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ProDeM: A Process-Oriented Delphi Method for Systematic Asynchronous and Consensual Surgical Process Modelling

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Abstract

Surgical process models support improving healthcare provision by facilitating communication and reasoning about processes in the medical domain. Modelling surgical processes is challenging as it requires integrating information that might be fragmented, scattered, and not process-oriented. These challenges can be faced by involving healthcare domain experts during process modelling. This paper presents ProDeM: a novel Process-Oriented Delphi Method for the systematic, asynchronous, and consensual modelling of surgical processes. ProDeM is an adaptable and flexible method that acknowledges that: (i) domain experts have busy calendars and might be geographically dispersed, and (ii) various elements of the process model need to be assessed to ensure model quality. The contribution of the paper is

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twofold as it outlines ProDeM, but also demonstrates its operationalisation in the context of a well-known surgical process. Besides showing the method's feasibility in practice, we also present an evaluation of the method by the experts involved in the demonstration.

Keywords: Delphi study, collaborative process modelling, adaptable and flexible process modelling, process model, surgical process, regional anaesthesia

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1. Introduction

Complexity and variability are two distinctive features of processes in the medical domain in general, and surgical processes in particular. Against this background, surgical process modelling offers a means to represent and reason about surgical processes in terms of their tasks and control-flow [1]. As process models clearly visualise how work is organised, they can be valuable to understand, communicate, and analyse surgical processes in order to improve the quality of healthcare provision [2, 3, 4]. In this realm, having a generic surgical process model (i.e. a model that is not specific for available resources, healthcare institutions, or personal preferences) would allow, among others, to assess a local implementation of the process against a benchmark, to analyse process improvement alternatives, and to generate training material for medical education.

Medical literature is a key information source to create a surgical process model. However, solely relying on medical literature is likely to be challenging for two key reasons [3]. Firstly, surgical process modelling will require integrating information that is fragmented and scattered along multiple sources of medical literature, e.g. clinical practice guidelines, checklists, and narrative descriptions. For instance, de la Fuente et al. [5] identified twelve sources describing the *bronchoscopy-guided percutaneous dilatational tracheostomy* process. Secondly, information from medical literature might not be process-oriented [6]. For instance, the list of tasks in the process might not be exhaustive, or the control-flow (expressing the order of tasks) might

only be specified in highly general terms. Considering these two challenges, the opinion of knowledgeable domain experts becomes crucial to complement, integrate and make sense of scattered information about surgical process of interest. However, reaching consensus among domain experts also carries challenges such as dealing with dominant opinions, and congregating experts who might have busy calendars and might be geographically dispersed. In such a scenario, a synchronous collaborative modelling approach might not be a suitable alternative. In this realm, we argue there is a need for a method that systematically supports asynchronous consensus building amongst domain experts for the purpose of surgical process modelling.

Against this background, this paper presents ProDeM, a Process-Oriented Delphi Method that supports the systematic, asynchronous, and consensual modelling of generic surgical processes. The initial stages of ProDeM involve: (i) composing a panel of experts in the surgical process of interest, (ii) collecting information about the process of interest in the medical literature, (iii) creating a literature-based model for the surgical process of interest, (iv) generating a questionnaire for assessing the correctness and completeness of the model based on a template also presented in this paper, and (v) configuring stopping conditions and integration criteria. Afterwards, a set of Delphi rounds are conducted until the desired level of consensus is reached. Each round involves asynchronously collecting expert feedback about the surgical process model using the questionnaire, and analysing the feedback in order to update the process model and the questionnaire. For

each stage, ProDeM adopts good practices and recommendations used in Delphi study research. Unlike other Delphi studies in surgical process modelling that mainly focus on tasks, ProDeM systematically assesses various elements of the model, namely start/end events, tasks, participants, task assignment, and control-flow.

The contribution of the paper is twofold. Firstly, it presents ProDeM, which constitutes a novel adaptable and flexible approach for surgical process modelling. Secondly, the paper demonstrates the proposed method within the context of the *single shot interscalene brachial plexus block* process – the *de facto* surgical process for analgesia and anaesthesia for shoulder surgery [7] – considering a panel of experts along three Delphi rounds. The experts that participated in the demonstration evaluated ProDeM positively in terms of ease of use, efficiency, generality, and operationality.

From a methodological perspective, the design, development end evaluation of ProDeM followed the principles of Design Science Research (DSR) [8]. To operationalise the DSR principles, the six research stages proposed in Peffers et al. [9] were used, i.e. identify problem and motivate, define objectives of the artefact, design and develop the artefact, demonstrate the artefact, evaluate the artefact, and communicate the findings.

The remainder of the paper is organised as follows. Section 2 analyses related work and highlights the research gap that ProDeM addresses. Section 3 presents the five design objectives that the proposed method needs to fulfil to accomplish its purpose. Section 4 describes in detail the stages of

ProDeM and shows how these stages were applied for modelling the *single shot interscalene brachial plexus block* process. Section 5 discusses how the design objectives were addressed in ProDeM, how the method is positioned with respect to other alternatives, as well as its strengths and limitations. Section 6 provides the conclusions of the work.

2. Related Work

Prior research on which this paper builds can be subdivided into four main areas: (i) process modelling in healthcare, (ii) collaborative process modelling, (iii) the Delphi method, and (iv) Delphi studies in surgical process modelling.

2.1. Process Modelling in Healthcare

Graphical models are widely used artefacts for capturing procedural medical knowledge. In this regard, two main categories of graphical models can be distinguished: process modelling languages (e.g., flowcharts [10], EPC [11], IDEF3 [12], UML Activity Diagrams [13], the Business Process Model and Notation (BPMN) [14], Declare [15]), which are used to represent the flow of activities and decisions within careflows, and Computer-Interpretable Guidelines (CIGs) formalisms (e.g., Asbru [16] , GLARE [17], GLIF3 [18], PROforma [19]), which are used to support the generation of patient-specific (clinical guideline-based) advice. While having different foci, process models and CIGs can be complementary. In this vein, Martínez-Salvador and Marcos

[20] proposed using a BPMN process model as a starting point for generating CIGs arguing that such an approach increases the involvement of clinicians in the automation of clinical guidelines. The present work focuses on the process model perspective.

Healthcare processes, in general, unfold to provide medical care for one or more patients with a specific clinical condition [21]. The use of process models in healthcare fosters benefits related to training and communication, compliance, as well as analysis and automation of care provision [22]. The present work focuses on a subset of healthcare processes called surgical processes, which are constrained to a surgical or surgery-related context of a single patient [1]. Surgical process models graphically represent the logical ordering of surgical steps (e.g., device setup, patient positioning, cutting, passing a guidewire, suturing) within the intraoperative part of surgery [1]. It follows that, unlike other healthcare processes such as clinical pathways [23], surgical processes focus on a single patient, involve a reduced number of participants and interdepartmental interactions, have a constrained degree of variability, are documented to a large extent in the medical literature, and have a well-defined scope (i.e., a clear start and end).

We will use BPMN in our proposed method as BPMN is considered to be the *de facto* standard for modelling processes [24]. We also justify our choice of process modelling language based on the evidence provided by recent studies on the benefits of using BPMN in the healthcare sector in aspects such as supporting users' comprehensibility and the inter-professional analysis of

processes [4], assisting process improvement cycles and automation initiatives [25], and aiding activities and decision-making in clinical contexts [26]. These findings are in line with an increasing uptake of BPMN in the healthcare sector, as shown by its use in a number of projects and also in the development of dedicated extensions for representing domain-specific aspects, e.g. [27, 28].

2.2. Collaborative Process Modelling

In process modelling, two relevant roles need to be distinguished: a process analyst (responsible for leading the modelling task), and a domain expert (highly knowledgeable about the process) [6]. Knowledge transfer from the domain expert to the process analyst can take place using techniques such as interviews and workshops [6, 29, 30]. However, as domain experts tend to have limited process modelling knowledge, the feedback they can give on process modelling efforts might be restricted [29, 31]. To this end, literature has proposed approaches to support collaborative process modelling, in which domain experts actively provide input during modelling process in order to create a shared understanding. For instance: Grosskopf et al. [29] introduce the Tangible Business Process Modelling (t.BPM) toolkit, which is a set of physical objects representing the building blocks of a BPMN model. Through the use of the t.BPM toolkit, domain experts make more changes to the model and report to have more insights compared to a setting in which

it has not been used [31]. t.BPM has also shown to be useful in a workshop setting with multiple experts [32]. Similarly, Kannengiesser and Oppl [33] developed a tabletop on which physical objects can be placed to actively involve domain experts.

While the aforementioned instruments are designed for a setting in which domain experts are present at the same physical location, other works focus on a context in which experts are geographically dispersed. For instance: Brown et al. [34] propose a 3D BPMN modelling environment in Second Life and Poppe et al. [35] create an augmented reality approach to support collaborative process modelling when domain experts are not at the same geographical location.

All of the aforementioned approaches require the synchronous presence of a group of domain experts, either at the same physical location or at distinct locations. This is far from trivial when involving a group of international clinical experts to create a model for a surgical process.

