Analysis and Modelling of Materials Management Processes in Healthcare

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Abstract: Materials management is a great issue for healthcare systems because it influences performances of structures in terms of clinical and financial outcomes. Before selecting, adapting and implementing leading or optimised practices, it is necessary to develop a good understanding of processes and activities in place (Landry and Philippe, 2004). In real applications, information flows and business strategies involved are practically different from hospital to hospital depending on context, culture and resources available and this is the reason why it is really difficult to find a comprehensive and exhaustive description of processes, even less a clear formalization of them. The objective of this paper is twofold: first of all, it proposes an integrated and detailed analysis and description of the hospital materials management data and tasks - able to tackle information from patient requirements to usage, from replenishment requests to supplying and handling activities - according to medical risk reduction, traceability and streamlined processes perspectives; second, it translates this knowledge into a business process model formalization. The study can provide a useful guide to the various technology-related, management and business issues, laying the foundations of an efficient reengineering of supply chain that reduces healthcare costs without affecting the quality of care (Jarrett, 1998), but improving it instead.

Keywords: hospital materials management, business process modelling, healthcare information system, drugs inventory management, healthcare logistics

1. Introduction

The progressive reduction in public resources - and the subsequent need to restore budgets - makes governments responsible for finding solutions to achieve more operational efficiency in hospital processes. Drug expenditure, in particular, is a relevant factor in profit and loss account of healthcare systems (EUROSTAT 2011; Jarrett, 1998) and the hospital pharmacy management is called to adopt techniques to reduce drug inventory costs and maximize the cost-effective use of personnel and resources (Aptel and Pourjalali, 2001; Awaya et al., 2005; Oliveira and Pinto, 2005).

Awareness regarding the logistics viewpoint is getting widespread and many initiatives and studies concerning supply chain integration are undertaken (for example, supply outsourcing strategies (Nicholson et al., 2004; Lapiere and Ruiz, 2007), but internal supply chain (vs. external, that is beyond the boundaries of an organization) “remains the sore spot or weak link” (Rivard-Rover et al. 2002) in the process integration and optimization. This lack of systemic approach to internal supply chain management reflects on huge costs in materials management and low service quality delivered to patients (Landry and Philippe, 2004).

On the other side, indeed, hospital materials management (HMM) involves the clinical sphere of healthcare service performance. Clinical errors in drug prescription and administration, for example, are always possible depending on human factor and procedure issues.

Regarding to the resource use optimization, the difficulties of transferring directly the manufacturing best practice to the hospital environment are evident (de Vries, 2011), although the first sector of intervention is the inventory management (consider, for example, Rivard-Rover et al. 2002). Exploring reasons of economic inefficiency in this field, it is conceivable to suppose that the main problem is the existence of hidden stocks in order to avoid stock-outs [9], that seems to be more politically and experience-based driven rather than data-driven (Nicholson et al., 2004).

Looking at personnel, it is clear that a significant percentage of a pharmacist’s time is consumed by order entry, verification, clarification, and follow-up activities (Nold, 2011), the same applies for nurses with prescription transcriptions, stock level control and administration recording.

In order to achieve a comprehensive image of HMM process able to lay the foundations of an efficient reengineering of supply chain - reducing healthcare costs without affecting the quality of care (Jarrett, 1998) - , it is fundamental to consider the previously presented logistical and clinical perspective as both sides of the same coin.

In literature, there are many collateral references on how the materials management works; in real cases analysed, information systems are usually built for fragmented applications and many information gets lost or are not recorded when they flow throughout processes. This implies losses in traceability and increases in clinical risk,
while inventory management techniques and logistics are hardly performed, causing high inventory costs.

The objective of this paper is twofold: first of all, on the basis of literature review, real cases analysis and international guidelines, it covers the gap found, providing an integrated and detailed analysis and description of the hospital materials management data and tasks - able to tackle information from patient requirements to usage, from replenishment requests to supplying and handling activities - according to medical risk reduction, traceability and streamlined processes perspectives; secondly, it translates this knowledge into a business process model formalization, showing the integrated information and physical flows in order to trace and share data among actors with the aim to reduce clinical risk and time consuming tasks while enabling requirements programmability and, more in general, knowledge management.

