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Health care process modelling: which method when?

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Objective: The role of process modelling has been widely recognised for effective quality improvement. However, application in health care is somewhat limited since health care lacks knowledge about a broad range of methods and their applicability to health care. Therefore, the objectives of this paper are to present a summary description of a limited number of distinct modelling methods and evaluate how health care workers perceive them.

Methods: Various process modelling methods from several different disciplines were reviewed and characterised. Case studies in three different health care scenarios were carried out to model those processes and evaluate how health care workers perceive the usability and utility of the process models.

Results: Eight distinct modelling methods were identified and characterised by what the modelling elements in each explicitly represents. Flowcharts, which had been most extensively used by the participants, were most favoured in terms of their usability and utility. However, some alternative methods, although having been used by a much smaller number of participants, were considered to be helpful specifically in understanding certain aspects of complex processes e.g. communication diagrams for understanding interactions, swim lane activity diagrams for roles and responsibilities and state transition diagrams for a patient-centred perspective.

Discussion: We believe that it is important to make the various process modelling methods more easily accessible to health care by providing clear guidelines or computer-based tool support for health care-specific process modelling. These supports can assist health care workers to apply initially unfamiliar, but eventually more effective modelling methods.

Word count: 248 (abstract), 3,465 (main body excluding abstract, references, tables and figure)

Keywords: Process modelling, process diagrams, quality improvement, systems understanding

Health care systems around the world are under pressure to reform and to improve the quality of service delivery. Care should be safe, effective, patient-centred, timely, efficient and equitable [1]. There is increasing recognition that developing good systems understanding of how the care process works is an essential step to effective quality improvement [2, 3], but such a systems understanding is often lacking in health care [4]. In other sectors various types of process models, i.e. process diagrams, have been developed and applied to assist the understanding of how people and resources interact to achieve outcomes, to redesign processes or to communicate prescriptive actions within a complex process [5-9]. The major aims of process modelling in the context of quality improvement can be summarised in two directions, first, to assist understanding of a process in order to identify areas of improvement, and second, to help document existing or planned processes to ensure a shared understanding which can eventually assist quality improvement.

Despite this recognition of the value of modelling, applications in health care have inclined too heavily toward flowcharts or hierarchical task analysis [10-14] or have been made in isolated situations without understanding of various process modelling methods or without consideration of potential users (health care practitioners) [15-18]. Therefore the need has been raised for better application of process modelling to the planning of health care delivery [3, 4]. In England for example, developments such as National Service Frameworks (NSFs) [19], clinical guidelines [20] and an increasing emphasis on care pathways [21] typically use no or only a narrow range of process modelling methods; mostly some form of flowchart.

The NHS Institute for Innovation and Improvement, which "supports the NHS to transform health care…by rapidly developing and spreading new ways of working, new technology and world-class leadership", (http://www.institute.nhs.uk/), places considerable emphasis on process modelling, including supporting a library for the "process modelling community". They state that because processes, especially health care processes, are varied and complex "It is not surprising to discover that process modelling approaches differ in their applicability to this spectrum of process types" [22]. They add that "some diagrams are well suited to describing stable procedures, some are focussed on processes where computers play a substantial role, others are more suitable for modelling processes where human interaction is dominant, and a few can reflect more complex and dynamic situations" [22]. When advising on the use

of modelling to address particular issues, however, they too present only flow diagrams [23].

Given the variation in health care processes, we argue that the sole use of flow diagrams limits the potential impact of process modelling on improving health care provision and there are additional methods which could be usefully applied. On closer inspection these diagram types very often differ only in their names, and are semantically identical. Thus, we suggest that, whilst a greater range of methods than flowcharts is potentially useful, health care workers need to be familiar with only a limited number of distinct modelling methods to describe, and thereby improve, their care process.

However, developing a methodology for making the most of these methods – i.e. knowing when to use which modelling method – is not straightforward. There are a large number of different methods used in various domains [24-26] and users in different domains could have different experience and preference. Many researchers in systems / software engineering developed various frameworks to categorise them: structural and behavioural [6]; vision, process, structure and behaviour [26], data, function, network, people, time and motivation [27], and organisation, data, control, function and product/service [28]. We think these categorisations are too broad and general to be readily helpful for health care workers to tell the difference between modelling methods.

Even after understanding the differences, a degree of experimentation has been considered often necessary to decide which modelling methods best suit users' needs and context [28]. However, this kind of experimentation can involve many challenges and complexities. For example, a model's comprehensibility may very much depend on how the model was generated (team or individual-based), the way the modeller communicates with the users (interactively or one-sidedly) and the degree of tool support (paper or computer-based) [29]. It could be even more so in health care where there is very restricted access to potential users.

This paper aims to assist health care workers to understand different utility and limitations of the limited number of distinct modelling methods so that they can select process modelling methods which are most appropriate to their needs. To do this we present a summary description of eight different modelling methods selected to represent most of primary functions of process modelling. Secondly, through the

diagram evaluation, we describe health care workers' perceptions of how easily understandable and how useful each diagram type is for gaining a better understanding of care processes.