An approach to asynchronously involve experts to perform a task is the Delphi method, which is discussed in general in Section 2.3 and in the specific context of healthcare process modelling in Section 2.4.

2.3. Delphi Method

The Delphi method, originally developed by the RAND corporation in the 1950s, has been commonly used in the medical domain to build consensus on a particular topic [36, 37, 38]. To achieve consensus, the opinion

of experts in a panel is collected via questionnaires administered in multiple rounds. After each round, the panel's views are summarised and fed back to the panel during the next round. This enables experts to reconsider their views based on the panel's opinion [37]. Besides the multi-round setting with controlled feedback, anonymity is another key characteristic of a Delphi study, i.e. panel members do not know the identity of the other panel members [37, 38, 39]. Anonymity avoids having dominant voices in the panel, e.g., based on their reputation within the topic area [40]. While universal methodological guidelines to design and conduct a Delphi study have not been established [37], literature provides support by reporting good practices on this matter [37, 38, 39, 40].

While a full review of the Delphi method is beyond the scope of this paper, it is important to note that this method has been used for various purposes in healthcare [37]. For instance: Schwermer et al. [41] use a Delphi study to build consensus around guidelines for the integrative anthroposophic treatment of acute gastroenteritis in children. Another example is Bradford et al. [42], who apply the Delphi method to identify the key elements of an early palliative care consultation in paediatrics. Mubarak et al. [43], in their turn, conduct a Delphi study to build consensus around statements regarding a collaborative medication therapy management model in chronic care in Malaysia.

2.4. Delphi Studies in Healthcare Process Modelling

Delphi studies have been performed within the context of process modelling in healthcare. For instance: Ghijselings et al. [44] seek consensus on statements regarding the treatment of idiopathic overactive bladder syndrome patients. To this end, a two-round Delphi study design is used in which, respectively, 20 and 18 experts participated. The statements on which agreement was reached, i.e. the final output of the Delphi study, constituted important input to develop a flowchart of the treatment process [44].

While Ghijselings et al. [44] do not develop a process model as part of their Delphi study, other studies have the generation of a consensus process model as their goal. Parker et al. [45] use a two-round Delphi study to develop a textual process description of the implementation process of healthcare interventions, together with a list of elements which are relevant in each task [45]. Due to its textual character, a detailed specification of the order of tasks is absent. Other works develop a visual process model using a Delphi study. For instance, Nasrabadi et al. [46] use a two-round Delphi study with respectively 24 and 21 participants as part of a mixed-methods research design in order to create a high-level conceptual flowchart of the home surgical process in Iran. The Delphi study aims to gather feedback on a process model that was developed based on interviews, focus groups and a literature review [46]. Within the context of surgical processes, de la Fuente et al. [47] use a Delphi study to obtain a BPMN process model for the central venous access placement process. In two rounds, the input of 13 experts is collected

with a sole focus on the tasks that should be included in the model [47]. In a subsequent work, de la Fuente et al. [48] develop a consensus BPMN model for the percutaneous dilatational tracheostomy process. This Delphi study consists of two rounds with 25 participants in the first round and 22 in the second round. Even though the predominant focus is still on the tasks that need to be included, a generic question is included to assess whether the sequence of tasks needs to be changed [48].

While the aforementioned works clearly have merits for the medical conditions on which they focus, this paper extends this stream of literature by proposing a novel method for modelling any surgical processes, namely ProDeM. Our proposed method clearly distinguishes itself by systematically validating and reaching consensus about all elements of a process model – such as the tasks, control-flow and process participants – instead of only focusing on tasks.

3. Design Objectives

Based on the problem identification and the literature review, the following design objectives are put forward for a method that supports the creation of consensus surgical process models.

DO1. Combine medical literature with domain expertise. The method should build upon both medical literature on a surgical process and domain expertise. For many surgical processes, several sources of evidence-based documentation are available (e.g. clinical practice guidelines and

checklists). Literature has limitations as information is often scattered and, e.g., the control-flow is usually only defined in general terms. Hence, the method should capture domain expertise to model the aspects of a surgical process which are not specified in literature or about which there might be conflicting views.

DO2. Consensus building method. The method should result in a consensual process model of the surgical process. Consensus is important in group decision making [49] when there is insufficient information or an overload of (often contradictory) information [36]. Additionally, consensus is key for the success of any process modelling effort [50], and thus also holds within the context of modelling surgical processes. Consensus building methods conform to the following features [36, 51], which should all be supported:

- **Anonymity.** The method should foster the mutual anonymity among the participants [38, 39, 40]. This feature has several advantages compared to face-to-face settings, including the reduction of the effect of dominant participants, and the opportunity to change opinion without feeling socially pressured [40, 51].

- **Iteration.** The method should support an iterative way of working. This feature allows the participants to modify their initial positions or ideas [36, 51].

- **Controlled feedback.** The method should provide controlled feedback in each iteration. This feedback might trigger domain experts to

modify their views after further reflection [51].

DO3. Asynchronous method. The method should be able to operate in an asynchronous way, i.e. the joint presence of all domain experts at the same point in time is not required. This feature enables the flexibility required when broadly consulting domain experts from different geographical regions and/or timezones. Moreover, it provides experts with the opportunity to provide input at a moment that is convenient for them.

DO4. Fulfil method quality criteria. The method should perform well with respect to quality criteria. Sonnenberg and Vom Brocke [52] propose the following criteria for evaluating methods that have been generated using DSR: ease of use, efficiency, generality, and operationality. *Ease of use* refers to the extent to which using the method is free of effort [53]. *Efficiency* refers to the effort required to use the method [54]. *Generality* refers to the extent to which the method can be applied to a diversity of scenarios, i.e., to diverse surgical processes. *Operationality* refers to the extent to which the method can be used to accomplish its goal, i.e. modelling a surgical process. Altogether, these method quality criteria are useful to evaluate whether the method addresses the research problem adequately.

DO5. Fulfil process model quality criteria. The method should ensure the syntactic, semantic, and pragmatic quality of the resulting surgical process model. The SEmiotic QUALity framework (SEQUAL) [55, 56] defines these quality criteria as follows: *syntactic quality* refers to how well the model corresponds to the process modelling language, i.e. the correct

use of symbols and the rules to combine them in a process model; *semantic quality* refers to how well the model corresponds to the domain, i.e. the model's validity and completeness, and *pragmatic quality* reflects how well the model corresponds to its audience interpretation, i.e. the model comprehensibility [55, 56]. The method should take into account the SEQUAL quality criteria in its design.

4. ProDeM: Method and Demonstration

This section presents ProDeM, a Process-Oriented Delphi method for systematic asynchronous and consensual surgical process modelling. The participants needed for applying the method are, on one hand, a modelling team composed of process analysts and domain experts and, on the other hand, an expert panel composed by a larger group of domain experts having in-depth expertise in the surgical process under consideration.

ProDeM consists of six stages, of which an overview is shown in Figure 1, i.e., panel composition, material collection, initial model proposal, initial questionnaire, configuration, and Delphi rounds. The remainder of this section is organised into seven subsections. The first six subsections each refer to a particular stage of ProDeM: a general overview of the stage is provided, after which a more detailed description is given, followed by the demonstration of the stage. The last subsection presents an evaluation of ProDeM with the expert panel participating in the demonstration.

The case we used to demonstrate ProDeM is the creation of a generic

process model for the *single shot interscalene brachial plexus block* process with a panel of 10-14 experts along three rounds. An *interscalene brachial plexus block* is the *de facto* surgical process for analgesia and anaesthesia for shoulder surgery [7] and consists of blocking the neural conduction of the brachial plexus at the neck level by distributing a sufficient volume of local anaesthetics within the interscalene space (i.e., the space between anterior and medial scalene muscles), which contains the C5 to C7 nerve roots [57].

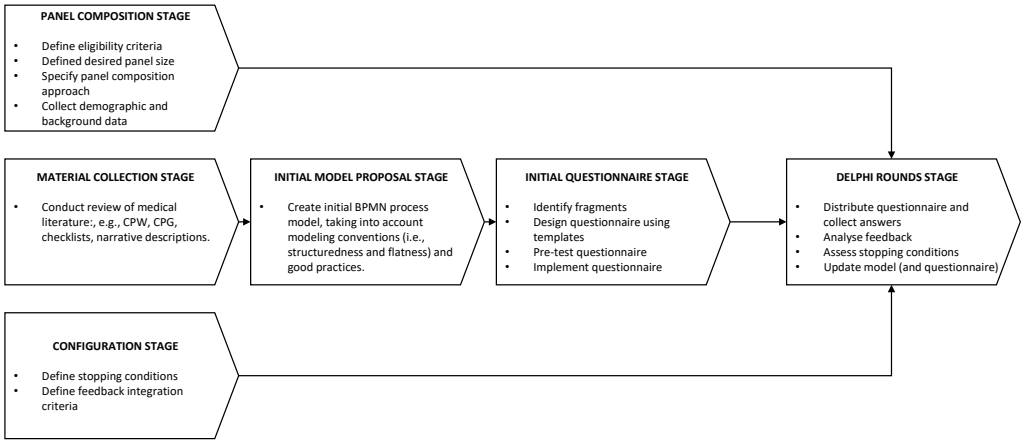

Figure 1: Overview of ProDeM

4.1. Panel Composition Stage

4.1.1. Overview

The goal of this stage is to compose a panel of experts that will provide feedback about a process model of the surgical process of interest. The stage consists of defining eligibility criteria for panel members, the desired panel size, a reproducible approach for panel composition, and the collection of

demographic and background information about panel members. The stage needs to be performed by the domain experts within the modelling team to define adequate eligibility criteria.

