Health care process modelling: which method when?

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Abstract

Objective. The role of process modelling has been widely recognized for effective quality improvement. However, application in health care is somewhat limited since the health care community 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 characterized. 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 characterized 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.

Keywords: process diagrams, process modelling, 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. diagrammatic descriptions of systems, 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 summarized 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 that can eventually assist quality improvement.

Despite this recognition of the value of modelling, applications in health care have inclined heavily towards flowcharts [10–14]. Additionally, applications have been made in isolated situations without understanding of various process modelling methods or without consideration of potential users (health care practitioners) [15, 16]. Therefore the need has been raised for better application of process modelling to the planning of health care delivery [3, 4].

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 that 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, while 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, making the most of these methods is not straightforward. There are a large number of different methods (individual diagram types), methodologies (knowing when to use which modelling method) and tools (software applications that support the notation and semantics associated with modelling methods) used in various domains

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[8, 17], and users in different domains could have different experience and preference. Many researchers in systems/software engineering have developed various frameworks to categorize them: structural and behavioural [6]; vision, process, structure and behaviour [18]; data, function, network, people, time and motivation [19]; and organization, data, control, function and product/service [20]. We think these categorizations are too broad and general to be readily helpful to health care workers to tell the difference between modelling methods.

Even after understanding the differences, a degree of experimentation has been suggested often necessary to decide which modelling methods best suit users' needs and context [20]. 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) [21]. 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 the advantages and disadvantages of a limited number of distinct modelling methods so that they can select process modelling methods that are most appropriate to their needs. To do this we present a summary description of eight different modelling methods, selected to represent most of the primary functions of process modelling. Secondly, through the diagram evaluation, we report 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 (PubMed and Web of Knowledge) and grey literature from either health care or other industries. The search was initially driven by combination of keywords such as (Modelling or Modelling or Mapping) and (Process) and (System), but narrowed down with additional criteria. For example, the scope of the search was limited to process modelling in terms of diagrammatic descriptions of systems, and therefore a great number of journal articles on purely mathematical and stochastic modelling were excluded. While 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 characterized by their main features and eight distinct modelling methods were identified. We applied them to three health care scenarios: a

patient discharge process from a ward; a diabetic patient care process in a general practitioner practice; and a prostate cancer patient diagnostic process in a hospital. 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 [22].

Process models were generated by one researcher (G.J.) in collaboration with one to four key health care workers per scenario. Semi-structured interviews (three to four 1-h interviews per scenario) were carried out to collect the information about the processes. National or local policy documents were used to build a high-level general understanding of the care processes.

Building and validating the eight different models for each scenario, the researcher (G.J.) explained each of the models to a range of clinical and non-clinical staff ($n = 29$). The participants were first asked whether they have previously used the modelling methods. They were then asked to evaluate the usability and utility of them: 17 participants for the patient discharge process, 6 for the diabetic patient care process and 6 for the prostate cancer patient diagnostic process. Most of the evaluations were carried out one-on-one using an interview-based questionnaire for 40 to 90 minutes.

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 systems 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) was collected and analysed. A (3×8) mixed analysis of variance (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.
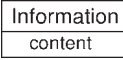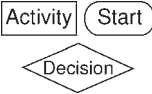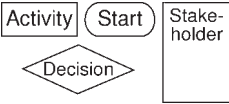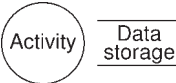
The study took place in Cambridgeshire, England with approval from the Cambridge Local Research Ethics Committee.

Results

Summary of diagram characterization

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 [23]. In the field of

Table I Node-link-based characterization of the eight different diagram types

Diagram type	Nodes	Links	Comparable diagrams
① Stakeholder diagrams	Stakeholder	◊ consists of △ has types of — Hierarchy	Entity relation diagrams Class diagrams
② Information diagrams	Information content	◊ consists of △ has types of — Hierarchy	Entity relation diagrams Class diagrams Information modelling method (IDEF1)
③ Process content diagrams	Activity	◊ consists of △ has types of — Hierarchy	Hierarchical task analysis Use case diagrams
④ Flowcharts	Activity Start Decision	↓ Sequence	Activity diagrams Process description diagrams (IDEF3)
⑤ Swim lane activity diagrams	Activity Start Stake-holder Decision	↓ Sequence	Not applicable
⑥ State transition diagrams	State	↓ condition action — Sequence	State machine diagrams State transition network diagrams (IDEF3)
⑦ Communication diagrams	Stakeholder	← – – → Information /material	Not applicable
⑧ Data flow diagrams	Activity Data storage	← – – → Information /material	Function modelling method (IDEF0)

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 [24, 25].