METHODS

We reviewed the literature on process modelling methods to identify methods with distinct differences. Multiple literature search strategies were employed to cover a number of disciplinary boundaries such as software engineering, systems engineering, business process modelling and operations management. This included searching electronic databases (Pub-Med, Web of Knowledge), grey literature from either health care or other industries and following the 'reference trail' provided by published materials as well as searching multiple websites (Google/ Google Scholar). A great number of journal articles on mathematical modelling were filtered out since they were beyond the scope of this research. Whilst journal papers provided a great number of variations adapted for specific contexts, printed books provided an overall view on original, principal modelling methods rather than the adapted variations.

Various modelling methods were characterised by their main features and eight distinct modelling methods were identified. They were applied to three health care scenarios: a patient discharge process from a ward (from a hospital to a community setting); a diabetic patient care process (in a general practitioner (GP) practice); and a prostate cancer patient diagnostic process (in a hospital). The multiple case studies were carried out to gain insights with a sufficient degree of generality to allow their projection to other contexts. All three cases had a large number of information interactions and patient transfers within or between departments, which are regarded as huge potential risks to the patient [30].

Process models were generated by one researcher (GJ) in collaboration with one to four key health care workers per scenario. Semi-structured interviews (three to four one-hour interviews per scenario) were carried out to collect the information about the processes. National or local policy documents were identified during the interviews and used to build a high-level general understanding of the care processes to be modelled. For the patient discharge scenario only, observation was additionally carried out by attending two multidisciplinary team meetings and shadowing two pharmacists' ward-rounds.

Building and validating the eight different models for each scenario, the researcher (GJ) explained each of the models to a range of clinical and non-clinical staff (n=29). The participants were first asked whether they have used or generated the modelling methods before and then asked to evaluate the usability and utility of them: seventeen participants for the patient discharge process; six for the diabetic patient care process and six for the prostate cancer patient diagnostic process. Most of the evaluations were carried out in one-on-one sessions using a structured interview/questionnaire and took forty minutes to one and half hours.

During the evaluation, participants were asked to rate their agreement on a five-point scale (strongly agree = 5 to strongly disagree = 1) with the two statements: "This diagram is easily understandable (usability)" and "This diagram is helpful in better understanding and communicating how the care process works (utility in better system understanding)". The first statement was adopted to evaluate the diagrams' comprehensibility by asking how easily understandable each diagram was. The second statement was adopted to evaluate the general utility of each diagram for system understanding. The participants were also invited to comment verbally on why they had made the particular rating, including what they thought were the strengths and weaknesses of each diagram. Their comments were audio-recorded.

The in-depth qualitative feedback about the usability and utility of each diagram as well as the quantitative ratings (the level of agreement with the statements) were collected and analysed. A (3×10) mixed ANOVA (case study×diagram types) was used to investigate the effect of the case study on the response patterns for each statement. The response patterns were analysed and compared using percentage agreement as a measure.

The study took place in Cambridgeshire, England with approval from the Cambridge Local Research Ethics Committee.

RESULTS

Summary of diagram characterisation

A large range of process modelling methods has been developed by various groups of researchers to describe different types and aspects of systems. For example, human factors specialists have used a range of task-analysis methods with a special interest in

understanding interactions between physical devices and individual behaviour. These methods include input-output diagrams, process charts, functional flow diagrams, information flow charts, etc [31]. In the field of management science, many process models have been developed to improve business processes on their own or in conjunction with simulation techniques. These methods include process maps, activity cycle diagrams, stock flow diagrams, etc [32, 33].

Various groups of software and systems engineers have also developed many types of modelling methods since the 1970s to design and analyse complex systems. These methods, which consist of several different individual diagram types, include Structured Analysis and Design (SA/SD), Integrated Definitions (IDEF) and Object-Oriented Method (OOM).

Collective efforts have been made since 1997 by software and systems engineers to unify diverse modelling methods [25]. The efforts toward unifying modelling languages were realised by the Unified Modeling Language (UML) for software engineering and the Systems Modeling Language (SysML) for broader domains including hardware, software, information, processes, personnel and facilities.

Analysing the collection of various modelling methods used across the disciplines, we found two things. First, the majority of the modelling methods used in different disciplines differ only in their names, but very often represent semantically identical aspects of a system. Second, the modelling languages developed in software and systems engineering cover most of modelling method variations used in other disciplines. We therefore identified principal modelling methods based on SA/SD, IDEF, UML and SysML.

Through the comparison of what each method semantically represents, eight diagram types with distinct differences were identified and summarised in Table 1. Nodes (boxes and circles) mainly describe stakeholders, information, activities or states, whereas links (connecting lines between nodes) represent hierarchy, sequence or information/material interactions. It is the particular combination of these nodes and links that lends each method its distinctive features and particular value.

INSERT TABLE 1 ABOUT HERE

The first three diagram types (stakeholder diagrams, information diagrams and process content diagrams) show hierarchical links between stakeholders, information

and activities, respectively. These structural models are equivalent to entity relation diagrams, IDEF1 and UML class diagrams.

