Towards Improving Modeling and Simulation of Clinical Pathways: Lessons Learned and Future Insights

Mahmoud Elbattah and Owen Molloy
National University of Ireland Galway, Galway, Ireland

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Abstract: Clinical pathways (CPs) have been increasingly recognised as an instrumental evidence-based artifact that can support clinical decision making and care planning. However, research focusing on modeling and simulation of CPs is still sparse, despite significant individual endeavours. Initially, the paper conducts a systematic literature review with the aim of thoroughly inspecting the state-of-the-art in literature. Through the review, potential improvements are investigated with regard to the application of modeling and simulation within CPs. In view of that, we identify four thematic areas that emphasise how research in this space can be further developed. Specifically, we propose the following directions: i) Development of a conceptual reference model of CPs, ii) Adoption of a multi-perspective modeling approach that can integrate clinical, operational, financial and demographic information of CPs, iii) Development of a generic semantic-based model of CPs, and iv) Adoption of Linked Data concepts.

1 INTRODUCTION

Healthcare services are delivered in complex environments involving interactions among many care providers and stakeholders. In this regard, numerous studies (Lowery et al., 1994; Lowery et al., 1996; Harper et al., 2004; Brailsford et al., 2005, Eldabi et al., 2009) aimed at identifying the particular profile of healthcare problems and the way modeling and simulation studies should approach them. However, compared to non-healthcare sectors, there is still an obvious shortcoming with respect to the gains of simulation modeling for healthcare in general, and for CPs in particular. A CP was defined as a management plan that displays goals for patients and provides the sequence and timing of actions necessary to achieve these goals with optimal efficiency (Pearson et al., 1995).The significance of CPs substantially lies in the potential to standardise the flow of information, processes and patients through well-designed care plans (Every et al., 2000; Renholm et al., 2002; De Bleser et al., 2006).

In this respect, this paper seeks to identify future directions aiming to bridge some of the gaps exposed in the literature. The proposed directions were developed in accordance with an exhaustive systematic review of the literature that addressed modeling and simulation of CPs. In general, we argue that there is an extensive need to embrace different methodological approaches utilising CPs towards: i) Developing new or improved models of patient-centred care schemes, and ii) Building data-driven decision models that can take advantage of the massive amounts of clinical data. In particular, four thematic arguments are discussed calling for expanded attention from future studies towards improving the practice of CPs modeling and simulation.

Further, on the premise that healthcare can avail of potentially applicable approaches or methods from other matured business-oriented sectors, affirmative exemplars from supply chains are invoked in line with some of the proposed directions. We believe that CPs and supply chains share the same problematic characteristics of being highly dynamic, context-sensitive, event-driven, knowledge-intensive, distributed executed, and having multitude of stakeholders.

2 REVIEW METHODOLOGY

The preliminary stage of the study adhered to a systematic literature review using methods informed by (Booth et al., 2011). The review endeavoured to comprehensively include state-of-the-art approaches and methods adopted for modeling and simulation of CPs. To the best knowledge of the authors, existing

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literature lacks a similar systematic review in this context, which was an additional motivation.

2.1 Search Strategy

Initially, we posed the five investigative questions presented in Table 1 in order to focus the review process. However, the review process was significantly challenged by the multiplicity of terms associated with CPs. Acknowledged by many studies (Every et al., 2000; Renholm et al., 2002; De Bleser et al., 2006; Pearson et al., 1995; Vanhaecht et al., 2010), CPs are also termed as "Integrated Care Pathways", "Care Pathways", "Critical Pathways", and "Care Maps". Therefore, all those terms had to be incorporated within the search keywords in order to ensure comprehensiveness. Specifically, the search was conducted using five keywords as follows: i) Clinical pathways modeling, ii) Critical pathways modeling, iii) Care maps modeling, iv) Integrated care pathways modelling, and v) Care pathways modeling. The search process targeted four major digital libraries, which also index the proceedings of vital conferences (e.g. Winter Simulation Conf.), including: i) IEEE Xplore, ii) ACM Digital Library, iii) ScienceDirect – Elsevier, and iv) SpringerLink.

Table 1: Investigative Questions and Motivations.

Question	Motivation
Q1: What are the modeling methodologies used to conceptually model CPs?	Identify state-of-the-art modeling methodologies adopted for CPs.
Q2: Are there formal standards for modeling CPs?	Identify whether there are well-established standards to formally depict CPs models.
Q3: What types of semantic-based models were developed for CPs?	Identify methods used to conceptualise the knowledge within CPs.
Q4: Is there a form of standardised ontology developed for CPs?	Identify whether there are common ontology models used to formalise CPs.
Q5: What are the implications of CPs modeling approaches for building simulation models?	Identify how the conceptual models of CPs contributed to produce simulation studies.