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, integrated definitions (IDEF), object-oriented method and unified modelling language.

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 methods developed in software and systems engineering cover most of modelling method variations used in other disciplines. We therefore identified principal modelling methods based on the modelling methods of software and systems engineering.

Through the comparison of what each method semantically represents, eight diagram types with distinct differences were identified. The modelling elements (nodes and links) of each of the eight diagram types are summarized in Table 1 along with comparable diagrams in different names. 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.

The first three diagram types (stakeholder diagrams, information diagrams and process content diagrams) show hierarchical links between stakeholders, information and activities, respectively. Stakeholder and information diagrams are equivalent to entity relation diagrams, class diagrams and information modelling method (IDEF1), whereas process content diagrams are equivalent to hierarchical task analysis and partially comparable to use case 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 process description diagrams (IDEF3) and activity diagrams, and state transition diagrams are equivalent to object state transition network diagrams (IDEF3) and state machine diagrams.

The last two diagram types (communication diagrams and data flow diagrams) describe information inputs and outputs between stakeholders or activities, respectively. Data flow diagrams are partially comparable to the function modelling method (IDEF0).

Table 2 Diagram evaluation results

Diagram type	Prior experience with diagram ($n = 29$) (%)	Usability: easily understandable ($n = 29$) (%)	Utility: helpful in better understanding how the system works ($n = 28$) (%)	Utility: helpful for specific purposes
① Stakeholder diagrams	48	86	57	Defining system boundaries Identifying key stakeholders
② Information diagrams	48	79	57	Understanding document standardization status, level of electronic document usage
③ Process content diagrams	48	90	64	Understanding a detailed task structure
④ Flowcharts	76	97	89	Understanding an overall process
⑤ Swim lane activity diagrams	76	79	61	Understanding roles and responsibilities
⑥ State transition diagrams	21	59	71	Understanding a process in a patient-centred way
⑦ Communication diagrams	14	38	39	Understanding communication and interactions between stakeholders
⑧ Data flow diagrams	21	62	50	Limited in describing overall care processes

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

Summary of process modelling and evaluation

The response patterns from the three case studies did not vary significantly ($P = 0.10$ for usability and $P = 0.40$ for utility) and therefore the aggregated responses from the three cases are reported here.

Table 2 shows the participants' previous experience with the diagrams, the percentage agreement (either 'agreed' or 'strongly agreed') with the two statements along with the participants' comments on the specific utilities.

Flowcharts had been previously used by the largest number of the participants, whereas state transition diagrams, communication diagrams and data flow diagrams formed the least previously used types. Around half of the participants had prior experience with the three hierarchical-link diagrams (stakeholder diagrams, information diagrams and process content diagrams).

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 eight models based on the simplified patient discharge process are included below along with further findings.

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

Stakeholder diagrams

Stakeholder diagrams are similar to organization charts and show how stakeholders are hierarchically structured. 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.