The second three diagram types (flowcharts, swim lane activity diagrams and state transition diagrams) address some limitations of the static nature of the hierarchical-link diagrams by showing sequential links of activities or states. Flowcharts are equivalent to IDEF3 process description diagrams and UML activity diagrams, whereas state transition diagrams are equivalent to IDEF3 object state transition network diagrams and UML state machine diagrams.

The last two diagram types (communication diagrams and data flow diagrams) describe information inputs and outputs between stakeholders or activities respectively. Communication diagrams are UML communication diagrams, whereas data flow diagrams are equivalent to SA/SD data flow diagrams and IDEF0.

The evaluation results of the eight diagram types are reported below based on the participants' ratings and comments.

Summary of process modelling and evaluation

The survey on the participants' previous experience with the modelling methods showed that flowcharts and swim lane activity diagrams had been previously used by the largest number of the participants (76%), whereas state transition diagrams, communication diagrams and data flow diagrams formed the least previously used types (21%, 14% and 21% of the participants). Around half of the participants (48%) had prior experience with the three hierarchical link diagrams (stakeholder diagrams, information diagrams and process content diagrams).

The response patterns from the three case studies did not vary significantly ($F_{(2,26)}$=2.49, $p>0.05$ for usability, $F_{(2,25)} = 0.96$, $p>0.05$ for utility) so the aggregated responses from three cases are reported here. Table 2 shows the percentage agreement (either 'agreed' or 'strongly agreed') with the two statements on usability and utility along with the participants' comments on the specific utilities. Overall, the greatest number of participants rated flowcharts as easily understandable (97% agreement) and helpful in understanding their processes (89% agreement). However, other alternative methods were perceived to be more helpful in understanding certain specific aspects of complex processes. The process models of

each diagram type (based on the simplified patient discharge process) are included and further findings for each diagram type are reported below.

INSERT TABLE 2 ABOUT HERE

First, the three hierarchical-link diagrams (stakeholder diagrams, information diagrams and process content diagrams) were generally considered to be simple enough to be easily understandable (86%, 79% and 90% agreement respectively), but not able to provide sufficient information to be helpful in understanding how the care process works (57%, 57% and 64% agreement respectively).

Stakeholder diagrams

Stakeholder diagrams show how stakeholders are hierarchically structured like organisation charts. Figure 1 shows who is involved in a patient discharge process and of whom a multidisciplinary team consists. The participants saw these as helpful in identifying key stakeholders and defining system boundaries.

INSERT FIGURE 1 ABOUT HERE

Information diagrams

Information diagrams show the hierarchical structure of documents or information. They were considered very effective in describing documentation issues such as degree of standardisation of documents, level of usage of electronic documents and links between electronic and paper-based documents. Figure 2 represents four different types of discharge summary used in one hospital.

INSERT FIGURE 2 ABOUT HERE

Process content diagrams

Process content diagrams represent a hierarchical list of activities. They were judged as effective in making an exhaustive list of activities of major concern. Figure 3 shows three groups of activities carried out for patient discharge.

INSERT FIGURE 3 ABOUT HERE

Flowcharts

Flowcharts are very widely used to describe the sequence of activities as Figure 4 shows. Flowcharts were rated the most favourable in terms of both usability and utility. Most participants commented that their familiarity with flowcharts from their previous experience made them more in favour of flowcharts. Flowcharts were

considered particularly helpful in understanding the overall sequence of care processes.

INSERT FIGURE 4 ABOUT HERE

Swim lane activity diagrams

Swim lane activity diagrams are designed to show sequence of activities with a clear role definition by arranging activities according to responsibilities. Figure 5 shows who is responsible for what in patient discharge. On the other hand, swim lane activity diagrams were considered less effective in understanding the overall process.

INSERT FIGURE 5 ABOUT HERE

State transition diagrams

State transition diagrams were originally developed to define the way in which a system's behaviour changes over time by showing the system's states (nodes), transition conditions (underlined text between nodes) and transition actions (text between nodes with no underline) [34]. To apply this concept to care processes, system's states in this study were defined as patient-related states such as the patient's physical status, the patient's location and the status of the patient's information. Figure 6 shows a state transition diagram describing the simplified patient discharge process.

INSERT FIGURE 6 ABOUT HERE

State transition diagrams were rated as the second most helpful (71% positive agreement) in understanding care processes in spite of the participants' relatively low usability perception (59% agreement) and very low prior experience (21%). Many participants appreciated that state transition diagrams helped them to see the process in a more patient-centred way by describing care processes using patient-related states.

Communication diagrams

Communication diagrams show information/material interactions between stakeholders. Communication diagrams, although rated the least understandable (38%) and the least helpful (38%) in general system understanding, were considered as particularly helpful in understanding interactions between trusts, departments, teams and individuals as shown in Figure 7.

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INSERT FIGURE 7 ABOUT HERE

Data flow diagrams

Data flow diagrams were originally developed to show how information is processed and where information is stored [34] as shown in Figure 8. Data flow diagrams were rated understandable and helpful in general system understanding by around half of the participants (62% and 50%). Data flow diagrams, in general, were considered limited in describing overall care processes which consist of more than information processing and storage.