The remainder of this paper is structured as follows: after the definition of the materials under examination, the main managerial intent is presented in section 2 (possibility to program materials replenishment while tracing order and consumption); the description of actors and processes in places is reported in section 3; the details about process modelling and analysis are given in section 4. Finally, conclusions and possible further researches are presented.

2. Hospital Materials, their traceability and requirements programmability

Management of materials in healthcare involves two kinds of items’ clusters, that is drugs (or medicines) and medical devices, subjected to different regulations harmonized by countries according to international guidelines. The properties of medicines in a hospital information system may be mandatory or optional depending on the contextual workflow. In addition to commercial drugs, drug administrations can also refer to galenics, such as personalized medicines prepared as a “mixture” of commercialized products at the bedside, in hospital pharmacy or in another defined medical unit. In parallel, medical devices can be required as surgical kit and apparatus compounded by many of them, that can be managed as single items by pharmacists or directly supplied as a pack. The item list (in other words, the set of medicines or medical devices that can be administered/dispensed or implanted to patient in a healthcare system) changes from hospital to hospital, depending not only on healthcare services managed, but also on physician’s expertise and preferences and following pharmaco-economics principles.

Materials traceability, from their admission to hospital till their consumption for a patient, is extremely important for clinical reasons (all information about medical processes should be recorded and available for checks), accountability reasons (to monitor expenditure and its attributions) but also for management motivations. Indeed a prescription, that is the step before materials delivery to patient in the most part of the cases, can be used to program replenishments or orders on the basis of patient needs and not only the past consumption. Materials requirements programmability can have an enormous impact on inventory management techniques, but it is not really developed because of the lack of managerial culture in the healthcare environment together with the difficulties in implementing accurate and usable information systems.

The material requirements programmability as a function of materials consumption traceability is reported in Fig. 1. In particular, events involving materials consumption are ranked from the least traceable to the most (the independent variable) as follows: “general” goods usage (by definition untraceable), materials employed for exams (traceable if the information system provides this feature), materials dispense (not traceable when it comes to administration because it is performed at patient home) and materials administration / implant (traceable till the end of the process, because the usage of an identified material, with its characteristics, expiration date, batch number, etc., can be fully recorded). On the other axis there is the materials requirements programmability that goes from the possibility only to forecast the consumption of some materials in a period of time, to the highest probability that a particular consumption is going to take place in a specific moment. On the diagram, activities concerning patient care are placed.

![Figure 1. Programmability of hospital materials requirements as a function of traceability of consumption](image)

It is clear that, when a prescription (for in or out-patient) is placed at a certain time before administration, time is given to organize medical unit replenishments or supply activities, while immediate needs have to use the local safety stock or be managed as a urgency. On the other hand, general goods usage is predictable with a low uncertainty as it is easily forecasted by time series techniques. Almost the same applies for exam demand. Outpatient dispense is in the middle of this plane because it regards a prescription kept by pharmacy for a period of time, but the exact date in which the patient will ask for these materials is not known.

Giving that “a plan must cover a period at least equal to the time required to accomplish it” (Fogarty et al., 1991), timing is a fundamental property of prescriptions, medical unit replenishment requests and supply orders. Indeed,
promising deliveries have to be based on what is or will be available (and not already committed) at their due time, entailing considerations about fulfillment feasibility. In particular, if the drug to be administered results unavailable in medical unit stock at the administration time, the check to carry out in order to evaluate the programming feasibility depends on the time given to perform the replenishment and/or supplying (in case of unavailability also in the hospital pharmacy stock) with respect to the requirement time. Generally, a prescription refers to more than one administrations of the same drug also in different doses. In particular, given that:

\[ a \in A \text{, set of administrations, each one with a number of attributes that is:} \]

- \( P_a \): prescription date-time, when a physician states the prescription that refers to the administration;
- \( D_a \): administration date-time;
- \( F_a \): drug prescribed, with the attribute:
  - \( L T_{F_a} \): Supply Lead Time for the drug \( F_a \), time between ordering a supply and receiving the order;
- \( Q_a \): administration quantity;
- \( M_a \): medical unit where the patient (to whom the prescription is assigned) is hospitalized, with the attribute:
  - \( T T_{M_a} \): average transportation time, needed for bag preparation and physical transportation from the pharmacy warehouse to the warehouse of the \( M_a \) medical unit.