Information diagrams

Information diagrams show the hierarchical structure of documents or information. They were considered very helpful in understanding documentation issues such as the degree of standardization 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.
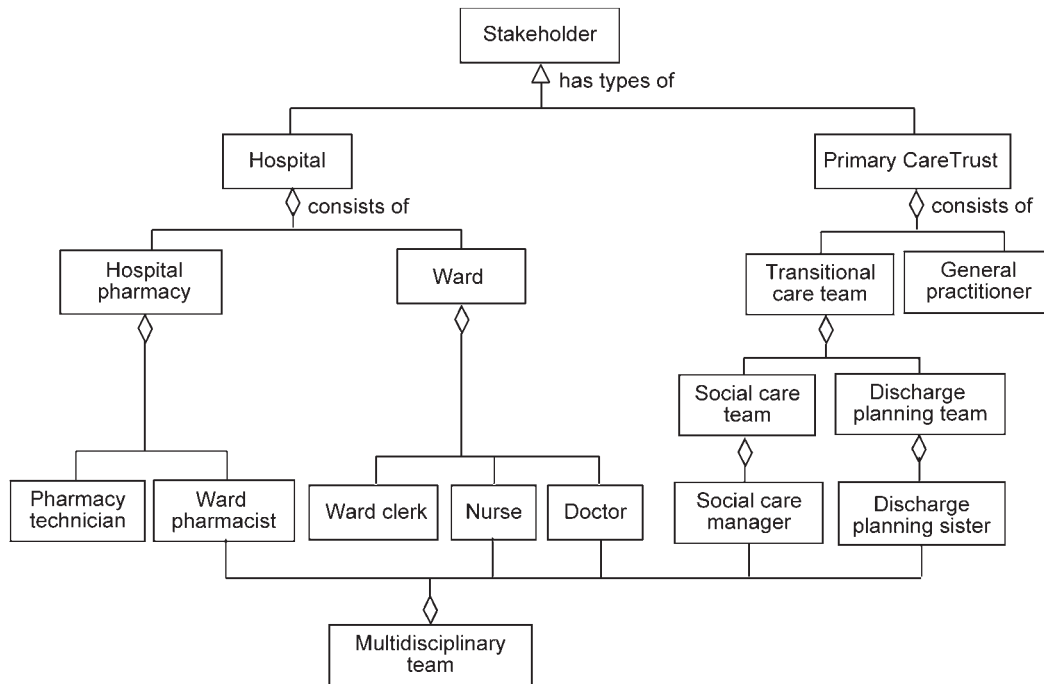
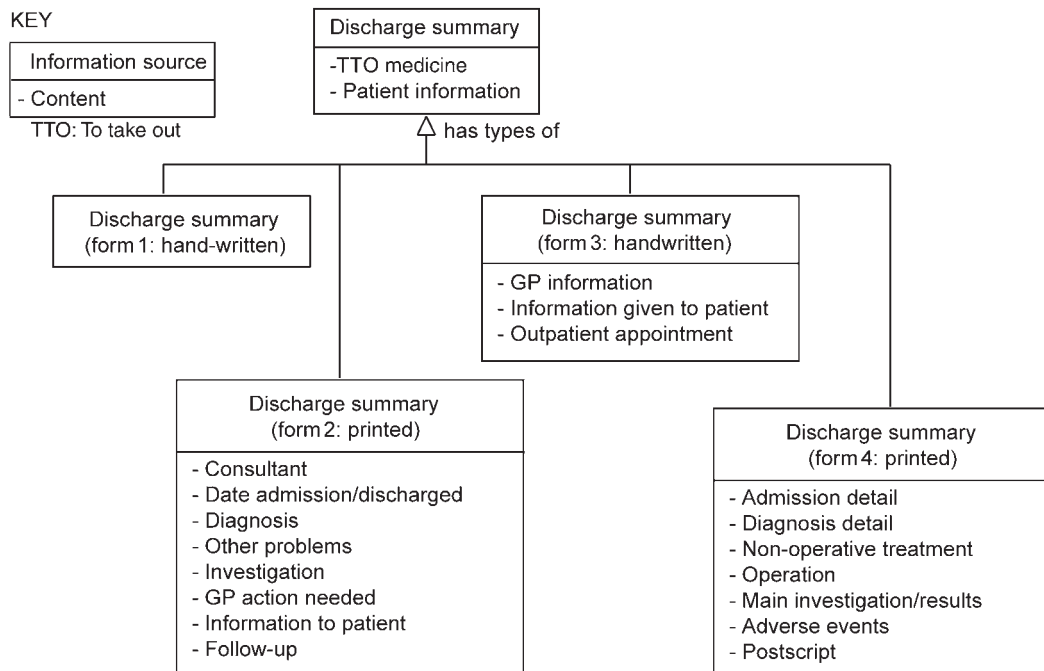Figure 1 Stakeholder diagram of a simplified patient discharge process.

Figure 2 Information diagram of a simplified patient discharge process.