INSERT FIGURE 8 ABOUT HERE

DISCUSSION AND CONCLUSIONS

Through the diagram characterisation, we identified eight different diagram types representing most of primary functions of process modelling. The diagram characterisation reconfirmed that models are all simplifications of a certain view of reality [32] and a single diagram can not effectively capture every aspect of complex health care delivery.

The diagram evaluation with the health care workers provided valuable insights into the pros and cons of each diagram in terms of the usability and utility in the health care contexts. Stakeholder diagrams and information diagrams could be particularly helpful at the initial stage of the modelling. Although they were considered not to provide a full-insight into how the care process works, they were considered very useful in setting the boundary of modelling, identifying stakeholders and understanding information structure. Process content diagrams, which have been widely used as a base of human error analysis [35, 36], could be also helpful at the initial stage of the modelling. They were found helpful in understanding an overall process structure and describing sub processes to the different level of detail. Flowcharts, which had been the most extensively used by the participants (75% of them), were rated as the most favourable in terms of both usability and general utility in system understanding. This could imply that flowcharts can provide an effective base for initial system understanding and for building other diagram types as well, if necessary. At the same time, the limitations of flowcharts in understanding certain specific aspects of a system, e.g. system interactions, were revealed through the diagram characterisation and also noticed through the diagram evaluation with the

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health care workers. Swim lane activity diagrams were considered especially helpful in obtaining a clear understanding of roles in various tasks, which is essential in effective multidisciplinary teamwork [37].

Some alternative diagram types, in spite of the participants' much less prior experience with them, were perceived particularly helpful in understanding certain aspects of care processes. For example, state transition diagrams, in particular, were considered to have great potential utility in understanding care processes in a patient-centred way and patient-centeredness has been known to be crucial for good quality care [38, 39]. Communication diagrams were considered to be very helpful in understanding interaction issues between people, teams and departments, which have been frequently one of the major causes of patient safety problems [40, 41]. Data flow diagrams, which have primarily been used to represent human-machine interactions [42], were considered not very helpful in understanding general care delivery processes which are not always data-driven. Data flow diagrams, however, still can be very useful in specifically representing human-medical device interactions in health care, where data interactions are main drivers.

Some of the diagram types identified in this study, although considered as very helpful for understanding certain aspects of complex care processes, were found difficult for some health care workers, especially with limited or no prior experience to understand and could be even more challenging to build. We believe it is important to make such process modelling methods more accessible to health care to accommodate the complex health care quality issues. We believe that clear guidelines or computer-based tool supports for health care-specific process modelling could reduce barriers in generating and understating such diagram types. There are many modelling tools in the market from general diagramming tools to more sophisticated business modelling tools, which allow users to generate all the eight diagram types identified in this paper. However, we believe such various diagram types could be best utilised in health care only when users are aware of the health care-specific utility and usability of each diagram type and make an extra efforts to apply initially unfamiliar, but eventually more effective diagram types.

Although there are some limitations in this study due to the challenges in having access to health care workers (relatively small sample size and perception-based

evaluation), we believe that this study provide valuable insight into how health care can make the most of process modelling methods.

ACKNOWLEDGEMENTS

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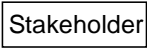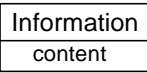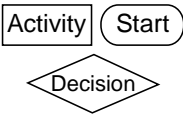Table 1 Node-link based diagram characterisation and simple examples
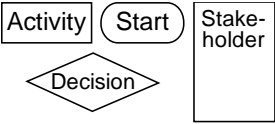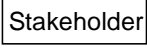
Diagram type	Nodes	Links
① Stakeholder diagrams	Stakeholder	◊ consists of △ has types of Hierarchy
② Information diagrams	Information content	◊ consists of △ has types of Hierarchy
③ Process content diagrams	Activity	◊ consists of △ has types of Hierarchy
④ Flowcharts	Activity Start Decision	↓ Sequence
⑤ Swim lane activity diagrams	Activity Start Stake-holder Decision	↓ Sequence
⑥ State transition diagrams	State	condition action ↓ Sequence
⑦ Communication diagrams	Stakeholder	← – – → Information /material
⑧ Data flow diagrams	Activity Data storage	← – – → Information /material

