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Peer-reviewed author version

Gonzalez-Lopez, Fernanda; MARTIN, Niels; de la Fuente, Rene; Galvez-Yanjari, Victor; Guzmán, Javiera; Kattan, Eduardo; Sepúlveda, Marcos & Munoz-Gama, Jorge (2023) ProDeM: A Process-Oriented Delphi method for systematic asynchronous and consensual surgical process modelling. In: ARTIFICIAL INTELLIGENCE IN MEDICINE, 135 (Art N° 102426).

DOI: 10.1016/j.artmed.2022.102426

Handle: <http://hdl.handle.net/1942/39166>

# 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

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

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

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

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

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

66 The remainder of the paper is organised as follows. Section 2 analyses  
67 related work and highlights the research gap that ProDeM addresses. Section  
68 3 presents the five design objectives that the proposed method needs to  
69 fulfil to accomplish its purpose. Section 4 describes in detail the stages of

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

## 75 **2. Related Work**

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

### 80 *2.1. Process Modelling in Healthcare*

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

91 [20] proposed using a BPMN process model as a starting point for generating  
92 CIGs arguing that such an approach increases the involvement of clinicians  
93 in the automation of clinical guidelines. The present work focuses on the  
94 process model perspective.

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

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



114 processes [4], assisting process improvement cycles and automation initia-  
115 tives [25], and aiding activities and decision-making in clinical contexts [26].  
116 These findings are in line with an increasing uptake of BPMN in the health-  
117 care sector, as shown by its use in a number of projects and also in the de-  
118 velopment of dedicated extensions for representing domain-specific aspects,  
119 e.g. [27, 28].

120

## 121 *2.2. Collaborative Process Modelling*

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

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

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

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

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

### 154 *2.3. Delphi Method*

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

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

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

179 *2.4. Delphi Studies in Healthcare Process Modelling*

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

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

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

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

### 216 **3. Design Objectives**

217 Based on the problem identification and the literature review, the follow-  
218 ing design objectives are put forward for a method that supports the creation  
219 of consensus surgical process models.

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

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

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

- 236 • **Anonymity.** The method should foster the mutual anonymity among  
237 the participants [38, 39, 40]. This feature has several advantages com-  
238 pared to face-to-face settings, including the reduction of the effect of  
239 dominant participants, and the opportunity to change opinion without  
240 feeling socially pressured [40, 51].
- 241 • **Iteration.** The method should support an iterative way of working.  
242 This feature allows the participants to modify their initial positions or  
243 ideas [36, 51].
- 244 • **Controlled feedback.** The method should provide controlled feed-  
245 back in each iteration. This feedback might trigger domain experts to

246 modify their views after further reflection [51].