4.1.2. Description

The expert panel constitutes the group of domain experts that will partake in the method to provide their clinical feedback about the process model. Panel members should have profound knowledge [37, 38] and a high level of clinical experience [58] in the surgical process under consideration. Accordingly, explicit eligibility criteria need to be defined to ensure adequate domain expertise and experience [40]. The expected panel size needs to be established in a range between 10 and 18 participants [38]. To reach the desired size, it is important to take into consideration expected dropout-rates when sending panel invitations [45]. Once eligibility criteria and panel size have been defined, the panel composition approach needs to be specified, i.e. specify how potential members will be identified, contacted, and invited. This approach should take into account contextual aspects, e.g. some experts might have the autonomy to decide to participate themselves while others might need consent from a hierarchical superior [37]. As a reference, Okoli and Pawlowski [38] describe a rigorous procedure for panel composition. The composition of the panel in terms of demographics and background also needs to be discussed when reporting on the method and, hence, these data need to be collected [40].

4.1.3. Demonstration

For identifying potential panel members, two strategies were used: (i) a snowball approach to invite experts (where the seed was one of this paper's authors), and (ii) a literature search for authors of papers in the field.

Initially, 49 candidates were invited via email, expecting a panel size between 10 and 18, following Okoli and Pawlowski [38]. These candidates were allowed to nominate other experts, resulting in one additional candidate, who was also invited. A total of 24 experts responded to the initial call, of which 16 accepted to participate and 8 declined. In the end, 14 experts participated in the first round, 13 in the second round, and 10 in the final round.

In order to be eligible for the panel, experts need to be a *medical doctor* fulfilling *at least one criterion in each of the following two categories*:

- *Category 1 - Clinical practice, which demonstrates the presence of clinical and technical expertise in the surgical process to be modelled*: (i) The candidate has worked 5 years or longer in regional anaesthesia or pain service over the last 10 years; (ii) The candidate has held the position of chief in a regional anaesthesia or pain service over the last 5 years; (iii) The candidate has executed (or directly supervised the execution of) the process, on average, at least 20 times per month over the last 6 months.

- *Category 2 - Beyond clinical practice, which demonstrates the pres-*

ence of academic expertise and a critical approach to the surgical process to be modelled: (i) The candidate has (co-)authored one or more accepted peer-reviewed scientific research paper(s) about the process within the last 5 years; (ii) The candidate has worked 6 months or longer as an instructor for regional anaesthesia or pain over the last 5 years; (iii) The candidate has participated in an anaesthesia or pain congress as a speaker or workshop instructor on topics associated with the process over the last 5 years; (iv) The candidate has participated in the generation of clinical guidelines or other consensus building team efforts on regional anaesthesia or pain over the last 5 years.

Table 1: Characterisation of the expert panel in the first round

	Number of participants
Country of origin	4: Chile, 2: Canada, 1: Argentina, 1: Colombia, 1: Greece, 1: Spain, 1: Switzerland, 1: Turkey, 1: Uruguay, 1: USA
Gender	10: male, 4: female
Age in years	4: 35-44 years old, 7: 45-54 years old, 3: 55-64 years old
Speciality	14: anaesthesiology (1: subspeciality in pain treatment)
Type of hospital they work in	8: university hospital, 3: private hospital, 3: both university and private hospital
Academic degree	14: MD, 4: PhD, 1: MSc
Years working in regional anaesthesia/pain service	11: 10 years, 1: 9 years, 1: 8 years, 1: 5 years
Have held the position of chief of regional anaesthesia or pain service	8
Number of process executions per month	average: 28, minimum: 6, maximum: 100
Have co-authored an accepted paper on the process over the last 5 years	7: yes, 7: no
Experience as instructor	14: yes, 0: no
Participation in related congresses	14: yes, 0: no
Participation in clinical guidelines/consensus building	12: yes, 2: no

Demographic and background data about the panel members were gathered in the first round questionnaire, and summarised in Table 1.

4.2. Material Collection Stage

4.2.1. Overview

The goal of this stage is to collect source materials that describe the surgical process of interest. The stage consists of conducting a review of medical literature to identify sources that describe the surgical process of interest in terms of its tasks, participants, and control-flow. The stage needs to be performed by the modelling team, led by its domain experts to properly assess the relevance and trustworthiness of the selected sources for describing the process.

4.2.2. Description

The method seeks to identify different source materials that specify the surgical process of interest within the following types of literature:

- *Clinical Practice Guidelines (CPGs)*, which consist of evidence-based recommendations for optimised patient care [59]. For various examples of CPGs we refer the reader to the University of Michigan Health [60] website.

- *Clinical Pathways (CPWs)*, which support the translation of CPG into local protocols and clinical practices that specify local structure, systems, and time-frames [23].

- *Checklists*, which list equipment, tasks, or behaviours that are relevant for a particular surgical process [61], and are often used during medical education [62].

- *Narrative descriptions* from peer-reviewed outlets offering clinicians information to support the delivery of effective care to their patients, such as medical education resources or point-of-care evidence-based resources, e.g., UpToDate® [63] and StatPearls [64].

These sources can provide valuable information regarding tasks within the process, as well as the combinations of such tasks into a given control-flow (e.g. sequence, choices, concurrency) [65]. However, this information might not be suitable to immediately generate a process model due to a number of issues, including its incomplete, fragmented and conflicting character. Moreover, the information might be provided at different levels of abstraction as, e.g., only high-level control-flow considerations might be reported, which is insufficient to develop a process model.

4.2.3. Demonstration

After reviewing the literature, the following three *narrative descriptions* (see Section 4.2.2) of the *single shot interscalene brachial plexus block* process were selected:

- UpToDate® [63], the most widely used website on point-of-care evidence-based medicine (POC-EBM) in the USA [66], which has been shown to impact clinical outcomes positively [67].This description is composed of 15 activities, two decision points, and considers the use of neurolocalisation with ultrasonography and/or peripheral nerve stimulation.

- StatPearls [64], which is an open access, web-based POC-EBM resource in PubMed that supports the search and retrieval of literature from the National Library of Medicine's (MEDLINE) database [68].This description is composed of 12 activities, four decision points, and considers the use of neurolocalisation with ultrasonography and/or peripheral nerve stimulation.

- New York School Of Regional Anesthesia (NYSORA) [69], one of the best regional anaesthesia online sources, that provides a wide variety of high-quality educational resources [70, 71, 72]. This description is composed of 20 activities, five decision points, and considers the use of neurolocalisation with ultrasonography and/or peripheral nerve stimulation.

4.3. Initial Model Proposal Stage

4.3.1. Overview

The goal of this stage is to generate the initial proposal of a BPMN process model of the surgical process of interest. This stage consists of an evidence-based process modelling method, in which the information from the previously selected source materials needs to be integrated into an initial process model while, at the same time, ensuring the correct use of the modelling language. This stage needs to be executed by the process modelling team, who needs to ensure both the syntactic and semantic quality of the process model. For the latter, domain experts within the modelling team have a key

role.

4.3.2. Description

The initial model proposal constitutes the first version of the process model of the surgical process of interest, which will be modified in a later stage according to the feedback provided by the expert panel. The model is generated based on the source materials from the material collection stage. Such sources may vary in level of detail (e.g. a CPW is more context-dependent than a CPG) and focus (e.g. a checklist is task-centric, while a CPG has a broader scope). It is also likely that the retrieved information is not readily organised in a process-oriented way [6].

BPMN has, altogether, a few dozen of constructs. However, research shows that only a limited number of these constructs are regularly used in practice [73]. Taking this into consideration, the method supports the most commonly used subset of BPMN elements (i.e. start/end event, task, participant, exclusive/parallel gateway, sequence flow) plus other two elements that are relevant to depict decision logic in surgical processes (i.e. text annotation and inclusive gateway). In this way, the method will also support widely used control-flow patterns [74] (i.e. skip, choice, parallel, loop, and sequence).

BPMN process model that results from this stage has to adhere to two conventions. Firstly, the model should be *fully flat*, i.e. it includes no sub-processes. By using a flat model, the method avoids dealing with the com-

plexities of asking for domain expert feedback at multiple levels of abstraction. Additionally, the comprehension of flattened process models has been found to be significantly better than models containing sub-processes [75]. Secondly, the model should be *as structured as possible*. In a fully structured model, every split gateway has a corresponding join gateway such that the sub-graph between both gateways forms a single-entry-single-exit (SESE) region[1] [6]. The structuredness feature eases the definition of process fragments for the systematic assessment of the control-flow perspective of the model, as will be discussed in a later stage.