Table 2 Diagram evaluation results

●: % agreement ≥ 70%, •: 70% > % agreement ≥ 50%. ·: % agreement < 50%

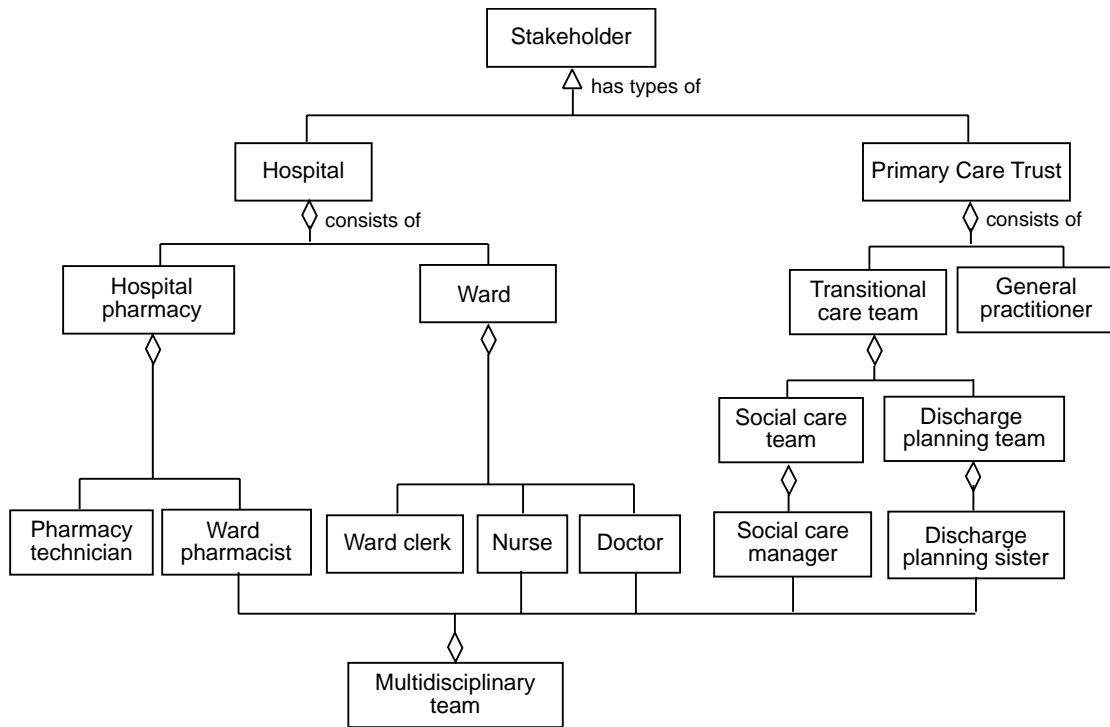| Diagram type	Usability: easily understandable (n = 29)	Utility: helpful in better understanding how the system works (n = 28)	Utility: Helpful for specific purposes
① Stakeholder diagrams	● (86%)	• (57%)	- Defining system boundaries - Identifying key stakeholders
② Information diagrams	● (79%)	• (57%)	- Understanding document standardisation status, level of electronic document usage
③ Process content diagrams	● (90%)	• (64%)	- Understanding a detailed task structure
④ Flowcharts	● (97%)	● (89%)	- Understanding an overall process
⑤ Swim lane activity diagrams	● (79%)	• (61%)	- Understanding roles and responsibilities
⑥ State transition diagrams	• (59%)	● (71%)	- Understanding a process in a patient-centred way
⑦ Communication diagrams	· (38%)	· (39%)	- Understanding communication and interactions between stakeholders
⑧ Data flow diagrams	• (62%)	• (50%)	- Limited in describing overall care processes

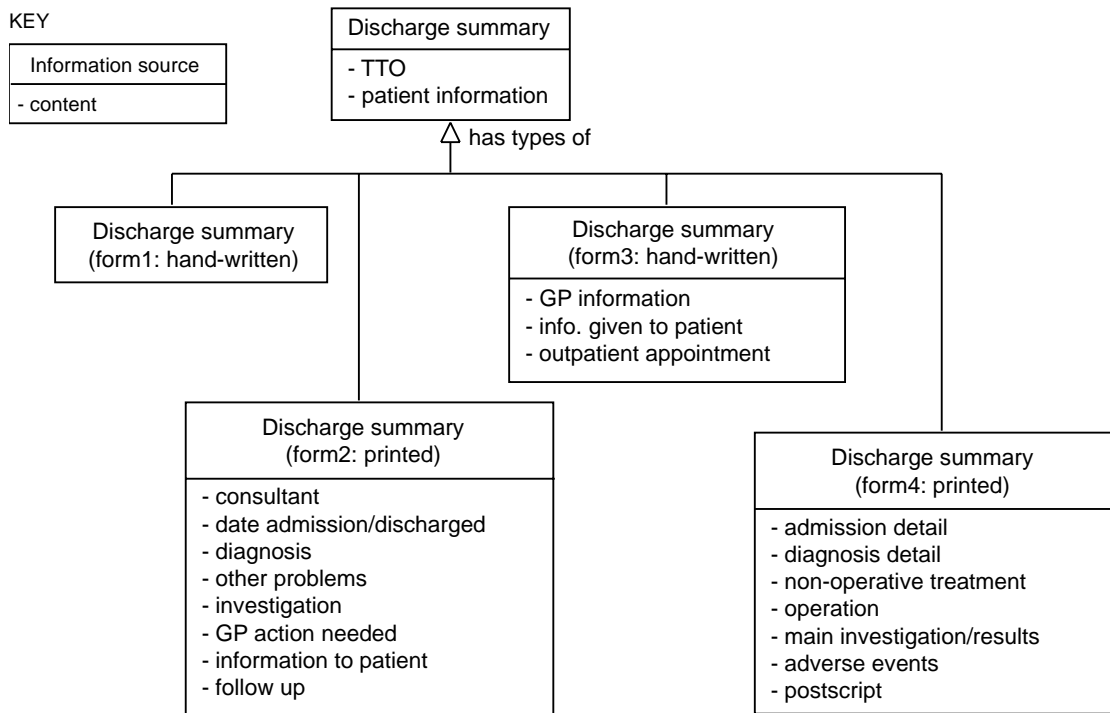Figure 1 Stakeholder diagram of a simplified patient discharge process