If (1) is true:

\[ P_a < D_a - TT_{M_a} \]  \hspace{1cm} (1)

then the replenishment for the administration \( a \) is programmable, otherwise it is urgent and a compression in the \( TT_{M_a} \) is required, obtaining the following (2):

\[ CTT_{M_a} = D_a - TT_{M_a} \]  \hspace{1cm} (2)

where \( CTT_{M_a} \) is the compressed transportation time to fulfill a replenishment on time in case of urgency of the medical unit \( M_a \).

The same applies in case the material is unavailable in the pharmacy warehouse. If (3) is satisfied:

\[ P_a < D_a - (LT_{F_a} + TT_{M_a}) \]  \hspace{1cm} (3)

then the supply dependent by the administration \( a \) is programmable, otherwise, it has to be compressed to fulfill the requirement on time.

3. Materials management elements: actors and processes

The first step to conduct the hospital pharmacy “micro-world” reengineering process towards optimization is to identify the behavior of this system, such as what to manage in terms of materials, actors and processes, taking into account information and legal constraints.

Having already given highlights about materials, the following paragraphs regard with actors and processes.

3.1 Actors involved in HMM

The following distinction is made taking into account the level at which the actors participate to the HMM, that is:

- **Medical Unit actors:** together with patient needing for care, physician (who delivers the care), nurse (who dispenses the care) and nurse manager (who supervisions the dispense of care) are basically the other actors involved at the medical unit materials management stage;
- **Pharmacy Unit actors:** international health care standards require a central pharmacy unit in hospitals that maintains and provides the inpatient pharmacy needs (Joint Commission International, 2011). The pharmacy unit is usually composed by hospital pharmacists, storekeepers and transporters;
- **Other organizational functions:** the Medical Director, the Superintendence and Treasure’s Office, the Accounting Office take part to the process.

3.2 Processes composing the HMM

Irani et al. in Vergidis et al. (2008) sustain that businesses should not be analyzed in terms of the functions in which they can be decomposed to or in terms of the output they produce, but taking into account the key processes they perform. The hospital medication workflow is triggered by patient needing drugs and medical devices. In this perspective the Technical Framework, developed for the pharmacy domain by the initiative Integrating the Healthcare Enterprise (IHE), was born to stimulate the integration of healthcare information systems operating with different standards (such as DICOM, HL7, etc.). In the proposed pharmacy interoperability model (IHE, 2011), the care path (clinical perspective) described is orthogonally combined with the supply path (logistical perspective) in the phase of distribution but - as explicitly stated - supply chain of ordering/delivering medication and stock management are out of IHE scope.

According to the Irani et al. opinion, we adopt and refine the IHE pharmacy interoperability model as an “information track” to classify and describe all the elements depending on logistics decisions in the hospital medication workflow. We readapt that model to define in more detail different care paths, distinguishing among the type of medicine or medical device employed; moreover, we explore the management area, depicting all the processes involved.

![Figure 2: Process Framework of Materials Management in a Hospital (the notation used is explained)](image-url)
Analyzing some hospital cases, literature review and international guidelines and considering the clinical/logistical perspective, we define the hospital materials management as to be composed by the main following macro-processes, that are fully described, together with their sub-processes (reported in Fig. 2) in the next sections:

(a) Patient Management
(b) Medical Unit inventory Management
(c) Centralized inventory Management

4. HMM process model

Business process management analysis is worldwide accepted to play “a major role in the perception and understanding of business processes” (Verdigis et al., 2008), that spans from organizational, managerial issues to information systems and even social problems (Trkman, 2010). Trkman, states that understanding and analyzing a business process “helps to recognize the sources of problems and ensure that they are not repeated in the new process”, thus providing a measure of value for the proposed changes.