Process content diagrams

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

Flowcharts

Flowcharts are very widely used to describe the sequence of activities as Fig. 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
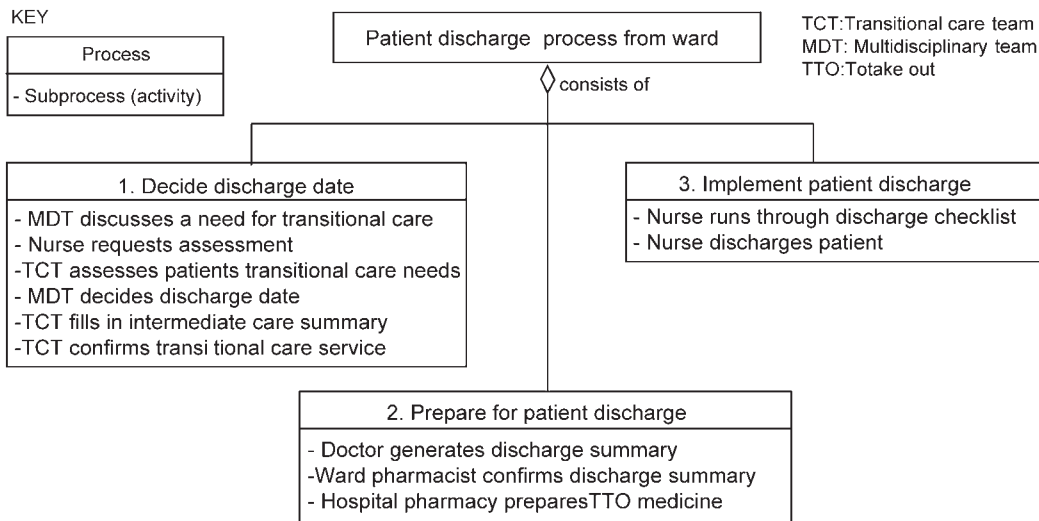
KEY

Process
- Subprocess (activity)

Patient discharge process from ward

◇ consists of

TCT:Transitional care team
MDT: Multidisciplinary team
TTO:Totake out

1. Decide discharge date
- MDT discusses a need for transitional care
- Nurse requests assessment
-TCT assesses patients transitional care needs
- MDT decides discharge date
-TCT fills in intermediate care summary
-TCT confirms transi tional 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 preparesTTO medicine

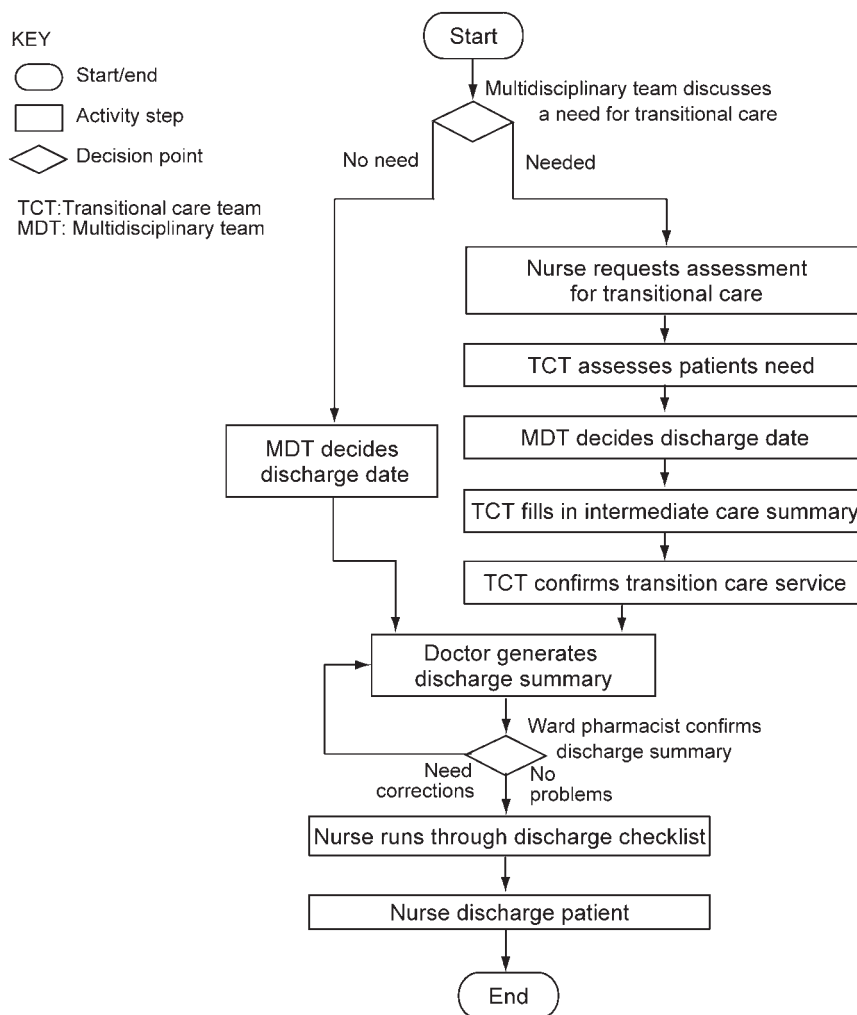**Figure 3** Process content diagram of a simplified patient discharge process.