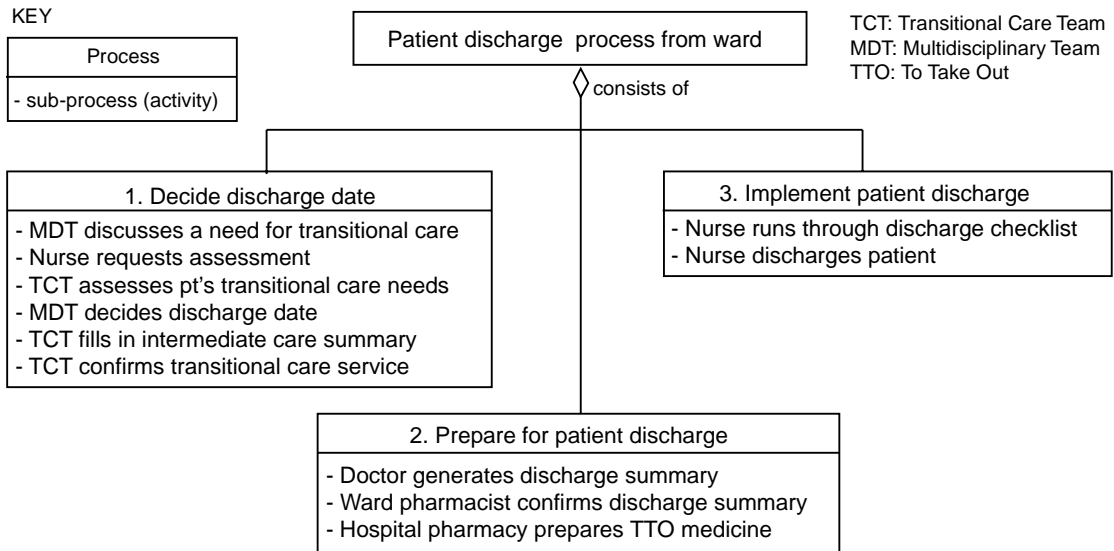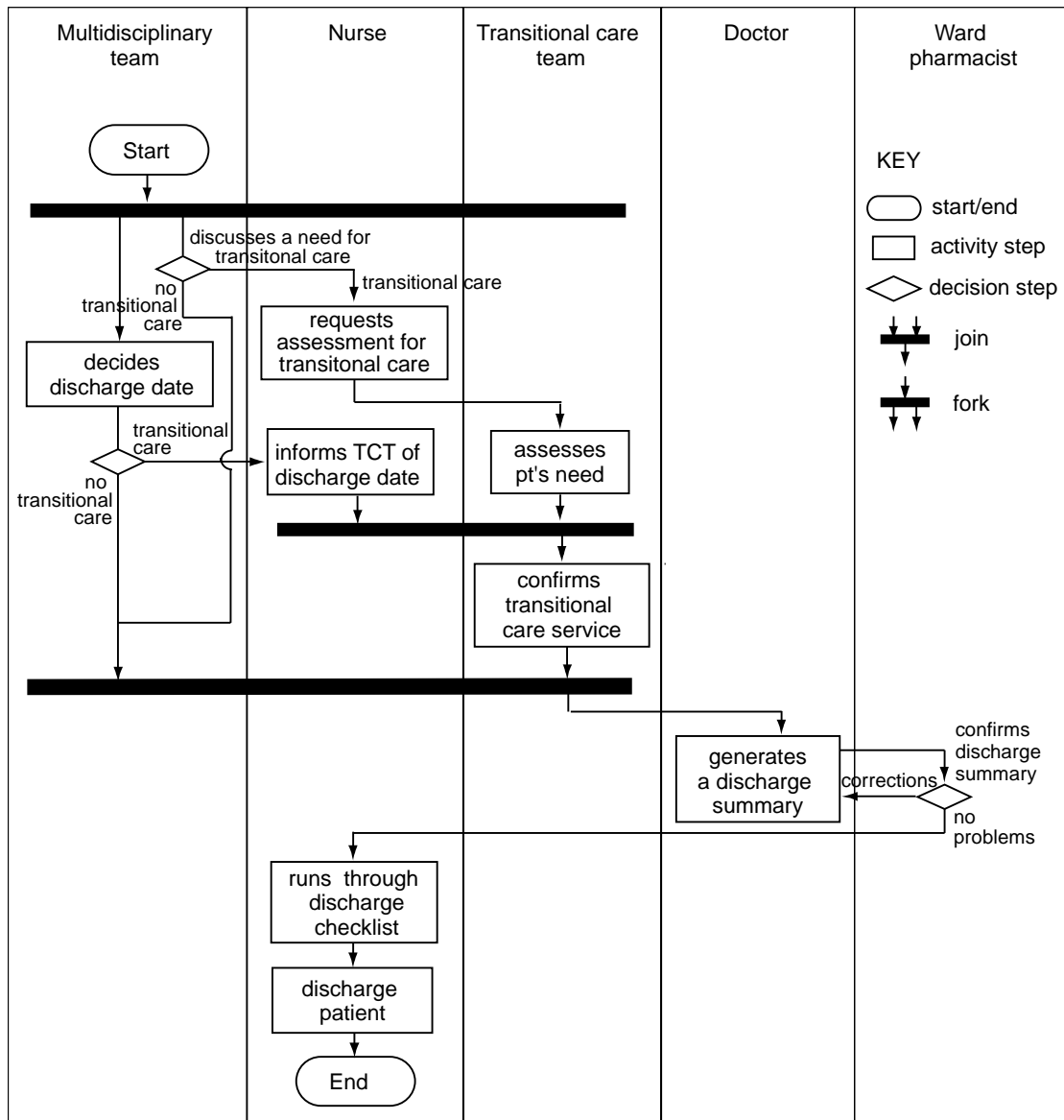Figure 2 Information diagram of a simplified patient discharge process