2.2 Stages of Review Process

The review process was accomplished through four stages. Stage (1) included searching digital libraries for potential relevant studies using the afore-mentioned search keywords. Stage (2) excluded irrelevant studies based on titles. Stage (3) excluded irrelevant studies based on abstracts, including studies that directly addressed modeling and simulation of CPs. Stage (4) involved inclusion and critical appraisal of the significant studies. The stages of the review process are sketched in Figure 1, where the number of included papers is identified at each stage.

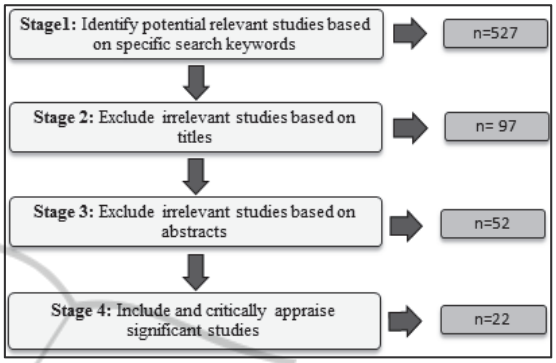

Figure 1: Stages of the review process.

3 PROPOSED DIRECTIONS

3.1 Development of a Conceptual Reference Model

The role of conceptual modeling was constantly recognised to be pivotal in simulation studies. According to (Shannon et al., 1976), simulation modeling is both art and science with conceptual modeling lying more at the artistic end. Furthermore, development of conceptual models is a necessary phase to achieve abstraction and simplification prior to simulation.

Nevertheless, literature obviously lacks a formal modeling structure of CPs, acknowledged by (Yang et al., 2012; Gupta et al., 2013; Yao et al., 2013). Based on reviewed studies (Michalowski et al., 2006; Zhang et al., 2008.; Li et al., 2008; Du et al., 2008; Du et al., 2009; Alexandrou et al., 2009; Zhen et al., 2009; Ye et al., 2009; Ozcan et al., 2011; Abidi et al., 2012; Hashemian et al., 2012; Yao et al., 2013; Combi et al., 2014; Braun et al., 2014), diverse approaches exist in the area of conceptual modeling with respect to CPs. Although those studies contributed to investigate CPs modeling regarding different perspectives, they are best described as case studies, apart from few studies (Michalowski et al., 2006; Zhang et al., 2008). Hence, we argue that literature clearly lacks a standard formalism for the representation of CPs in general.

In addition, there is a pronounced multiplicity of concepts, terms and relationships within developed CPs models, evident by the plethora of adopted modeling methodologies. Specifically, there is no

single modeling methodology or framework that thoroughly covered all of the following issues necessary for modeling CPs:

- Comprehensively consider the various activities of CPs including assessments, treatments, tests, medications, hygiene and education.
- Explicitly provide structured descriptions of pre-operative, operative and post-operative activities through treatment courses.
- Enable to structure interventions with different types of simple, atomic or composite processes or activities.
- Provide performance metrics/indicators that allow analysis of time and resources within CPs.

In this respect, we draw attention to the need to establish a common conceptual modeling methodology through the development of a reference model for CPs. A reference model can yield many benefits including: i) Standardise the abstraction of CPs via progressively building consensus over concepts, terms and process relationships of CPs, ii) Serve as a robust base for developing ontologies or sematic-based models, iii) Enable flexible dissemination of good practice within stakeholders on an institutional level, endorsed as one of the key ingredients for successful adoption of simulation techniques (Terry, 2005), and iv) Facilitate stakeholders involvement as a part of conceptual modelling process, recognised to increase potentials for a successful simulation implementation (Lehaney et al., 1995; Tako et al., 2010).

However, development of a reference model should take into account that healthcare-oriented problems are better approached by forms of resolutions and consensus (Maliapen et al., 2010). In other words, a standard model should strike a reasonable balance between modeling accuracy and consensus. More importantly, a reference model can be useful only if sustainably developed and maintained by an active community, such as the European Pathway Association (EPA) (e-p-a.org) for example.