Besides the aforementioned conventions, it is desirable that the initial process model considers guidelines that ease its comprehension by the members of the expert panel. For instance, it is recommended to minimise the number of arcs that cross each other [78], to use a *verb + noun* style for task labels (e.g. Check oxygen saturation level) [79], among others. For a more extensive overview of process modelling guidelines, the reader is referred to works such as Avila et al. [80] and Figl [81].

4.3.3. Demonstration

Considering the three descriptions of the *single shot interscalene brachial plexus block* process selected in the material collection stage, the initial process model was generated using the process modelling tool *Signavio*. This

[1]The SESE decomposition has been used as a strategy to define sub-processes within process models [76], and also in algorithms for computing control-flow verification analysis [77].

process model contains 34 activities and 7 process fragments and, for the sake of space, it is shown in Figure A.4 in the Appendix.

4.4. Initial Questionnaire Stage

4.4.1. Overview

The goal of this stage is to generate an initial questionnaire to gather feedback about the process model of the surgical process of interest. The stage consists of designing, implementing, and pretesting a questionnaire with the structure shown in Table 2, which includes the question types specified in Table 3 to assess the different elements of the process model. This stage needs to be performed by the modelling team, who needs to generate the questions and implementing the questionnaire in the platform of choice.

4.4.2. Description

The questionnaire is a central element of the method as it allows to systematically gather the views of the expert panel and also to provide controlled feedback to them. After a first version of the initial questionnaire is implemented, it is advisable to conduct a pre-testing [37, 38, 40] with respondents that are not part of the actual Delphi panel [40]. This enables fine-tuning the questionnaire and ensuring the clarity of all formulations. Afterwards, the initial questionnaire is used in the first round of the study. Moreover, it constitutes the baseline for the questionnaires used in the remaining rounds.

In the following, the structure and the content of the questionnaire is discussed and templates are provided, which can be adapted to the surgical

process of interest.

Structure of the Questionnaire. The high-level structure of the questionnaire is summarised in Table 2 and described in the following.

Table 2: High-level structure of the initial questionnaire

Id	Part	Content
1	Welcome	Welcome message and request to indicate agreement with the content of the informed consent document.
2	Introduction	Description of the round's goal, the research team, and overview of the main sections and key aspects of the questionnaire.
3	Full process model	Description of the surgical process as a process model, indicating the inputs used to generate the model, the modelling goal, and the used modelling notation.
4	Tasks	Request for feedback regarding candidate tasks to be included in the process model.
5	Process participants	Request for feedback regarding process participants to be included in the process model, and the tasks assigned to each of them.
6	Start of the process	Request for feedback regarding the start of the process.
7	Ordering of tasks	Request for feedback regarding the ordering of tasks based on a number of fragments in which the model is decomposed.
8	End of the process	Request for feedback regarding the end of the process.
9	Final questions	Request for feedback regarding constraints, contradictions, redundancies, or any other aspect.
10	Farewell	Thank you message.

Part 1 of the questionnaire (*Welcome*) is used to ensure that panel members are adequately informed about what will be asked from them, the estimated answering time investment, as well as how the provided input will be used [37]. Also, as pointed out by Boulkedid et al. [82], the use of an explicit informed consent checkbox is recommended such that each panel member can formally agree to participate in the study. Part 2 (*Introduction*) introduces the modelling objective, round's goal, research team and the forthcoming sections of the questionnaire. Part 3 (*Full process model*) shows and describes the complete process model to which the remainder of the questionnaire will refer.

Parts 4 to 8 (*Tasks*, *Process participants*, *Start of the process*, *Ordering of tasks*, *End of the process*) constitute the core of the questionnaire and focus on elicitating feedback on the different elements of the process model in a guided, stepwise, way. This structure is consistent with Baloian et al. [83], where it is mentioned that process elicitation consists of two stages: (i) the identification of individual process activities and (ii) the identification of the control-flow.

In Part 9 (*Final questions*), some final questions regarding constraints, contradictions and redundancies in the model are presented. Moreover, there is a final open question providing the opportunity to give feedback on any element of the process model. The questionnaire ends with Part 10 (*Farewell*) which thanks the panel member for the input.

Content of the Questionnaire. To define the specific questions used in the questionnaire, the process model quality dimensions of the 3QM framework [84] are used as a starting point. As a consequence, for each set of elements in the model (i.e. tasks, participants, start event, task ordering, and end event) the following dimensions are to be assessed (when applicable): completeness, correctness, flexibility, redundancy, relevance, unambiguity, and understandability. The question types to address each dimension for a given model element are shown in Table 3. Questions with the form *'Indicate the extent to which you agree with the following statement: [...]'* are 5-point Likert scale closed-ended questions, ranging from *1: strongly disagree* to *5: strongly agree*. The remaining questions are either yes/no questions or

open-ended questions. For tasks, participants, and start/end events, the question templates in Table 3 can be directly used. However, before formulating questions to assess task ordering, it is necessary to define a set of process fragments around which questions will be centred. The use of process fragments to assess control-flow implies that not every connection between all tasks are covered by questions. This design decision aims to balance the completeness of the questionnaire (i.e. explicitly asking input on each component of the model) and the workload on experts (in terms of number of questions). In the present work, each (non-trivial) single-entry-single-exit (SESE) region of the process model is defined as a fragment (see Section 4.3) .

As shown in Table 3, task ordering involves the following control-flow patterns [74]: skip/enforce, choice, parallel, loop, and sequence. To gather feedback on a process fragment in the questionnaire, the fragment is first visualised along with a representation of its position in the full process model. For such a visualisation, it has been found that an *overview+detail* strategy (i.e. the full process and the process fragment are shown alongside but as separate models) is preferred by process model readers [85]. Additionally, the part of the full process model that does not correspond to the process fragment under consideration can be represented in a lighter shade. The use of colour visual cues, such as this one, has been found to lower mental effort and time taken for process model comprehension tasks [86]. Besides the visualisation representation of the fragment, a textual description of the

fragment can also be provided [87]. Since there is no conclusive evidence on whether textual descriptions are superior to diagrams (or vice-versa) in terms of process understanding among users with different levels of process modelling expertise (e.g., [88, 89]), dual coding is recommended for facilitating a consistent interpretation of the model [90]. Note that open-ended questions are included at the end of each part of the questionnaire to provide panel members with the opportunity to formulate feedback on elements which are not explicitly covered by the questions.

Table 3: Question types

Element	Dim.	Question type
Task	R	Indicate the extent to which you agree with the following statement: `<task>` should be part of the process model.
	Cr	Feedback regarding the correctness of the task name, the textual annotation (if present), or any other aspect of the task.
	Cm	Are you missing any other tasks? If yes, please provide the following information about each missing task: the task name, a short description, its position within the model, and the person responsible for its execution.
	Und	Do you think that any tasks should be subdivided into two or more tasks? If yes, please provide the following information for each task that you would like to subdivide: the task name of the task that should be subdivided, the task names in which it should be subdivided, a short description of these tasks, their position within the model, and the person responsible for their execution.
	-	Do you have any further feedback regarding the tasks included in the process model?
Participant	R	Indicate the extent to which you agree with the following statement: `<participant>` should be part of the process model.
	Cr	Feedback regarding the correctness of the name of the process participant, if applicable.
	Cm	Are you missing any other process participants? If yes, please provide the following information for each process participant that you are missing: the name of the process participant, and a short description of the role of the proposed process participant in the process, e.g. which tasks (s)he performs.
	Cr	Is the assignment of `<task>` to `<participant>` correct? If not, reassign it. [Note: it is possible to indicate here whether the task should be deleted altogether.]
	-	Do you have any further feedback regarding the process participants included in the process model or the assignment of tasks to process participants?
Start event	R	Indicate the extent to which you agree with the following statement: `<event>` starts the process.

Continued on next page

Table 3 – continued from previous page

Element	Dim.	Question type
	Cm	Are you missing any other start event(s)? If yes, please describe the start event(s) that you are missing.
	-	Do you have any further feedback regarding the start event included in the process model?
End event	R	Indicate the extent to which you agree with the following statement: `<event>` marks the end of the process.
	Cm	Are you missing any other end event(s)? If yes, please describe the event(s) that you are missing.
	-	Do you have any further feedback regarding the end event included in the process model?
Task order - skip/ enforce	R	Indicate the extent to which you agree with the following statement: the process model should allow skipping `<task>` at this position / the process model should enforce `<task>` at this position if the condition is met.
	Cr	Do you have feedback regarding the correctness of the task that can be skipped/ enforced?
	Cr	Indicate the extent to which you agree with the following statement: The question to decide whether to skip / enforce `<task>` (i.e. `<gateway label>`) is correct.
Task order - choice	R	Indicate the extent to which you agree with the following statement: The process model should allow alternative paths at this position (in this context, this means that only one of the arrows is followed).
	Cr	Do you have feedback regarding the correctness of the tasks among which a choice needs to be made?
	Cr	Indicate the extent to which you agree with the following statement: The question to decide which task to perform (i.e. `<gateway label>`) is correct.
Task order - parallel	R	The process model should allow parallel paths at this position (meaning that all of the arrows are followed).
	Cr	Do you have feedback regarding the correctness of the tasks that can be performed in parallel?
Task order - loop	R	Indicate the extent to which you agree with the following statement: The process model should allow the repetition of the tasks in gray in the figure above (i.e. looping behaviour) at this position.
	Cr	Do you have feedback regarding the correctness of the tasks that can be repeated?
	Cr	Do you have feedback regarding the correctness of the ordering of task(s) that can be repeated?
	Cr	Indicate the extent to which you agree with the following statement: The question to decide whether to initiate the repetition of tasks (i.e. `<gateway label>`) is correct
Task order - sequence	R	Indicate the extent to which you agree with the following statement: these tasks should be included in the process model in a sequential way (meaning one task is performed only after its predecessor is completed).
	Cr	Do you have feedback regarding the order of the task sequence?
Full model	F	Are you missing any constraints (i.e. a condition that must always be true for some portion of the model) in the model?
	Una, Rd	Do you observe any contradictions or redundancies in the model?