Process
- sub-process (activity)

Patient discharge process from ward

◇ consists of

TCT: Transitional Care Team
MDT: Multidisciplinary Team
TTO: To Take Out

1. Decide discharge date
- MDT discusses a need for transitional care - Nurse requests assessment - TCT assesses pt's transitional care needs - MDT decides discharge date - TCT fills in intermediate care summary - TCT confirms transitional care service

3. Implement patient discharge
- Nurse runs through discharge checklist - Nurse discharges patient

2. Prepare for patient discharge
- Doctor generates discharge summary - Ward pharmacist confirms discharge summary - Hospital pharmacy prepares TTO medicine

Figure 3 Process content diagram of a simplified patient discharge process

KEY

⬭ Start / End

▭ Activity step

◇ Decision point

TCT: Transitional Care Team
MDT: Multidisciplinary Team

Start

Multidisciplinary team discusses
a need for transitional care

No need   needed

Nurse requests assessment
for transitional care

TCT assesses pt's need

MDT decides
discharge date

MDT decides discharge date

TCT fills in intermediate care summary

TCT confirms transition care service

Doctor generates
discharge summary

Ward pharmacist confirms
discharge summary

need
corrections   no
                   problems

Nurse runs through discharge checklist

Nurse discharge patient

End

Figure 4 Flowcharts of a simplified patient discharge process

Multidisciplinary team | **Nurse** | **Transitional care team** | **Doctor** | **Ward pharmacist**

Start

discusses a need for transitonal care

no transitional care

transitional care

requests assessment for transitonal care

decides discharge date

transitional care

informs TCT of discharge date

assesses pt's need

no transitional care

confirms transitional care service

KEY

start/end

activity step

decision step

join

fork

confirms discharge summary

generates a discharge summary

corrections

no problems

runs through discharge checklist

discharge patient

End

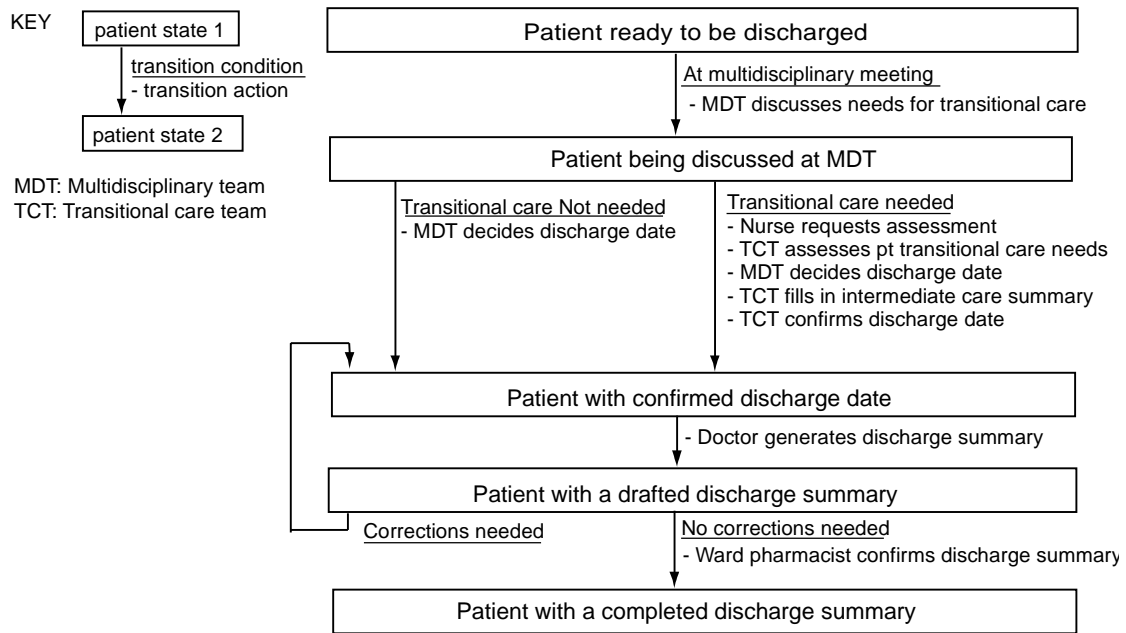Figure 5 Swim lane activity diagram of a simplified patient discharge process