Figure 4 Flowcharts of a simplified patient discharge process.
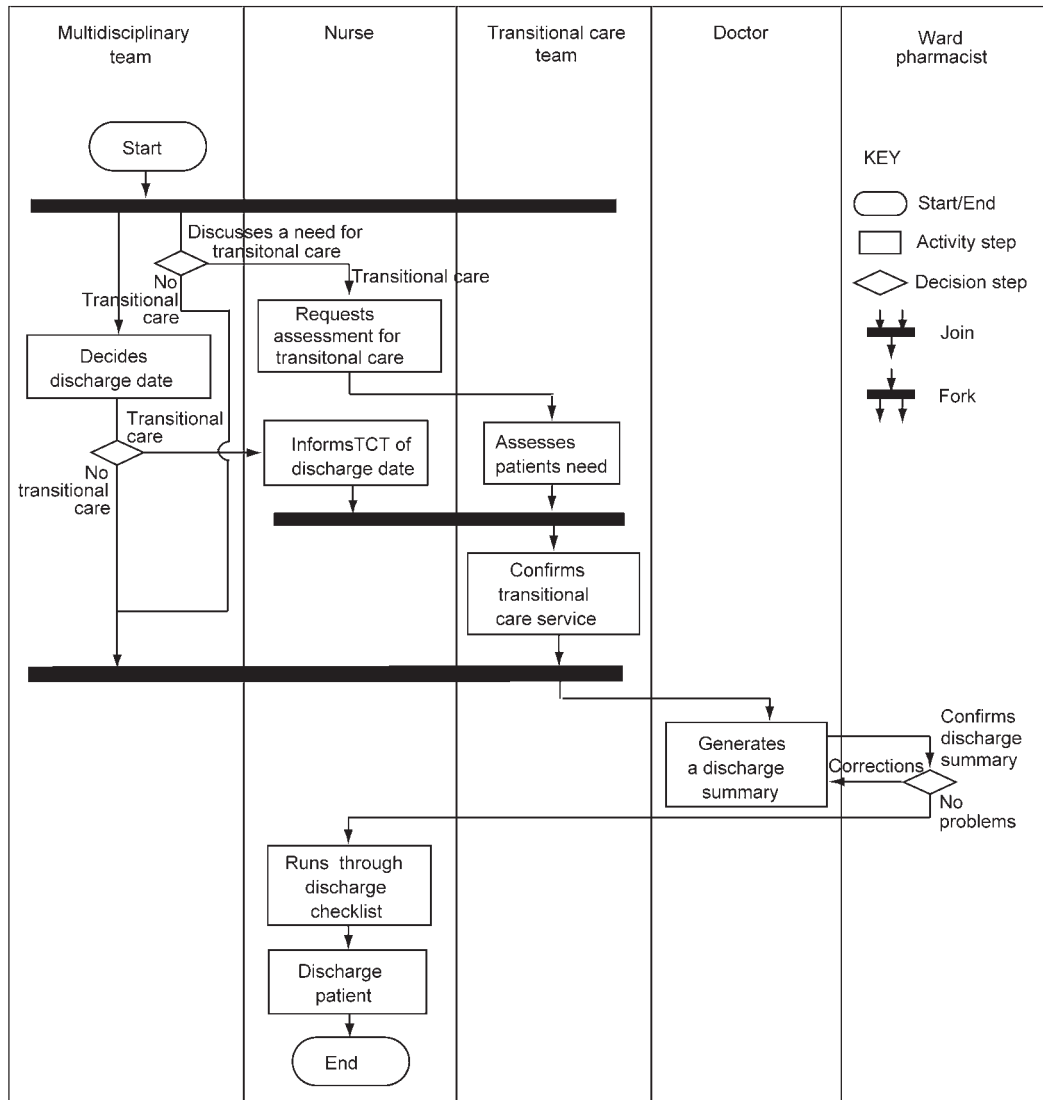
Figure 5 Swim lane activity diagram of a simplified patient discharge process.

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

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.

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) [26]. 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.