Cm: completeness, Cr: correctness, F: flexibility, Rd: redundancy, R: relevance, Una: unambiguity, Und: understandability

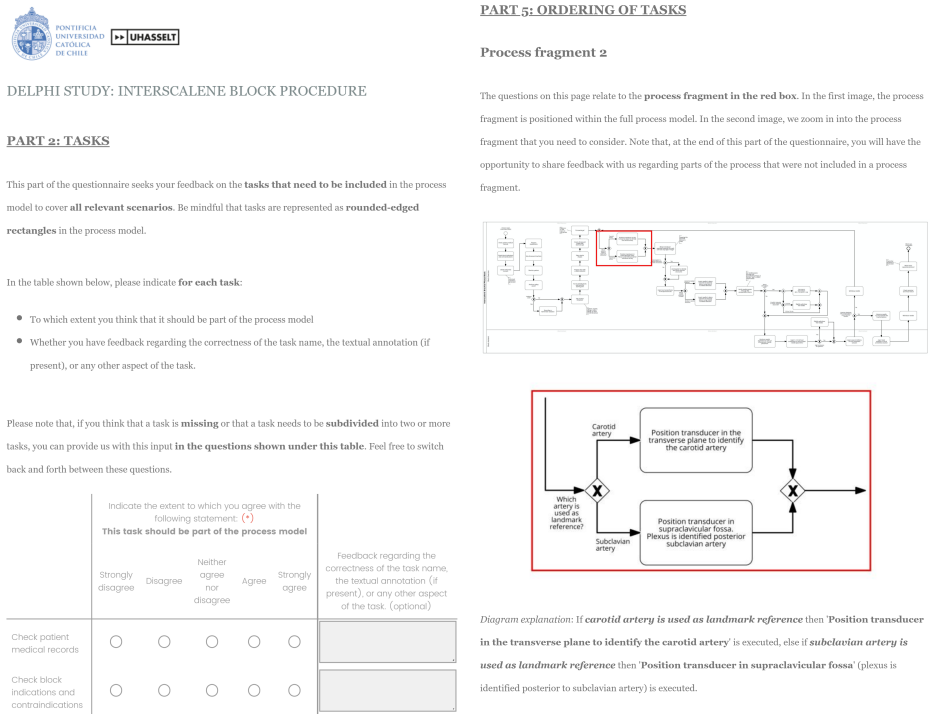

Figure 2: Screenshots from the initial round questionnaire.

4.4.3. Demonstration

We composed the initial questionnaire according to Section 4.4.2 and implemented it using the survey platform *Qualtrics*. The questionnaire has been piloted with four domain experts outside the modelling team that were also not invited to join the expert panel. Figure 2 shows screenshots of the implemented questionnaire.

Note that the initial questionnaire sets the baseline for the creation of the questionnaires for the other rounds.

4.5. Configuration Stage

4.5.1. Overview

The goal of this stage is to configure stopping conditions and feedback integration criteria. While the former determines when to stop conducting additional Delphi rounds, the latter specifies criteria for keeping, modifying, and dropping elements from the process model.

The stage needs to be performed by the process modelling team.

4.5.2. Description

It is important to define *stopping conditions* for the study, i.e. conditions that, when true, halt the initiation of further rounds. Stopping the study too soon risks obtaining non-valuable results, while stopping it too late may lead to fatigue effect among the panel members [37, 91]. Stopping conditions typically relate to reaching either a fixed number of rounds or a particular level of consensus among responses [39]. Consensus, however, can be operationalised in a number of ways [39, 51, 82], e.g. as a target level of agreement of the panel or the stability of responses between rounds [37].

Feedback integration criteria define how to incorporate the responses of the panel into the upcoming rounds, i.e. how to modify the process model based on the responses to the questionnaire. The criterion for the first round is to maximise inclusion of suggestions from the expert panel within the process's defined scope. This intends enlarging the amount of valid/admissible process variations, such that all the panel members can evaluate different

practices followed by other members in the following rounds. For the second and successive rounds, criteria for feedback integration is defined by the modelling team in such a way that the criteria are consistent with the modelling objectives.

4.5.3. Demonstration

The following two stopping conditions (SC) were defined, i.e. no new Delphi round is started when one of the following conditions is satisfied:

- *SC1.* Three rounds had already been conducted.
- *SC2.* No changes were made to the process model after a round or, at most, only minor changes (i.e. rewording of labels or textual annotations) were made.

The following feedback integration criteria were defined:

- *Criterion in first round.* None of the process model elements will be dropped and the inclusion of suggestions of the panel (i.e. new tasks/participants/flows within the scope of the process, as well as proposed rewordings of tasks or participants to improve readability of the model by its audience) will be maximised.
- *Criteria in second and subsequent rounds.* Some elements will be dropped while others will be (conditionally) kept based on the level of agreement among experts to include it, i.e. the proportion of experts that 'strongly agree' or 'agree' with including it. Suggestions of the panel to

add new elements and reword some existing ones are taken into consideration. For elements that were in the process model at the beginning of a round, there are three possible alternatives:

- *Keep.* An element of the model is *kept* when it is maintained in the updated version of the process model. The criterion to keep an element is the following: the level of agreement of the panel about including the element in the model in the present round (i.e. the proportion of experts that 'strongly agree' or 'agree' with including it) is equal or greater than 75%.
- *Conditionally keep.* An element of the model is *conditionally kept* when it is maintained in at least one version of the updated process model.

  An element is conditionally kept when one of the following two conditions hold: (i) it is the first time that the element has been included in the model, and the level of agreement about including it in the current round is between 50% and 75%, or (ii) the level of agreement about including the element in the current round is below 50%, but the element is part of a process fragment for which a high level of consensus has been reached.
- *Drop.* An element of the model is *dropped* when it is no longer part of the updated version of the process model.

  An element is dropped when one of the following conditions holds:

(i) the element was already present in the model in a prior round, and the level of agreement about including it in the current round is lower than 75%, or (ii) it is the first time that the element has been included in the model, and the level of agreement about including it in the current round is lower than 50%.

4.6. Delphi Rounds Stage

4.6.1. Overview

The goal of this stage is to run Delphi rounds for gathering feedback from the panel based on a questionnaire.

The collected data are then used to assess the achieved level of consensus and to check the stopping conditions of the study. If a stopping condition has been met, the study halts. If none of the stopping conditions have been satisfied, a new round is performed.

In this stage participate the domain experts that conform the panel and the process modelling team. The former provide feedback via answering the questionnaire; and the latter analyses the feedback and integrates it into a new version of the process model, as well as updates the questionnaire and distribute it for a new round. Domain experts within the modelling team support making sense of the feedback provided by the expert panel and they settle which alternative to include in the process model whenever panel experts put forward conflicting opinions.

4.6.2. Description

A round starts by distributing the questionnaire among the panel members to collect their feedback about the process model. After a data collection period, data are analysed: responses for closed-ended questions are analysed in terms of the distribution of answers for each alternative, while responses for open-ended questions are analysed manually. Results from the analysis are used to generate an updated version of the process model, taking into account the feedback integration criteria. If one of the stopping conditions is met, no further rounds are conducted and the final process model is shared with the panel. Else, the questionnaire is updated according to the updated model. In a new round, some questions might be dropped and others might be kept, based on the feedback integration criteria discussed earlier. For those that are kept, a summary of the results of the previous round is provided to ensure that panel members can consider this information when providing feedback on the updated process model. Additionally, all feedback captured in open-ended questions of the prior round is shared with panel experts in the questionnaire as a drop-down anonymised list of bullet points placed before the related question.In this way, panel experts can also reflect upon the open-ended input provided by others when filling out the questionnaire.

