reviews) we are basing our results on an own systematic literature review with a comprehensive catalogue of 41 Industry 4.0 concepts. In this literature review we reviewed more than 400 papers. The authors in Beaulieu and Bentahar (2021) identified in their umbrella review three main topics (inventory management, integration of the internal supply chain, and integration of the external supply chain) providing digitalisation measures. Summarising the main difference (in addition to the comprehensiveness) of our approach to the one in Beaulieu and Bentahar (2021) is the systematic and structured roadmap organised in different phases. While in Beaulieu and Bentahar (2021) practitioners do only find measures to implement, our approach provides a timely sequence starting from an assessment, initiation, planning, execution of the measures and monitoring as well as further development. Thus our approach is much more comprehensive and structured.

However, the roadmap approach has also some limitations regarding the subjectivity during the assessment process and the constellation of the assessment team To counteract the risk of a subjective assessment the authors suggest to conduct the assessment only in teams of at least 4–5 team members. When defining the assessment team hospital managers should define a heterogeneous group of doctors, nurses, lab technicians, administration staff and other involved disciplines. Further it makes sense to collect in a first step individual assessments by each group member and then discuss the results by spending more time for discussion in achieving a consensus for those points where individual assessments leaded to different results. An additional limitation of this work is the fact, that the Industry 4.0 concepts used to derive Hospital 4.0 concepts is composed on industry operations and not service operations. Conducting a further literature review about Industry 4.0 concepts in service industry could lead to a few additional Hospital 4.0 concepts.

While most of the tools, we choose, are simple to apply, some of them, such as the axiomatic design methodology utilised to govern the design complexity related to the hospital system, require an elevated degree of expertise, which cannot be presumed from any project management team. Nonetheless, external experts can be consulted in this step to ensure a high-quality outcome. The whole Hospital 4.0 roadmap offers managers the possibility to customise the transformation process of the hospital, which on the other side means that concepts or outcomes of single roadmap phases cannot be simply copied and transferred and might be adapted based on the specific case (e.g., specific medical focus of the hospital).

The presented work has significant academic implications, since the result of the study should inspire researchers to investigate on Industry 4.0 and its transferability to other sectors. The work contributes to the current state of the art in scientific literature providing a theoretical frame to implement Hospital 4.0 concepts step by step providing also the needed methodological support. Other researchers will be encouraged to develop further tools and methods facilitating each step or phase in the roadmap process.

The work has also strong managerial and practical implications as it provides guidelines that hospital managers can use to plan and implement initiatives for the introduction of digitalisation and Hospital 4.0 concepts. A certain focus has been set to keep the methodology and roadmap simple and to consider also an initial phase for awareness building and training preparing the involved staff to run such implementation projects. The roadmap is designed to be ready for adoption in practice and to be used as a tool from the beginning of a Hospital 4.0 project/initiative until the end or better also during the phase of operationalisation. The impact of the proposed roadmap is of high significance if implemented first in a pilot hospital and later than on a regional (or higher) level in order to exploit the potential of the methodology to numerous hospitals learning also from the implementation in a pilot case.

6 Conclusions and outlook

The pressure pushed on healthcare systems forces managers to take profound changes into consideration. The digital revolution also denominated as Industry 4.0 has proven the potentiality to increase productivity and efficiency within manufacturing environments. The paper presents and proposes a Hospital 4.0 roadmap that should serve as guideline for the 4.0 implementation process within hospitals.

Starting with the identification of specific Hospital 4.0 concepts forming the base for the assessment model, the maturity levels of a hospital with respect to specific concepts can be determined. Thanks to such an assessment, a first identification of the most relevant and urgent Hospital 4.0 concepts is facilitated. Finally, based on the roadmap structure composed of

1. initiation
2. planning
3. execution
4. monitoring and control
5. innovation and development, the management of hospitals is guided through the change and transformation process.

Further research consists in enhancing the validity and functionality of the presented approach through its realisation. Applications of the proposed approach in practical and long-term case studies with healthcare systems will undeniably reveal potential improvements capable of facilitating the applicability for healthcare managers but also the effectiveness of the roadmap itself.