State transition diagrams were rated as the second most helpful (71%) in understanding care processes in spite of the participants' relatively low usability perception (59%) 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,
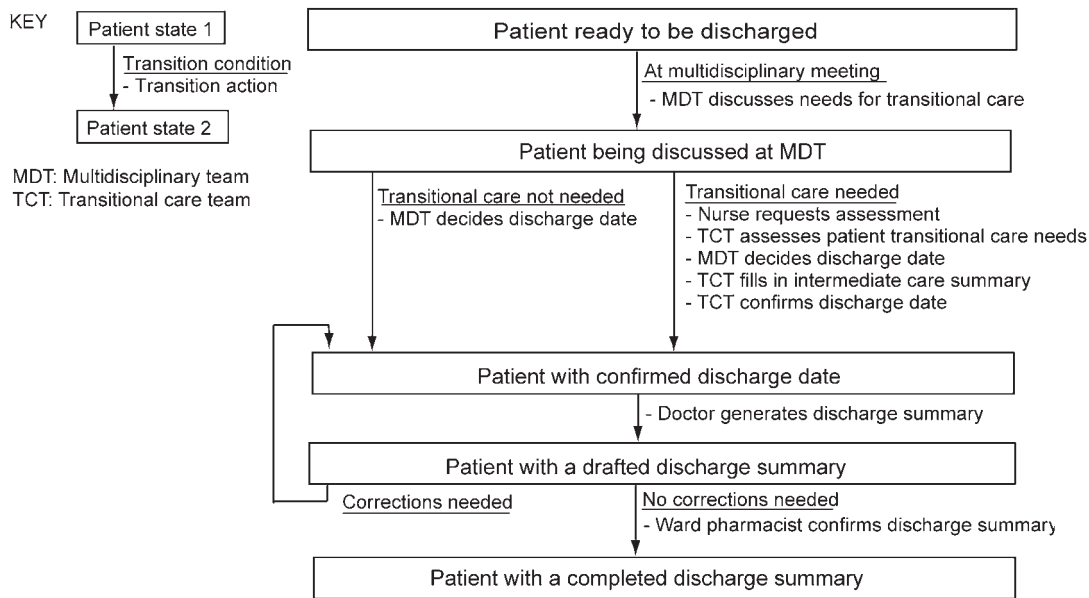
Figure 6 State transition diagram of a simplified patient discharge process.
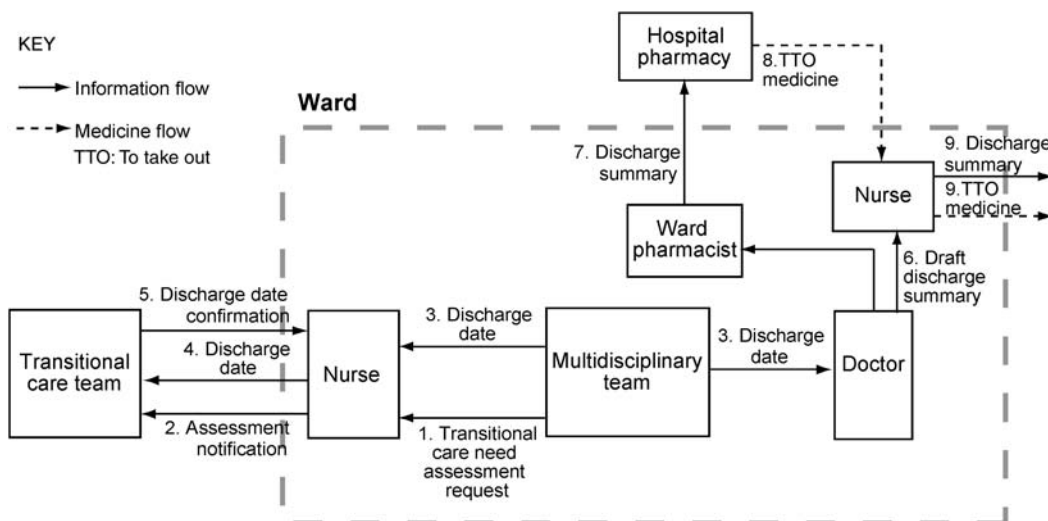

Figure 7 Communication diagram of a simplified patient discharge process.

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 Fig. 7.

Data flow diagrams

Data flow diagrams were originally developed to show how information is processed and where information is stored [26] as shown in Fig. 8. Data flow diagrams were rated understandable and helpful in 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.

Discussion and conclusions

Through the diagram characterization, we identified eight different diagram types representing most of the primary functions of process modelling. The diagram characterization reconfirmed that models are all simplifications of a certain view of reality [24] and a single diagram cannot effectively capture every aspect of complex health care delivery.