4.6.3. Demonstration

A total of three Delphi rounds were conducted. Each round began by distributing the questionnaire among panel members via email. Once the

data collection period was over (1-2 weeks during which 1-2 reminders were sent), responses were analysed. Responses for closed-ended questions were analysed in terms of the distribution of answers for each alternative, while responses for open-ended questions were analysed manually. For the latter, annotated intermediate process models were generated, in which the feedback provided by the panel members via open-ended questions during a round was included as coloured textual annotations. For an example, see Figure A.5 in the Appendix. This type of annotated models was used to facilitate the visualisation and analysis of data gathered from open-ended questions in each round. The data analysis outcomes, together with feedback integration criteria, were used to generate a new version of the process model. In this new process model, some elements are (conditionally) kept and others dropped, modified, or added. To prepare the next round, the questionnaire was updated according to the updated version of the model. In order to reduce the effort and cognitive load for the panel members, the need to include an element in the model was only retested (i.e. explicitly asked again to the panel) for some elements. In this way, we avoided repeating questions on which consensus was already reached, resulting in the following trade-off to determine which elements to retest:

- *Retested.* The inclusion of an element in the process model was retested for all elements that were conditionally kept and those with major modifications in their labels. For these elements, a summary of the results of the previous round was shown.

- *Not retested.* In other cases (i.e. elements that should be kept or dropped), the updated questionnaire ceased to ask whether the element should be included in the model. Panel members still had the option to provide feedback on these elements in the open-ended questions at the end of each section.

When any of the stopping condition was met (in our case, *SC1* after the third round), the study was concluded by providing the resulting model to the panel. Figure 3 shows the final process model.

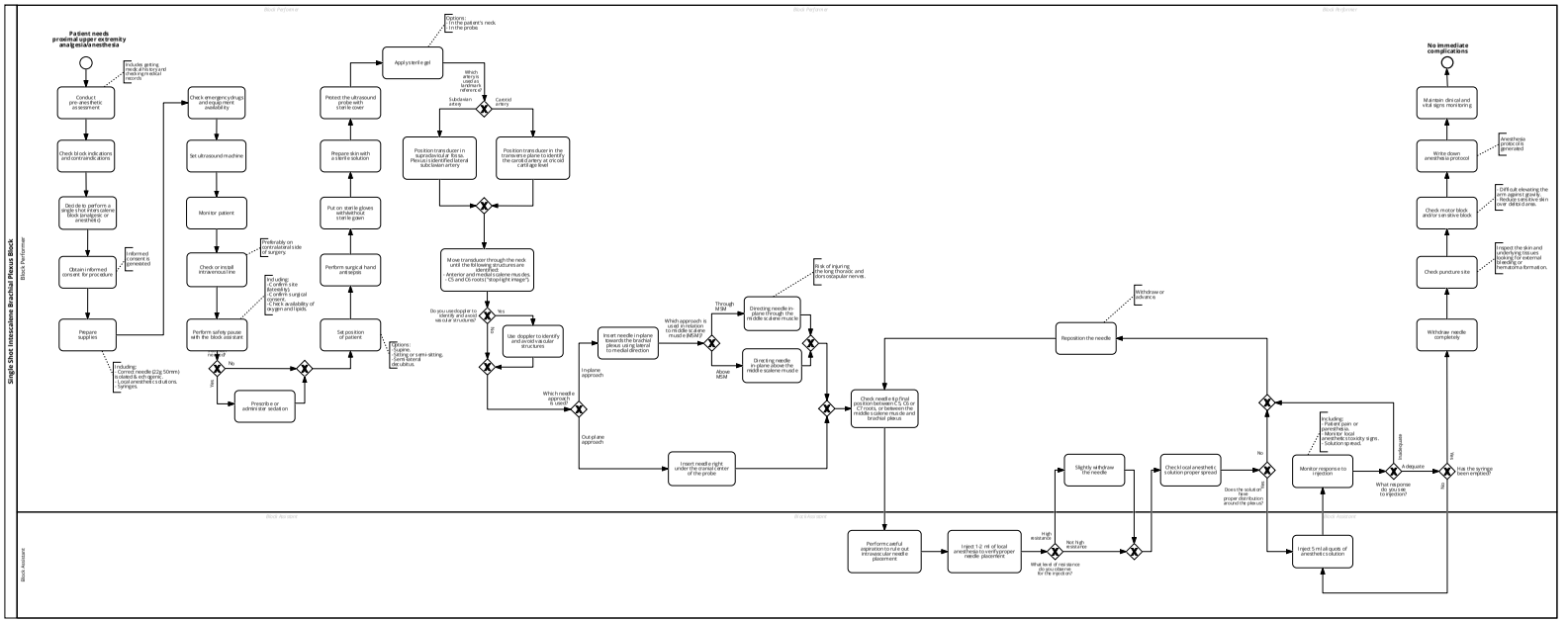

Figure 3: Final process model

Table 4: Summary of the process model presented in each round.

	1st round	**2nd round**	**3rd round**	**final model**
N° of tasks present in the process model	34	48	38	38
N° of process fragments in the process model	7	9	7	7
N° of dropped tasks (in comparison with the previous round)	-	1	10	0
N° of new tasks (in comparison with the previous round)	-	15	0	0
N° of reworded tasks (in comparison with the previous round)	-	15	10	0
N° of dropped process fragments (in comparison with the previous round)	-	0	2	0
N° of new process fragments (in comparison with the previous round)	-	2	0	0
N° of reworded process fragments (in comparison with the previous round)	-	2	1	0

Table 5: Agreement with start event, end event and process participants (% of answers to the question 'To what extent do you agree with ... of the process model').

	1st round					2nd round					3rd round				
	5	4	3	2	1	5	4	3	2	1	5	4	3	2	1
Start event	57.1	21.4	7.1	14.3	0.0	61.5	23.1	7.7	7.7	0.0	-	-	-	-	-
End event	21.4	57.1	0.0	21.4	0.0	7.7	76.9	0.0	15.4	0.0	-	-	-	-	-
Participant 'Block performer'	100.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	-	-	-	-	-
Participant 'Block assistant'	75.0	12.5	12.5	0.0	0.0	61.5	15.4	23.1	0.0	0.0	-	-	-	-	-

5: strongly agree, 4: agree, 3: neither agree nor disagree, 2: disagree, 1: strongly disagree, -: not asked.

To show how the process model evolved over the rounds, Table 4 shows how the process model changed after each round in terms of added, dropped and reworded tasks and process fragments. Table 5 contains the details per round regarding the agreement of panel members about the start event, end event, and the process participants of the process model (i.e. 'Block

performer' and 'Block assistant'). Details regarding the agreement of panel members about control-flow aspects in the process model along the rounds is shown, for the sake of space, in Table A.7 in the Appendix.

4.7. Evaluation

After the three Delphi rounds, the panel members involved in the demonstration were invited to evaluate the artefact (i.e., ProDeM). To this end, the applicable quality criteria suggested by Sonnenberg and Vom Brocke [52] – i.e. ease of use, efficiency, generality, and operationality – have been used as defined in Section 3.

Table 6: Evaluation of the entire study (%).

Dim.	Statement	5	4	3	2	1
EoU	The questionnaires provided in each of the three rounds were easy to answer.	20	70	10	0	0
EoU	The study as a whole (questionnaires, invitations, reminders, among others) was easy to follow.	30	70	0	0	0
Ef	The time and mental effort needed for answering the questionnaires provided in each of the three rounds was reasonable.	20	80	0	0	0
Ef	Participating in the study as a whole required reasonable mental effort and time.	20	80	0	0	0
G	The questionnaires provided in each of the three rounds can be adapted to achieve a consensus about the process model of other surgical processes.	10	90	0	0	0
G	The study as a whole can be adapted to reach consensus about the process model of other surgical processes.	10	90	0	0	0
O	The questionnaires provided in each of the three rounds contributed to achieving a consensus model for the process.	20	80	0	0	0
O	The study was useful for reaching consensus about a process model for the process.	50	50	0	0	0

EoU: ease of use, Ef: efficiency, G: generality, O: operationationality.
5: strongly agree, 4: agree, 3: neither agree nor disagree, 2: disagree, 1: strongly disagree.

Table 6 shows the results of the evaluation, based on the responses of the ten experts who completed the final round. Data were collected by including eight questions of the form *'Indicate the extent to which you agree with the*

following statement: [...]'. The questions were 5-point Likert scale closed-ended questions with possible answers ranging from *1: strongly disagree* to *5: strongly agree*. As shown in Table 6, the level of agreement with all statements is high; no disagreements were present with any statement. Experts were also invited to share other comments in an open-ended question. One participant mentioned that the communication between the research team and the participants was excellent. Another participant indicated that it became easier to understand the process model after the first round and that mental load lowered down across the rounds.

5. Discussion

The method presented in this paper, ProDeM, was designed to support the collaborative and asynchronous generation of high-quality generic surgical process models. ProDeM addresses the challenge of creating a consensus surgical process model with a panel of domain experts, starting from source materials that might be incomplete, fragmented, conflicting, and also might be specified at different levels of abstraction.