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

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

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

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

#### 275 **4. ProDeM: Method and Demonstration**

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

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

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



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

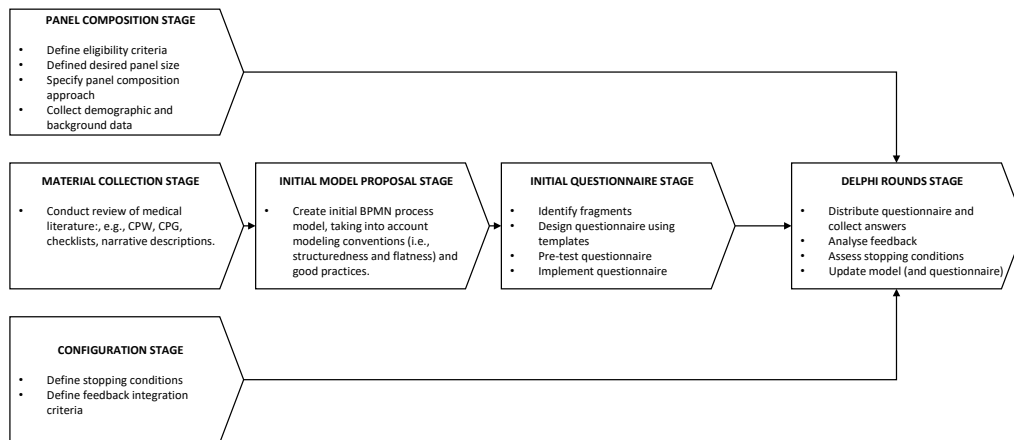


Figure 1: Overview of ProDeM

#### 298 4.1. Panel Composition Stage

##### 299 4.1.1. Overview

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

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

#### 307 *4.1.2. Description*

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

326 *4.1.3. Demonstration*

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

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

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

- 339 • *Category 1 - Clinical practice, which demonstrates the presence of clinical and technical expertise in the surgical process to be modelled:* (i) The  
340 candidate has worked 5 years or longer in regional anaesthesia or pain  
341 service over the last 10 years; (ii) The candidate has held the position  
342 of chief in a regional anaesthesia or pain service over the last 5 years;  
343 (iii) The candidate has executed (or directly supervised the execution  
344 of) the process, on average, at least 20 times per month over the last 6  
345 months.  
346
- 347 • *Category 2 - Beyond clinical practice, which demonstrates the pres-*

348 *ence of academic expertise and a critical approach to the surgical pro-*  
349 *cess to be modelled:* (i) The candidate has (co-)authored one or more  
350 accepted peer-reviewed scientific research paper(s) about the process  
351 within the last 5 years; (ii) The candidate has worked 6 months or  
352 longer as an instructor for regional anaesthesia or pain over the last  
353 5 years; (iii) The candidate has participated in an anaesthesia or pain  
354 congress as a speaker or workshop instructor on topics associated with  
355 the process over the last 5 years; (iv) The candidate has participated in  
356 the generation of clinical guidelines or other consensus building team  
357 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

358 Demographic and background data about the panel members were gath-  
359 ered in the first round questionnaire, and summarised in Table 1.

360 *4.2. Material Collection Stage*

361 *4.2.1. Overview*

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

369 *4.2.2. Description*

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

- 372 • *Clinical Practice Guidelines (CPGs)*, which consist of evidence-based  
373 recommendations for optimised patient care [59]. For various examples  
374 of CPGs we refer the reader to the University of Michigan Health [60]  
375 website.
- 376 • *Clinical Pathways (CPWs)*, which support the translation of CPG into  
377 local protocols and clinical practices that specify local structure, sys-  
378 tems, and time-frames [23].
- 379 • *Checklists*, which list equipment, tasks, or behaviours that are relevant  
380 for a particular surgical process [61], and are often used during medical  
381 education [62].

382 • *Narrative descriptions* from peer-reviewed outlets offering clinicians in-  
383 formation to support the delivery of effective care to their patients,  
384 such as medical education resources or point-of-care evidence-based re-  
385 sources, e.g., UpToDate<sup>®</sup> [63] and StatPearls [64].

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

#### 394 4.2.3. *Demonstration*

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

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

- 403 • StatPearls [64], which is an open access, web-based POC-EBM resource  
404 in PubMed that supports the search and retrieval of literature from the  
405 National Library of Medicine’s (MEDLINE) database [68]. This descrip-  
406 tion is composed of 12 activities, four decision points, and considers the  
407 use of neurolocalisation with ultrasonography and/or peripheral nerve  
408 stimulation.
  
- 409 • New York School Of Regional Anesthesia (NYSORA) [69], one of the  
410 best regional anaesthesia online sources, that provides a wide variety  
411 of high-quality educational resources [70, 71, 72]. This description is  
412 composed of 20 activities, five decision points, and considers the use of  
413 neurolocalisation with ultrasonography and/or peripheral nerve stimu-  
414 lation.

### 415 *4.3. Initial Model Proposal Stage*

#### 416 *4.3.1. Overview*

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

425 role.