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Figure 6 State transition diagram of a simplified patient discharge process
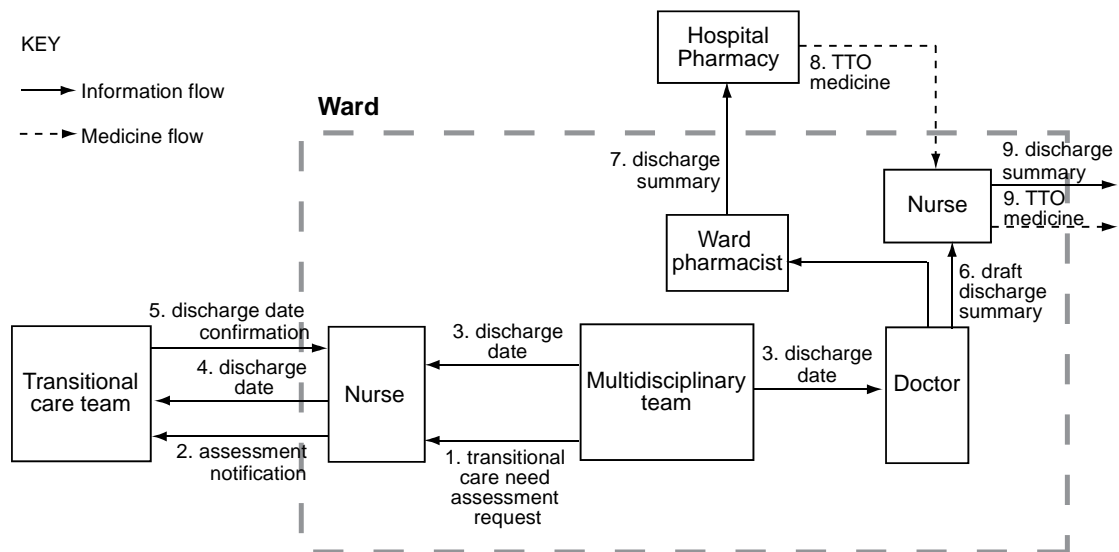

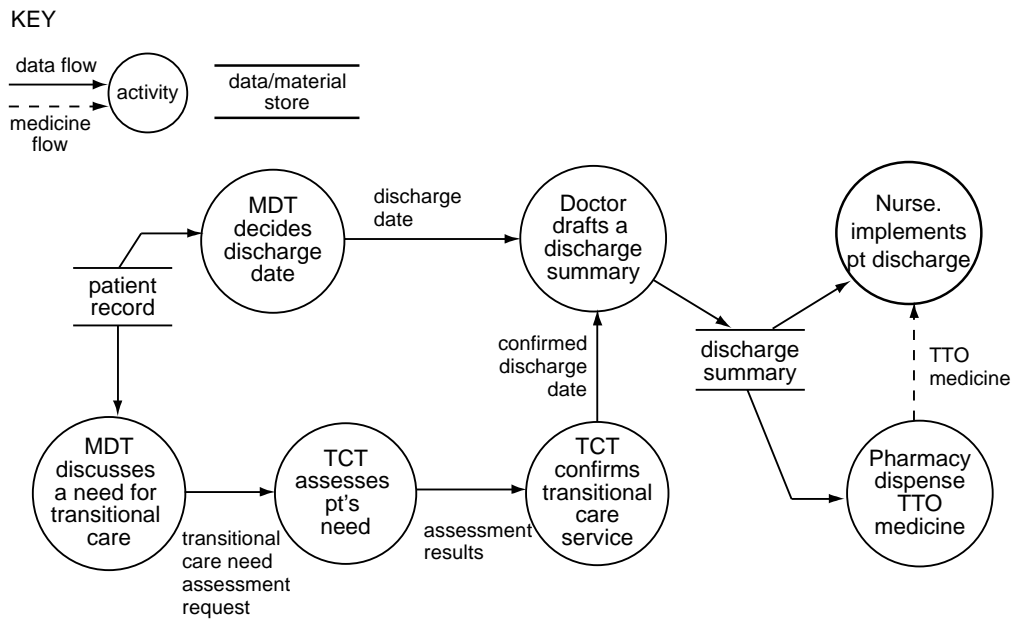Figure 7 Communication diagram of a simplified patient discharge process

Figure 8 Data flow diagram of a simplified patient discharge process