The diagram evaluation with the health care workers provided valuable insights into the advantages and disadvantages of each diagram in terms of their usability and utility in the
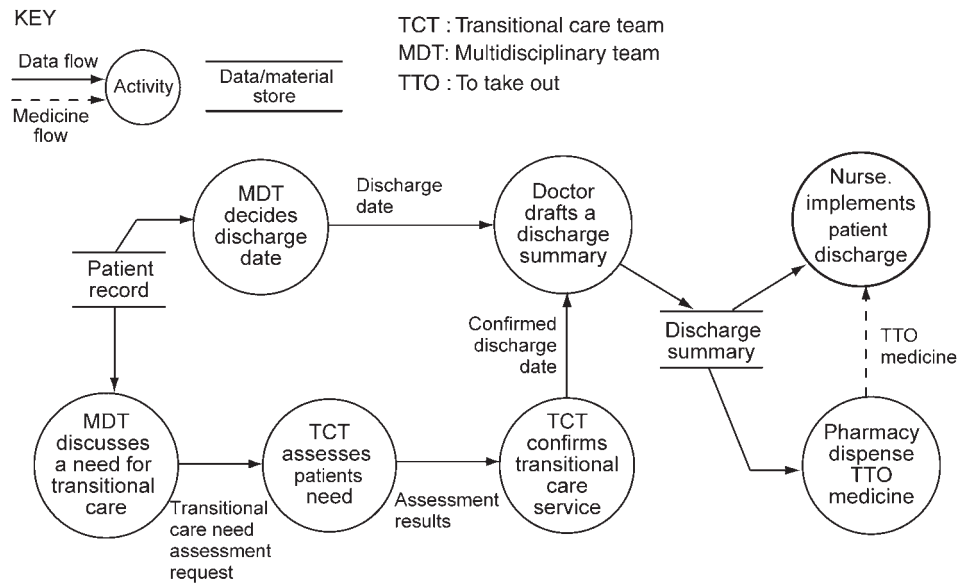
Figure 8 Data flow diagram of a simplified patient discharge process.

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 [27, 28], could be also helpful at the initial stage of the modelling. They were found helpful in understanding an overall process breakdown structure and describing subprocesses to the different levels of detail. Flowcharts, which were rated as the most favourable, can provide an effective base for initial system understanding and for building other diagram types as well, when necessary. At the same time, the limitations of flowcharts in understanding system interactions, were revealed through the diagram characterization and also noted by participants. 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 [29].

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, which has been known to be crucial for good quality care [30, 31]. 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 [32]. Data flow diagrams, which have primarily been used to represent human–machine interactions [33], 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–machine interactions in health care, where data interactions are main drivers.

Considering the findings from this study, we first recommend the use of multiple diagram types to deal with complexities in health care. Thus many inter-linked issues in health care between task, people and information/material can be more clearly understood through the use of multiple diagram types. The choice of diagrams at the first stage, though, is recommended to be made in consideration of its usability rather than utility. Especially when doing team-based modelling, where health care workers have different experience and familiarity with diagram types, it is important to build shared understanding using diagrams familiar to a wide range of users such as the three hierarchical-link diagrams and flowcharts. In addition, these diagram types can be easily generated using pen and paper or Post-its, which could be more suitable to team-based modelling. After building the basic understanding, care processes can be further modelled at the second stage according to the specific issue. When the issue of roles and responsibilities in a multidisciplinary team is a matter of concern, swim lane activity diagrams can be easily generated from flowcharts and stakeholder diagrams. When interactions between individuals, departments and trusts are key issues, communication diagrams can be generated from stakeholder diagrams and information diagrams. When data interactions between medical devices and humans are of great concern, data flow diagrams can be generated from process content diagrams and information diagrams. Overall care processes can also be understood in a more patient-centred way through state transition diagrams, which can be easily generated from flowcharts or process content diagrams. The diagram types recommended for the second stage could be difficult to generate from scratch, but can be

much easily generated when there are simple models to be based on.

We also 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 utilized in health care only when users are aware of the health care-specific utility and usability of each diagram type and make extra efforts to apply initially unfamiliar but eventually more effective diagram types.

Although more research is needed to examine the empirical utility with a large number of users, we believe that this study provides valuable insight into how health care can make the most of process modelling methods.

Acknowledgements

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