5.1. Assessment of Design Objectives

Following a Design Science Research approach, ProDeM was designed to fulfil a set of design objectives (DO). First, the proposed method combines medical literature with domain expertise (DO1) by using various sources of medical literature to build an initial process model, which is the basis for the

expert panel to provide feedback in an iterative manner. Second, ProDeM is a consensus building method (DO2) using the Delphi study principles and, hence, supports iteration, anonymity, and controlled feedback. Moreover, ProDeM fulfils the methodological quality criteria by Diamond et al. [39]: it defines explicit stopping criteria, a planned number of maximum rounds, reproducible criteria to select panel members, and criteria for dropping items at each round. Third, the proposed method is asynchronous (DO3) as experts from different geographical locations and/or timezones can provide their feedback at their own pace. Fourth, we gathered evidence in favour of ProDeM fulfilling a set of method quality criteria (DO4), in particular ease of use, efficiency, generality, and operationality. This evidence has been collected via an evaluation survey about the perceptions of the panel of experts involved in the demonstration with respect to the named variables. Finally, ProDeM was designed to fulfil process model quality criteria (DO5). Syntactic quality and pragmatic quality were ensured through the use of guidelines from the literature, as well by gathering a process modelling team with the needed competences. The semantic quality of the model, on the other hand, was ensured by the composition of an adequate panel of domain experts, selected based on explicit criteria.

5.2. Findings of the Demonstration

The demonstration of ProDeM showed the feasibility of the method. A total of three rounds with a panel of 10-14 experts from diverse geographical

locations resulted in a BPMN process model for the *single shot interscalene brachial plexus block* process. In this demonstration, the modelling team used three descriptions of the process available in the medical literature to generate the initial process model. This initial process model was significantly modified through the Delphi rounds: 14 tasks were added, 10 tasks were modified, 1 process fragment was added, 1 process fragment was considerably modified, and 1 process fragment was dropped. These changes illustrate the ability of ProDeM to incorporate the knowledge held by the experts into process modelling. An evaluation of ProDeM was conducted at the end of the last round of the study, which provided preliminary evidence that the method is easy to use, efficient, general, and operational. However, further research is needed to confirm this. It might also be interesting to include an evaluation of the perceived usefulness of the models developed with the method in such an assessment.

Besides showing ProDeM's feasibility, three further key observations follow from the demonstration. First, the variability that is captured in the resulting process model relates to some aspects of the implementation of the method. For instance, the feedback integration criteria in regard to dropping items as defined during the configuration stage, and the interplay of questions about tasks and questions about fragments including those tasks, play a role in how many variants of the execution of the process are captured in the final process model. We also conjecture that personal factors of the panel members might also play a role in this regard, e.g. they might favour

variants they use more frequently or with which they feel more comfortable. Second, the response rate of the panel decreased along the different rounds, which might be attributed to expert fatigue [37]. Finally, having domain experts in the modelling team was found crucial: it allowed adequate panel composition and material collection, as well as making sense the feedback provided by the expert panel and it contributing to the pragmatic quality of the generated models.

5.3. Limitations

ProDeM's contributions need to be reflected against some potential limitations. First, the structuredness and flatness conventions for the process models in the method allow the direct application of ProDeM as presented in this paper. If these do not hold, the method can still be used after modifications. Second, the proposed method is based on BPMN as a process modelling language. Moreover, only the most frequent set of BPMN elements is considered in our proposal, which leaves aside other constructs that might be relevant for more complex surgical processes, e.g., timer events, message events. This means that the questionnaire might need to be extended to new modelling constructs, leading to a stream for future research related to ProDeM. Also, the selection of BPMN as a process modelling language does not imply that the general idea presented in this paper is exclusively applicable for BPMN surgical process models. However, it demonstrates that BPMN is an adequate formalism for the purposes of modelling surgical processes. We

expect that the generality of ProDeM supports adapting it for using a formalism other than BPMN (see Section 2). Such an extension, however, requires development and testing. Finally, when ProDeM is to be applied within the context of other healthcare processes, further aspects of the method would need to be adapted. For instance, there might be limited material available in medical literature regarding the process of interest, which might be tackled by including a focus group (or similar) in the Material Collection Stage. It might also be the case that in other healthcare processes, participants hold more diverse profiles and responsibilities in the execution of the process (e.g. clinical vs. administrative staff). In such a case, the Panel Composition Stage needs to consider more than one profile, and the Configuration Stage might need to include additional criteria for reaching consensus among perspectives of these experts with distinct profiles. Nevertheless, we expect that the basic principles of ProDeM would be helpful to reach consensus in such settings as well, or even outside the healthcare domain. However, further research is needed to confirm this.

5.4. Strengths and Applications

ProDeM has various strengths, of which the key strengths are summarised here. First, it addresses one of the main drawbacks of collaborative modelling strategies, namely, the prevalence of dominant opinions among domain experts involved in the modelling. In ProDeM, the use of blind interactions between members of the expert panel allows that the viewpoints of all mem-

bers are taken into account independent from who emitted it. Second, the process models generated using ProDeM are likely to be generic in the sense they may hold – to a large extent – independent from specific scenarios, resources, types of healthcare institution, or preferences of a specific operator. The reasons for this include the use of multiple sources in the *material collection stage*, the diversity of experts recruited in the *panel composition stage*, and the consensus building approach defined in the *Delphi rounds stage*. These development conditions and a method that allows a progressive refinement of the model, generate the conditions for creating models that can be considered generic. Third, ProDeM might facilitate the adoption of BPMN models in the healthcare domain by guiding clinical workers into the use of this standard based on an approach that is highly familiar to them, i.e. the Delphi method. Despite the recognised advantages of having BPMN surgical process models [4, 22, 92], the adoption of BPMN in the healthcare sector has been rather low [3] and representations such as flowcharts are still the most frequently used [93]. One of the most critical barriers to BPMN adoption is the pragmatic quality of BPMN process models, i.e. they are difficult to understand by healthcare workers. ProDeM addresses this issue by involving healthcare experts at diverse stages of process modelling, while focusing only on a subset of BPMN modelling constructs.

A generic process model developed using ProDeM can be a valuable input for different institutions, which can adapt the model to their clinical contexts, physical and human resources, or other local conditions. Such a model can

be used for different purposes, e.g., serve as a substrate for (partial) process automation, be a comparison and analysis tool for continuous improvement programs, and support medical education and training. The latter is an interesting application that would unify the procedural perspectives of different participants of the healthcare team, enhancing situational awareness and decreasing the chances of medical error and adverse events [92].

6. Conclusions

This paper introduced ProDeM, a novel Process-Oriented Delphi Method that supports the systematic, asynchronous, and consensual modelling of generic surgical processes. Consensus allows for establishing best practices in the medical community in the presence of incomplete, fragmented, or even conflicting information [94]. Through successive questionnaires interspersed with feedback, consensus is built amongst a panel of experts regarding a process model for a surgical process. The asynchronous character of ProDeM is highly suitable for the healthcare context as it enables geographically dispersed experts with busy calendars to share their views on each of the model's elements. In such a setting, synchronous collaborative process modelling approaches are less suitable. The proposed method also extends existing literature that uses Delphi principles for healthcare process modelling by systematically validating and reaching consensus regarding all elements of a process model, instead of only focusing on tasks. Besides introducing the method, the paper also demonstrates ProDeM within the context of the *sin-*

gle shot interscalene brachial plexus block process, highlighting the method's feasibility in a practical setting. Moreover, an evaluation of the method with the expert panel participating in the demonstration has confirmed its ease of use, efficiency, generality and operationality.

Several relevant directions for future research can be distinguished. Firstly, ProDeM can be applied to other surgical processes to investigate the extent to which the questionnaires need to be customised. Secondly, the extendability of ProDeM to other types of healthcare process modelling, such as clinical pathways, can be investigated. Finally, a benchmarking study can be set up to compare ProDeM's performance with synchronous collaborative process modelling approaches. Key outcomes that should be considered in such a benchmark include the quality of the final process model, as well as the sentiment amongst experts regarding their ability to share their views during the modelling trajectory.