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References

Aceto, G., Persico, V. and Pescapé, A. (2020) 'Industry 4.0 and health: internet of things, big data, and cloud computing for healthcare 4.0', *Journal of Industrial Information Integration*, Vol. 18, p.100129.

Alloghani, M., Al-Jumeily, D., Hussain, A., Aljaaf, A.J., Mustafina, J. and Petrov, E. (2018) 'Healthcare services innovations based on the state of the art technology trend industry 4.0', *2018 11th International Conference on Developments in eSystems Engineering (DeSE),* September, IEEE, pp.64–70.

Arcidiacono, G., Matt, D.T. and Rauch, E. (2017) 'Axiomatic design of a framework for the comprehensive optimization of patient flows in hospitals', *Journal of Healthcare Engineering*, Doi: 10.1155/2017/2309265

Beaulieu, M. and Bentahar, O. (2021) 'Digitalization of the healthcare supply chain: a roadmap to generate benefits and effectively support healthcare delivery', *Technological Forecasting and Social Change*, Vol. 167, p.120717.

Brem, A. (2019) 'Creativity on demand: how to plan and execute successful innovation workshops', *IEEE Engineering Management Review*, Vol. 47, No. 1, pp.94–98.

Buchelt, B., Frączkiewicz-Wronka, A. and Dobrowolska, M. (2020) 'The organizational aspect of human resource management as a determinant of the potential of polish hospitals to manage medical professionals in healthcare 4.0', *Sustainability*, Vol. 12, No. 12, p.5118.

Cáceres, C., Rosário, J.M. and Amaya, D. (2019) 'Towards health 4.0: e-hospital proposal based industry 4.0 and artificial intelligence concepts', *Conference on Artificial Intelligence in Medicine in Europe,* June, Springer, Cham, pp.84–89.

Choosri, N., Khwanngern, K., Yu, H., Thongbunjob, K., Sukhahuta, R., Natwichai, J. and Sitthikham, S. (2018) 'ICT enabled collaborative e-health for cleft lip/palate treatment', *International Journal of Agile Systems and Management*, Vol. 11, No. 3, pp.270–292.

Culot, G., Orzes, G. and Sartor, M. (2019) 'Integration and scale in the context of industry 4.0: the evolving shapes of manufacturing value chains', *IEEE Engineering Management Review*, Vol. 47, No. 1, pp.45–51.

Czifra, G. and Molnár, Z. (2020) 'Covid-19 and Industry 4.0', *Research Papers Faculty of Materials Science and Technology Slovak University of Technology*, Vol. 28, No. 46, pp.36–45.

da Silveira, F., Neto, I.R., Machado, F.M., da Silva, M.P. and Amaral, F.G. (2019) 'Analysis of industry 4.0 technologies applied to the health sector: systematic literature review', *Occupational and Environmental Safety and Health*, Springer, Cham, pp.701–709.

Faramondi, L., Oliva, G., Setola, R. and Vollero, L. (2019) 'Iiot in the hospital scenario: hospital 4.0, blockchain and robust data management', *Security and Privacy Trends in the Industrial Internet of Things*, Springer, Cham, pp.271–285.

Javaid, M. and Haleem, A. (2019) 'Industry 4.0 applications in medical field: a brief review', *Current Medicine Research and Practice*, Vol. 9, No. 3, pp.102–109.

Jayaraman, P.P., Forkan, A.R.M., Morshed, A., Haghighi, P.D. and Kang, Y.B. (2020) 'Healthcare 4.0: a review of frontiers in digital health', *Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery*, Vol. 10, No. 2, p.e1350.

Lapão, L.V. (2016) 'The future impact of healthcare services digitalization on health workforce: the increasing role of medical informatics', *Studies in Health Technology and Informatics*, Vol. 228, pp.675–679.

Matt, D.T., Orzes, G., Rauch, E. and Dallasega, P. (2020) 'Urban production–a socially sustainable factory concept to overcome shortcomings of qualified workers in smart SMEs', *Computers and Industrial Engineering*, Vol. 139, p.105384.