#### 426 4.3.2. Description

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

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

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



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

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

### 463 4.3.3. *Demonstration*

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

---

<sup>1</sup>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].

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

#### 469 *4.4. Initial Questionnaire Stage*

##### 470 *4.4.1. Overview*

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

##### 478 *4.4.2. Description*

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

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

489 process of interest.

490 *Structure of the Questionnaire.* The high-level structure of the questionnaire  
491 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.

492 Part 1 of the questionnaire (*Welcome*) is used to ensure that panel mem-  
493 bers are adequately informed about what will be asked from them, the esti-  
494 mated answering time investment, as well as how the provided input will be  
495 used [37]. Also, as pointed out by Boulkedid et al. [82], the use of an explicit  
496 informed consent checkbox is recommended such that each panel member can  
497 formally agree to participate in the study. Part 2 (*Introduction*) introduces  
498 the modelling objective, round’s goal, research team and the forthcoming sec-  
499 tions of the questionnaire. Part 3 (*Full process model*) shows and describes  
500 the complete process model to which the remainder of the questionnaire will  
501 refer.

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

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

514 *Content of the Questionnaire.* To define the specific questions used in the  
515 questionnaire, the process model quality dimensions of the 3QM frame-  
516 work [84] are used as a starting point. As a consequence, for each set of  
517 elements in the model (i.e. tasks, participants, start event, task ordering,  
518 and end event) the following dimensions are to be assessed (when applica-  
519 ble): completeness, correctness, flexibility, redundancy, relevance, unambi-  
520 guity, and understandability. The question types to address each dimension  
521 for a given model element are shown in Table 3. Questions with the form  
522 ‘*Indicate the extent to which you agree with the following statement: [...]*’ are  
523 5-point Likert scale closed-ended questions, ranging from 1: *strongly disagree*  
524 to 5: *strongly agree*. The remaining questions are either yes/no questions or

525 open-ended questions. For tasks, participants, and start/end events, the  
526 question templates in Table 3 can be directly used. However, before for-  
527 mulating questions to assess task ordering, it is necessary to define a set of  
528 process fragments around which questions will be centred. The use of process  
529 fragments to assess control-flow implies that not every connection between  
530 all tasks are covered by questions. This design decision aims to balance the  
531 completeness of the questionnaire (i.e. explicitly asking input on each com-  
532 ponent of the model) and the workload on experts (in terms of number of  
533 questions). In the present work, each (non-trivial) single-entry-single-exit  
534 (SESE) region of the process model is defined as a fragment (see Section 4.3)  
535 .

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

548 fragment can also be provided [87]. Since there is no conclusive evidence on  
 549 whether textual descriptions are superior to diagrams (or vice-versa) in terms  
 550 of process understanding among users with different levels of process mod-  
 551 elling expertise (e.g., [88, 89]), dual coding is recommended for facilitating a  
 552 consistent interpretation of the model [90]. Note that open-ended questions  
 553 are included at the end of each part of the questionnaire to provide panel  
 554 members with the opportunity to formulate feedback on elements which are  
 555 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
End event	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?
	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.
Task order - skip/ enforce	-	Do you have any further feedback regarding the end event included in the process model?
	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?

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

DELPHI STUDY: INTERSCALENE BLOCK PROCEDURE

**PART 2: TASKS**

This part of the questionnaire seeks your feedback on the **tasks that need to be included** in the process model to cover **all relevant scenarios**. Be mindful that tasks are represented as **rounded-edged rectangles** in the process model.

In the table shown below, please indicate **for each task**:

- To which extent you think that it should be part of the process model
- Whether you have feedback regarding the correctness of the task name, the textual annotation (if present), or any other aspect of the task.

Please note that, if you think that a task is **missing** or that a task needs to be **subdivided** into two or more tasks, you can provide us with this input **in the questions shown under this table**. Feel free to switch back and forth between these questions.