In this context, we invoke a related exemplar from supply chains. The presented exemplar is the SCOR (Supply Chain Operations Reference) model (Bolstorff, 2007), regarded as one of the most widely accepted and shared reference models for supply chains. The SCOR model also has the advantage of being continuously developed and maintained by the Supply Chain Council (SCC) (apics.org/sites/apics-supply-chain-council).The SCOR model contributed to found a basis for building either abstract or simulation models for supply chains in considerable studies (Hermann et al., 2003; Haung et al., 2005; Persson et al., 2009).

3.2 Multi-perspective Modeling

"*Only by developing a well-rounded picture of the clinical, financial and patient characteristics, it can be possible to proactively address issues for clinical outcomes, reducing costs, and patient satisfaction*", emphasised by (Pol et al., 2000).

In this regard, CPs should be effectively endorsed, whereas they were originally introduced to comprehensively capture clinical and operational practice through care schemes (Pearson et al., 1995; Campbell et al., 1998; Zander, 2002). Furthermore, the pathway-attributable economic gains were delineated in numerous studies (Huber et al., 1998; Pritts et al., 1999; Pitt et al., 1999; Porter et al., 2000; Vanounou et al., 2007). For instance, (Vanounou et al., 2007) observed an overall cost savings of $5,542 per patient using deviation-based cost modeling that compared a pathway group of patients to another non-pathway group. Moreover, another economic impact of CPs was highlighted in promoting and complementing the implementation of Diagnostic Related Groups (DRG's) (Collier 1997; Maliapen 2010). Consequently, CPs can and should be used as a pro-active method to support healthcare decision making.

However, in order to adequately depict operational and clinical features of CPs, a multi-perspective modeling approach should be embraced. Particularly, CPs models should incorporate clinical, operational, financial and demographic information. The multi-perspective modeling of CPs can facilitate integration within Clinical Decision Support System (CDSS). The integration of CPs into CDSS was considered of significant importance (Fieschi et al., 2003; Karsh, 2009; Kawamoto et al., 2005; Wears et al., 2005) for delivering evidence-based recommendations by examining behaviour of patients and identifying service bottlenecks.

We argue that the literature lags behind taking advantage of integrating CPs within CDSS due to lack of a multi-perspective view. Obviously, little research (Cole et al., 1999; Yao et al., 2013) aimed at modeling CPs on that basis. For instance, (Cole et al.1999) developed a framework that considered CPs of chronic obstructive pulmonary disease (COPD) patients in UK. The framework incorporated CPs to model probability of progression to multiple readmissions, as a way to help healthcare providers in the management of care. While another (Yao et al., 2013) proposed a data-driven approach for decision

making to improve customisation of CPs. The methodology applied semantic analysis and reasoning to historical clinical data from the Navy General Hospital in Beijing. Generally, the absence of a multi-perspective modeling approach hampers to conduct a robust analysis of raw healthcare data in order to measure outcomes, cost and effectiveness of care services.

3.3 Generic Semantic-based Modeling

It has become imperative to realise CPs-aware healthcare systems involving the knowledge within CPs as a centric component. In accordance with that, the formalisation of CPs knowledge is inevitable to attain knowledge sharing and interoperability among heterogeneous stakeholders.

Based on literature, numerous studies (Abidi, 2009; Yang et al., 2012; Yao et al., 2013) embraced ontology in order to develop semantic-based models of CPs, as ontology is a formal explicit specification of a shared conceptualization (Studer et al., 1998). For instance, study (Daniyal et al., 2010) presented a framework that formalised CPs using ontologies of medical domain knowledge and workflow model, separately. The medical domain knowledge was captured as RDFS/OWL ontologies, while the workflow model was described as an instantiation of CPWMO, which is an OWL-based ontology for UML activity diagrams. However, the framework lost sight of the temporal relationships and variance-related representations underlying CPs. Another important study (Yao et al., 2013) proposed a novel framework, referred as CONFlexFlow. The framework proposed an integrated ontology model to capture contextual knowledge and clinical guidelines using OWL and SWRL rules. Additionally, adaptable clinical processes were performed using Business Process Execution Language (BPEL).

However, we argue that apart from very few studies, such as (Yao et al., 2013), literature seldom laid emphasis on developing a generic semantic formalization of CPs. On the contrary, the produced semantic models were mainly developed with regard to disease-specific care plans or case studies. Accordingly, the low-level conceptualisation of CPs did not help to reach a semantic model that can capture knowledge within CPs in a generic fashion.