Matt, D.T., Rauch, E. and Franzellin, V.M. (2015) 'An axiomatic design-based approach for the patient-value-oriented design of a sustainable lean healthcare system', *International Journal of Procurement Management*, Vol. 8, Nos. 1–2, pp.66–81.

Mishra, V., Samuel, C. and Sharma, S.K. (2018) 'Lean, agile and leagile healthcare management – a case of chronic care', *International Journal of Healthcare Management*, Vol. 12, No. 4, pp.314–321, Doi: 10.1080/20479700.2018.1428520

Mourtzis, D., Vlachou, E., Dimitrakopoulos, G. and Zogopoulos, V. (2018) 'Cyber-physical systems and education 4.0–the teaching factory 4.0 concept', *Procedia Manufacturing*, Vol. 23, pp.129–134.

Mutingi, M. (2013) 'Integrating lean and agile manufacturing paradigms: a dynamic simulation analysis', *International Journal of Agile Systems and Management*, Vol. 6, No. 4, pp.391–402.

P.M. Institute (2017) A Guide to the Project Management Body of Knowledge (PMBOK Guide).

Peruzzini, M. and Germani, M. (2016) 'Design of a service-oriented architecture for AAL. International Journal of Agile Systems and Management, Vol. 9, No. 2, pp.154–178.

Rauch, E. (2013) *Konzept Eines Wandlungsfähigen Und Modularen Produktionssystems Für Franchising-Modelle*, Schriftenreihe zu Arbeitswissenschaft und technologiemanagement. Fraunhofer Verlag, Stuttgart.

Rauch, E., Dallasega, P. and Matt, D.T. (2016) 'The way from lean product development (LPD) to smart product development (SPD)', *Procedia CIRP*, Vol. 50, pp.26–31.

Rauch, E., Spena, P.R. and Matt, D.T. (2019) 'Axiomatic design guidelines for the design of flexible and agile manufacturing and assembly systems for SMEs', *International Journal on Interactive Design and Manufacturing (IJIDeM)*, Vol. 13, No. 1, pp.1–22.

Rauch, E., Unterhofer, M., Rojas, R.A., Gualtieri, L., Woschank, M. and Matt, D.T. (2020) 'A maturity level-based assessment tool to enhance the implementation of industry 4.0 in small and medium-sized enterprises', *Sustainability*, Vol. 12, No. 9, p.3559.

Sarkis, J., Cohen, M.J., Dewick, P. and Schröder, P. (2020) 'A brave new world: lessons from the COVID-19 pandemic for transitioning to sustainable supply and production', *Resources, Conservation, and Recycling*, Vol. 159, p.104894, Doi: 10.1016/j.resconrec.2020.104894

Shamim, S., Cang, S., Yu, H. and Li, Y. (2017) 'Examining the feasibilities of industry 4.0 for the hospitality sector with the lens of management practice', *Energies*, Vol. 10, No. 4, p.499.

Stark, J. (2020) 'PLM and project management', *Product Lifecycle Management*, Springer, Cham, Vol. 1, pp.411–441.

Tortorella, G.L., Fogliatto, F.S., Espôsto, K.F., Mac Cawley Vergara, A., Vassolo, R., Tlapa Mendoza, D. and Narayanamurthy, G. (2020) 'Measuring the effect of healthcare 4.0 implementation on hospitals' performance', *Production Planning and Control*, pp.1–16.

Unterhofer, M. (2020) *Hospital 4.0: The Novel Convergence of the Healthcare and Industrial Sector in the Era of Industry 4.0*, Schriftenreihe zu Arbeitswissenschaft und technologiemanagement, Fraunhofer Verlag, Stuttgart.

Yang, G., Pang, Z., Deen, M.J., Dong, M., Zhang, Y.T., Lovell, N. and Rahmani, A.M. (2020) 'Homecare robotic systems for healthcare 4.0: visions and enabling technologies', *IEEE Journal of Biomedical and Health Informatics*, Vol. 24, No. 9, pp.2535–2549.

Zohoori, B., Verbraeck, A., Bagherpour, M. and Khakdaman, M. (2019) 'Monitoring production time and cost performance by combining earned value analysis and adaptive fuzzy control', *Computers and Industrial Engineering*, Vol. 127, pp.805–821.