	Indicate the extent to which you agree with the following statement: (-)					Feedback regarding the correctness of the task name, the textual annotation (if present), or any other aspect of the task. (optional)
	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	
Check patient medical records	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	
Check block indications and contraindications	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	

**PART 5: ORDERING OF TASKS**

**Process fragment 2**

The questions on this page relate to the **process fragment in the red box**. In the first image, the process fragment is positioned within the full process model. In the second image, we zoom in into the process fragment that you need to consider. Note that, at the end of this part of the questionnaire, you will have the opportunity to share feedback with us regarding parts of the process that were not included in a process fragment.

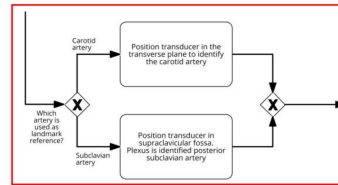
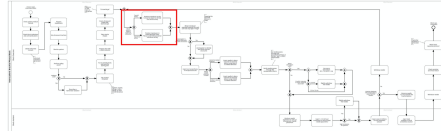


Diagram explanation: If **carotid artery** is used as **landmark reference** then 'Position transducer in the transverse plane to identify the carotid artery' is executed, else if **subclavian artery is used as landmark reference** then 'Position transducer in supraclavicular fossa' (plexus is identified posterior to subclavian artery) is executed.

Figure 2: Screenshots from the initial round questionnaire.

558 *4.4.3. Demonstration*

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

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



566 4.5. Configuration Stage

567 4.5.1. Overview

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

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

573 4.5.2. Description

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

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

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

#### 592 4.5.3. *Demonstration*

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

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

599 The following feedback integration criteria were defined:

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

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

612 – *Keep*. An element of the model is *kept* when it is maintained in  
613 the updated version of the process model. The criterion to keep  
614 an element is the following: the level of agreement of the panel  
615 about including the element in the model in the present round  
616 (i.e. the proportion of experts that ‘strongly agree’ or ‘agree’ with  
617 including it) is equal or greater than 75%.

618 – *Conditionally keep*. An element of the model is *conditionally kept*  
619 when it is maintained in at least one version of the updated process  
620 model.

621 An element is conditionally kept when one of the following two  
622 conditions hold: (i) it is the first time that the element has been  
623 included in the model, and the level of agreement about including  
624 it in the current round is between 50% and 75%, or (ii) the level  
625 of agreement about including the element in the current round  
626 is below 50%, but the element is part of a process fragment for  
627 which a high level of consensus has been reached.

628 – *Drop*. An element of the model is *dropped* when it is no longer  
629 part of the updated version of the process model.