Furthermore, semantic-based models should be able to represent CPs in terms of: i) Common concepts and terms of the medical domain, ii) Structural and temporal relationships within processes/activities, iii) Variance-related representation, and iv) Contextual data that characterise a specific clinical process or activity. Literature endorsed those issues relatively individually, and we could not identify a single framework enabling all of them, to the best knowledge of the authors.

3.4 Adoption of Linked Data Concepts

Healthcare-oriented problems have been always characterised by the dilemma of process multi-ownership and plurality of stakeholders, and CPs are no exception. Generally, management of a patient's health involves dealing with a number of inter-related CPs. Although a single CP can address a specific clinical problem, it can be inter-dependent on progress of other CPs.

Furthermore, the presence of "comorbidity" through treatment schemes is an additional challenge for CPs modeling. The term comorbidity refers to the existence of medical conditions that concurrently co-occur with a primary condition in the same patient (Feinstein et al., 1970). For instance, Chronic Heart Failure (CHF) is a common chronic condition that is often associated with comorbidities such as Atrial Fibrillation (AF), diabetes, chronic lung disease and stroke (Abidi et al., 2012). Undoubtedly, the complexity of CPs models can directly increase due to the necessity of aligning activities/processes of multiple disease-specific CPs, while ensuring clinical suitability and patient safety.

However, the impacts of multiple CPs and comorbidities have been slightly endorsed in literature. Only studies (Abidi, 2009; Abidi et al., 2012) considered the existence of comorbidities within CPs. Specifically, (Abidi, 2009) presented a framework for computerisation and merging of CPs for comorbidities to provide point of care decision support. The framework provided integration of multiple CPs for comorbid diseases to realise a single patient-specific trajectory.

In view of that, we propose the adoption of a Linked Data approach in order to address the challenges of multiple inter-related CPs. Generally, Linked Data refers to a set of best practices for publishing and connecting structured data on the Web (Bizer et al., 2009). However, we see big chances for CPs to avail of Linked Data practices. We argue that knowledge within CPs can be best conceptually conceived as Linked Data models. Particularly, the network-based and context-intensive characteristics of CPs information make it feasible to take advantage of the Linked Data concepts and principles. In Figure 2, we conceive the knowledge stack of CPs models as should be evolving towards Linked Data representa-

tion.

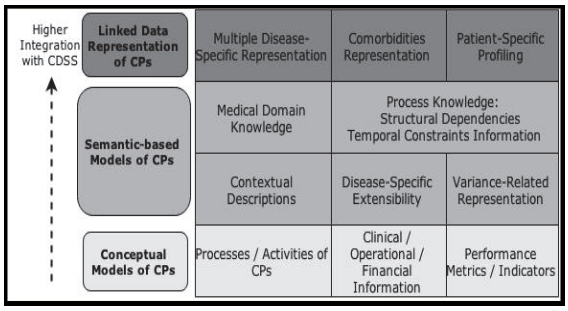

Figure 2: Knowledge stack of CP Models.

We expect the following gains by embracing Linked Data concepts:

- Realising conceptual amalgamation of knowledge within multiple disease-specific CPs towards a full-scale vision of a patient's health.
- Having the inter-related information of CPs in a Linked Data form can compose a significant powerful source of recommendations for clinical decision making.
- Storing CPs information as Linked Data can considerably facilitate diagrammatic representations of CPs.
- Enabling potential usage of CPs knowledge in the Open Data cloud (LOD).

Once more, we invoke an affirmative exemplar from supply chains. A recent Study (Robak et al., 2013) analysed the capabilities of using Linked Data principles in business process management within supply chains to tackle problems of information interchange between independently designed data systems. The study expected that the application of Linked Data can substantially contribute to: i) Data integration between diverse formats from the network participants ii) Support the automated extraction of the information.

4 CONCLUSIONS

The paper aims to convey considerations in relation to improving the modeling and simulation of clinical pathways (CPs). We formulate our view based on observations and findings stemming from a systematic literature review. A clear finding of the review is that there is a need to establish a common research agenda for modeling and simulation of CPs, and for future studies to pay particular attention to fit their research methods to the state of prior work. Through this paper, we draw from literature a summary of future directions as follows:

- Development of a conceptual reference model for CPs.
- Adoption of a multi-perspective modeling approach that can integrate clinical, operational, financial and demographic dimensions of CPs.
- Development of a generic semantic-based modeling that can realise higher semantic abstraction of CPs.
- Adoption of Linked Data concepts and principles.

The paper discusses the above-mentioned directions, and how they can considerably boost the integration of CPs within the Clinical Decision Support System (CDSS) in order to yield improved quality and lower costs of healthcare services.

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