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Appendix A. Supplementary Material

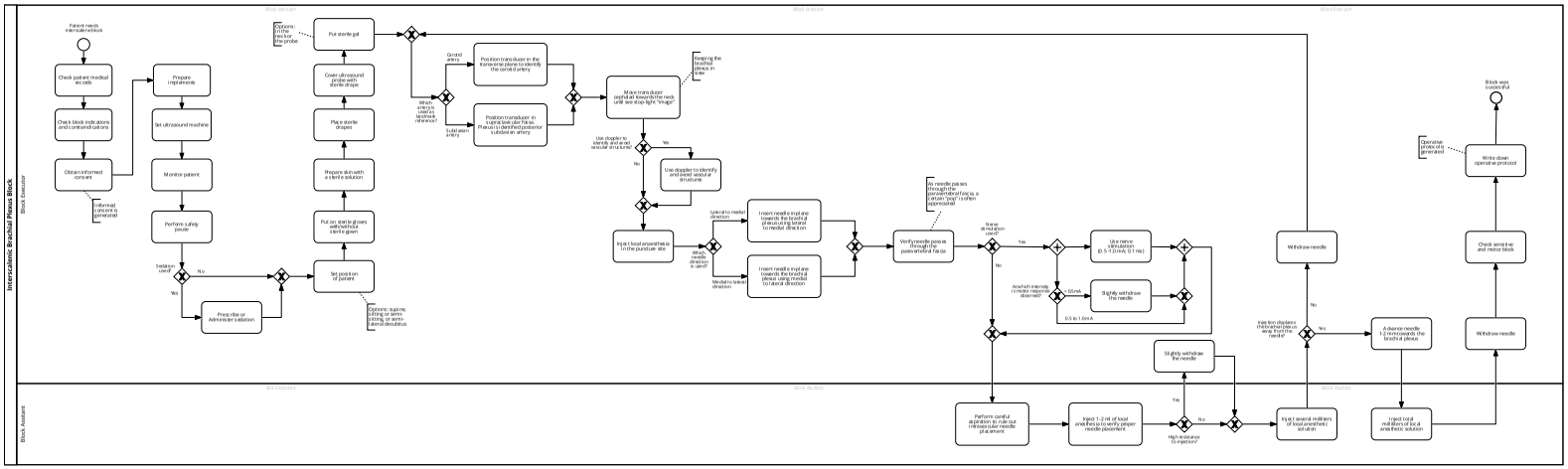

Figure A.4: Initial process model

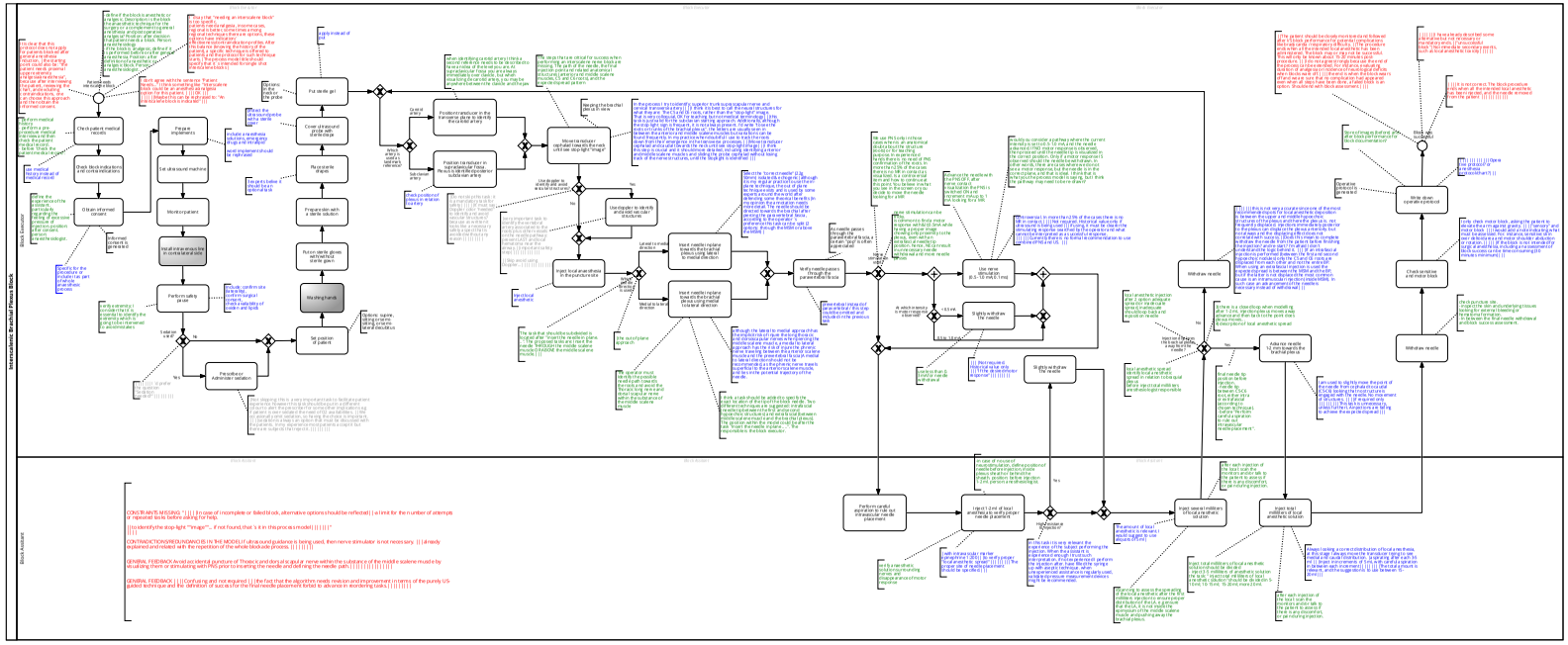

Figure A.5: Intermediate process model annotated for data analysis

Table A.7: Agreement regarding control-flow aspects of the process model presented in each round. (%)

Question	Control-flow pattern	Statement	1st round					2nd round					3rd round				
			5	4	3	2	1	5	4	3	2	1	5	4	3	2	1
The process model should allow... at this position.	Skipping	Prescribe or Administer sedation	33.3	50	8.3	0	8.3	38.5	38.5	15.4	0	7.7	-	-	-	-	-
		Place sterile drapes	-	-	-	-	-	22.2	55.6	0	22.2	0	-	-	-	-	-
		Use Doppler colour to identify vascular ...	36.4	36.4	9.1	9.1	9.1	15.4	69.2	7.7	7.7	0	-	-	-	-	-
		Use nerve stimulation... and Slightly withdraw the needle	42.9	28.6	0	14.3	14.3	69.2	15.4	7.7	7.7	0	-	-	-	-	-
		Slightly withdraw the needle	0	28.6	0	42.9	28.6	-	-	-	-	-	-	-	-	-	-
	Parallel paths between	Use nerve stimulation... and Slightly withdraw the needle	14.3	42.9	0	0	42.9	0	38.5	15.4	0	46.2	-	-	-	-	-
	Alternatives paths between	Position transducer in supraclavicular fossa or transverse plane...	38.5	38.5	7.7	7.7	7.7	30.8	53.8	7.7	0	7.7	-	-	-	-	-
		Position transducer in- or out-plane...	-	-	-	-	-	16.7	66.7	8.3	8.3	0	10	0	0	50	40
		Select in-plane towards the brachial plexus using lateral to medial or medial to lateral direction	21.4	35.7	14.3	21.4	7.1	0	53.8	15.4	7.7	23.1	-	-	-	-	-
		Insert needle in-plane through or above the middle scalene muscle	-	-	-	-	-	0	66.7	11.1	22.2	0	0	0	10	90	0
		Repeating Inject 5 ml aliquots of anesthetic solution and Withdraw needle completely	-	-	-	-	-	40	60	0	0	0	-	-	-	-	-
	Repeating	The whole process	7.1	57.1	7.1	7.1	21.4	-	-	-	-	-	-	-	-	-	-
		Section involving the needle placement						30.8	53.8	7.7	0	7.7	-	-	-	-	-
	Enforcing	Withdraw the needle" if inadequate response	-	-	-	-	-	22.2	55.6	11.1	11.1	0	-	-	-	-	-
		Slightly withdraw the needle", if high resistance is observed ...	64.3	28.6	7.1	0	0	84.6	7.7	7.7	0	0	-	-	-	-	-
The question to decide ... is correct	Whether to skip activities	Sedation needed?	25	58.3	8.3	8.3	0	23.1	53.8	15.4	7.7	0	-	-	-	-	-
		Do you use drapes?	-	-	-	-	-	22.2	55.6	0	22.2	0	-	-	-	-	-
		Use Doppler to identify and avoid vascular structures?	27.3	36.4	9.1	18.2	9.1	15.4	69.2	7.7	7.7	0	-	-	-	-	-
		Nerve stimulation used?	0	57.1	0	28.6	14.3	7.7	53.8	7.7	30.8	0	-	-	-	-	-
		At which intensity is motor response observed?	0	42.9	0	28.6	28.6	-	-	-	-	-	-	-	-	-	-
	Which task to perform between	Which artery is used as landmark reference?	15.4	53.8	7.7	15.4	7.7	15.4	69.2	15.4	0	0	-	-	-	-	-
		Which needle direction is used?	21.4	28.6	21.4	7.1	21.4	0	53.8	15.4	7.7	23.1	-	-	-	-	-
		Which needle approach is used?	-	-	-	-	-	25	66.7	8.3	0	0	0	0	0	60	40
		Which approach use in relation to middle scalene muscle (MSM)?	-	-	-	-	-	22.2	55.6	11.1	11.1	0	0	0	10	80	10
		Has syringe been emptied?	-	-	-	-	-	30	70	0	0	0	-	-	-	-	-
	To repeat tasks	Does the solution have proper distribution around the plexus?	14.3	50	0	14.3	21.4	53.8	46.2	0	0	0	-	-	-	-	-
	Whether to enforce	Do you observe deltoid muscles response?	-	-	-	-	-	15.4	23.1	30.8	7.7	23.1	-	-	-	-	-
		What response do you see to injection?	-	-	-	-	-	22.2	66.7	0	0	11.1	-	-	-	-	-
		What resistance do you observe for the injection?	21.4	57.1	0	7.1	14.3	46.2	53.8	0	0	0	-	-	-	-	-

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