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

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

#### 636 *4.6. Delphi Rounds Stage*

##### 637 *4.6.1. Overview*

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

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

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

652 *4.6.2. Description*

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

671 *4.6.3. Demonstration*

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

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

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

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

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

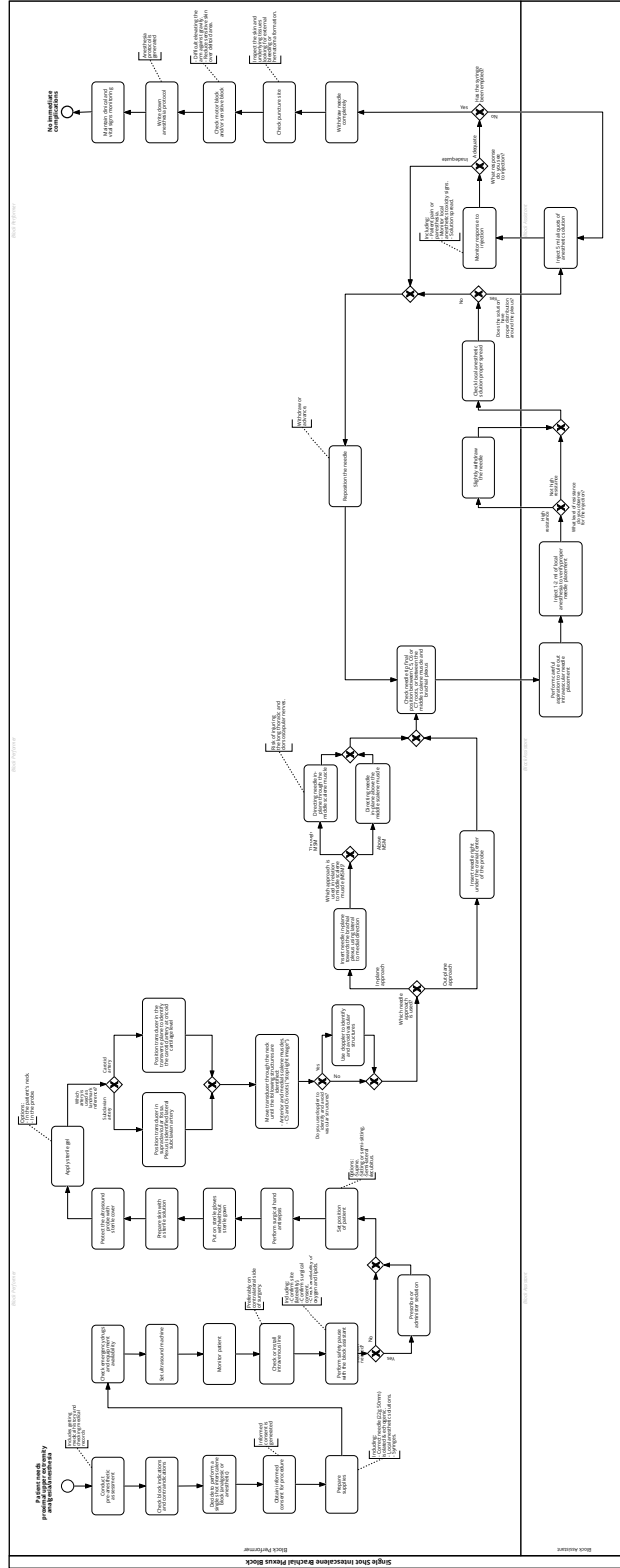


Figure 3: Final process model



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 reworted 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 reworted process fragments (in comparison with the previous round)	-	2	1	0

<sup>705</sup> 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.

<sup>706</sup> To show how the process model evolved over the rounds, Table 4 shows  
<sup>707</sup> how the process model changed after each round in terms of added, dropped  
<sup>708</sup> and reworted tasks and process fragments. Table 5 contains the details  
<sup>709</sup> per round regarding the agreement of panel members about the start event,  
<sup>710</sup> end event, and the process participants of the process model (i.e. ‘Block

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

714 *4.7. Evaluation*

715 After the three Delphi rounds, the panel members involved in the demon-  
 716 stration were invited to evaluate the artefact (i.e., ProDeM). To this end, the  
 717 applicable quality criteria suggested by Sonnenberg and Vom Brocke [52] –  
 718 i.e. ease of use, efficiency, generality, and operationality – have been used as  
 719 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: operationality.  
 5: strongly agree, 4: agree, 3: neither agree nor disagree, 2: disagree, 1: strongly disagree.

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

723 *following statement: [...]*'. The questions were 5-point Likert scale closed-  
724 ended questions with possible answers ranging from *1: strongly disagree* to  
725 *5: strongly agree*. As shown in Table 6, the level of agreement with all state-  
726 ments is high; no disagreements were present with any statement. Experts  
727 were also invited to share other comments in an open-ended question. One  
728 participant mentioned that the communication between the research team  
729 and the participants was excellent. Another participant indicated that it be-  
730 came easier to understand the process model after the first round and that  
731 mental load lowered down across the rounds.

## 732 **5. Discussion**

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

### 739 *5.1. Assessment of Design Objectives*

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

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

## 763 *5.2. Findings of the Demonstration*

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

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

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

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

### 796 *5.3. Limitations*

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

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

#### 827 *5.4. Strengths and Applications*

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

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

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



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

## 862 **6. Conclusions**

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

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

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

## 892 **Acknowledgements**

893 This work was supported by the National Agency for Research  
894 and Development (ANID) under ANID FONDECYT 3210147, ANID  
895 FONDECYT 1200206 and ANID FONDECYT 1220202 projects, ANID-  
896 PFCHA/Doctorado Nacional/2019-21190116 and ANID-PFCHA/Doctorado  
897 Nacional/2020-21201411 doctoral scholarships. We would especially like to  
898 thank the physicians who participated in the expert panel and in the pilot  
899 tests of our study.

900 Appendix A. Supplementary Material

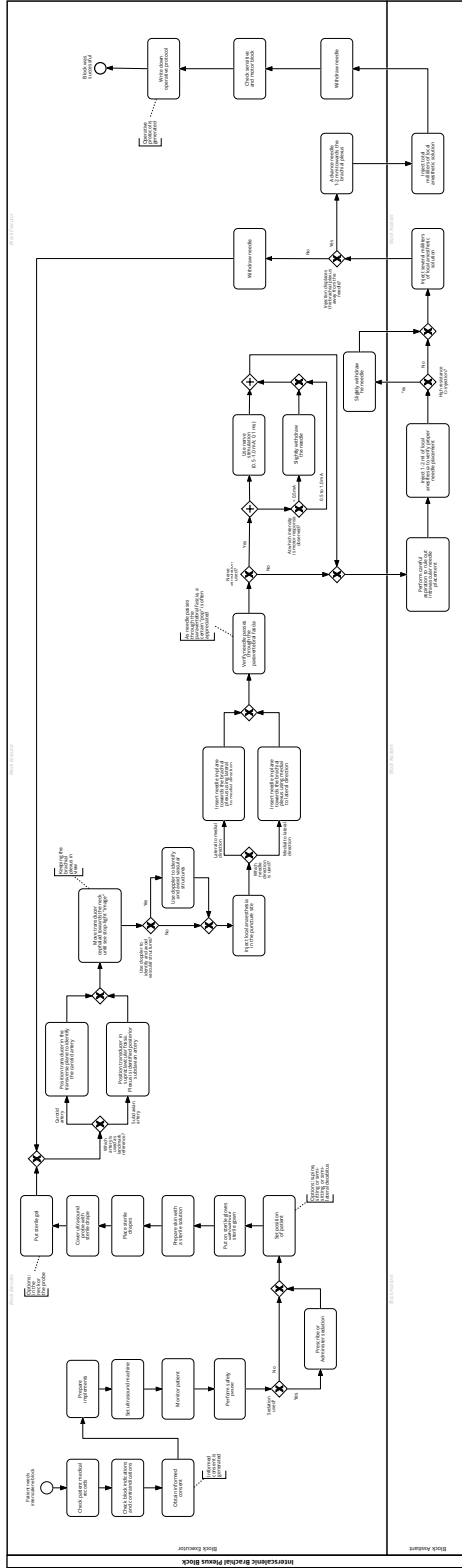


Figure A.4: Initial process model

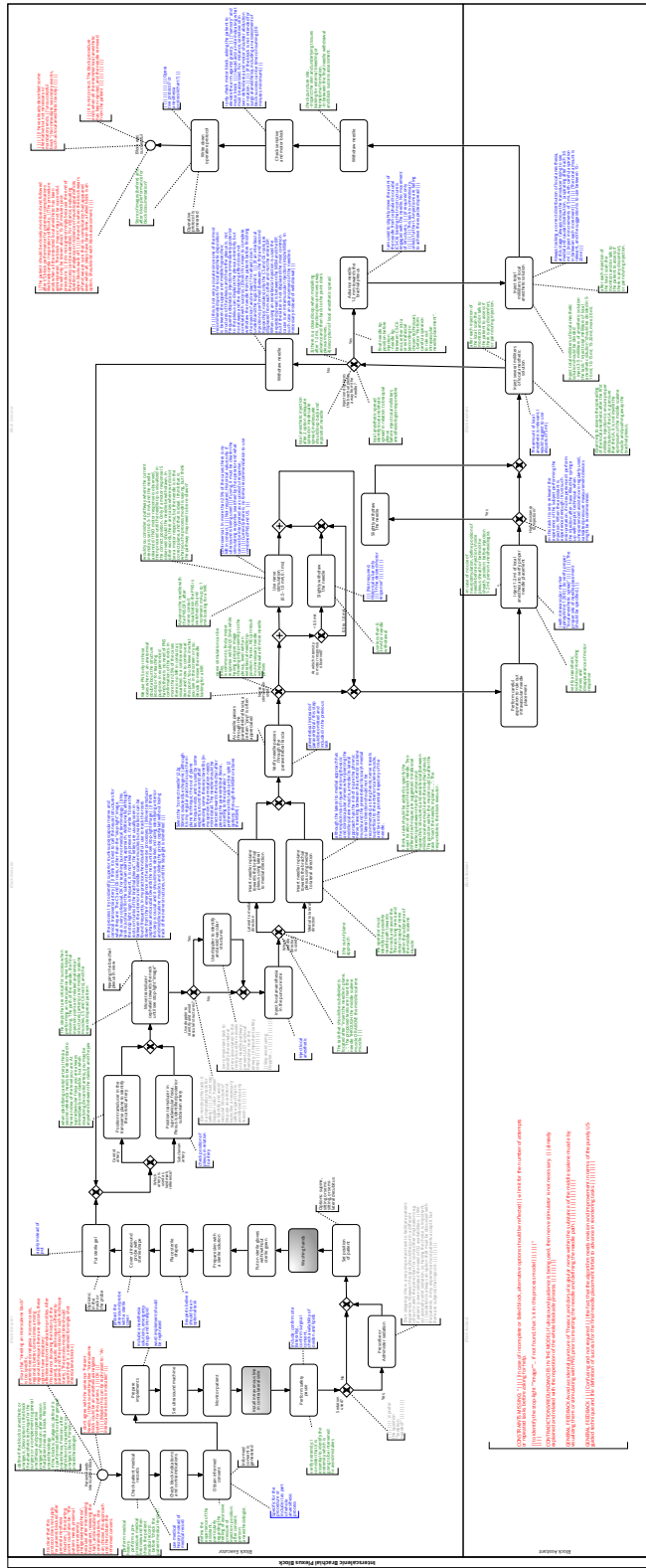


Figure A.5: Intermediate process model annotated for data analysis

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	
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	-	-	-	-	-	
Parallel paths between		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	-	-	-	-	-	-	-	-	-	-	
The process model should allow... at this position.		Use nerve stimulation... and Slightly withdraw the needle	14.3	42.9	0	0	42.9	0	38.5	15.4	0	46.2	-	-	-	-	-	
		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	-	-	-	-	-	-
		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	-	-	-	-	-	-
		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	-	-	-	-	-	-
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	-	-	-	-	-	
The question to decide ... is correct		At which intensity is motor response observed?	0	42.9	0	28.6	28.6	-	-	-	-	-	-	-	-	-	-	
		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	
To repeat tasks		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	-	-	-	-	-	
Whether to enforce		Does the solution have proper distribution around the plexus?	14.3	50	0	14.3	21.4	53.8	46.2	0	0	-	-	-	-	-	-	
		Do you observe deltoid muscles response?	-	-	-	-	-	15.4	23.1	30.8	7.7	23.1	-	-	-	-	-	
Whether to enforce		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	-	-	-	-	-	-	

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