Many authors have provided frameworks for presenting and classifying different business process modeling techniques. Using the classification proposed by Verdigris et al. (Verdigis et al., 2008) among Diagrammatic, Formal/Mathematical and Business Process Language models, we choose to use one technique from the last area – that allows for “tackling the complexity of the formal models but retaining their consistency and potential for further analysis” and, in particular, the Business Process Modeling Language (BPML), being the most distinctive.

BPML, defined by the Business Process Modeling Initiative, is also an XML-based language that encodes the flow of a business process in an executable form. BPML is accompanied by Business Process Modeling Notation (BPMN), a graphical flowchart language that is able to represent a business process in an intuitive visual form. Each BPML process has a name, a set of activities, a handler and also supports sub-processes.

In what follows, the three processes previously described are visually represented with the BPMN. For clarity and easiness of understanding, the representation is confined within the limits of drug to be administered, excluding the other reasons of consumption indicated in Fig. 1.

4.1 Patient Management process (a)

The representation of this first process is showed in Fig. 3. Three actors take part to the process (physician, nurse and pharmacist) that is composed by 3 sub-processes:

(a) Prescription, that is: (a.1)Drug Prescription or surgical intervention plan and (a.2)Exam prescription;
(a.3)Materials delivery to patient, already presented in Fig. 1 as: (a.3.1)Preparation, administration or implant (inside dispense), (a.3.2)Dispense to patient (outside dispense), (a.3.3)Exam accomplishment and (a.3.4)“General” goods usage.

The process entity that flows throughout the system is the drug prescription. According to clinical risk reduction, in the J frame of Fig. 3, the patient identification is performed before the prescription, that is provided also of diagnosis, anamnesis and double reconciliation. In the K frame, the prescription is split in the dependent administrations, that are evaluated in terms of dose availability at the administration time $D_{a}$ and possibly activate the (b) process. The possibility to manage urgent deliveries caused by unavailability of administration materials is also presented. Delivery urgencies mean lead time compression and, consequently, higher delivery costs, not excluding being behind schedule. However, they may be easily evaluated by the physician before activated. Indeed, according to administration urgency, a time can be given to the physician to answer the question about the feasibility of the administration behind the schedule, providing him with the information about the ‘ordinary delivery time’ in comparison with the expected one obtained by urgent procedures. In particular,

$$OD_{a} = \begin{cases} P + TT_{M} & \text{if the material is available in hospital pharmacy warehouse} \\ P + TT_{M} + LT_{F} & \text{if the material has to be supplied.} \end{cases}$$

Figure 3. Patient Management Process frames (J, K, M and L)
If the OD$_a$ is considered as acceptable, the possibility to delay the administration or change it is contemplated. In the L frame, at the D$_a$ occurrence, an availability check is done and, if negative, an administration feasibility evaluation is asked to the physician when the material becomes in stock. Then, nurses carry out picking and preparation activities. After transportation and patient identification, the prescription check is performed (right patient, right drug, quantity, etc.), administration is done and, at the end, recorded.

In the M frame, the cancellation of the prescription, or the discharge of an inpatient, are transmitted to (b) process.

4.2 Medical Unit Inventory Management process (b)

The first element to consider when modeling the (b) process is the management technique adopted. Going to the bottom of the issue, the two fields of intervention which need to be globally optimized are medical unit replenishments and pharmacy supplies. Look-back (for example Re-Order Level, Re-Order Cycle, Just in Time), look-ahead (for instance Material Requirements Planning) or mixed (for example Vendor Managed Inventory) approaches can be used. All of these approaches can be adopted inside the same healthcare system depending on the item characteristics (ordering prices, inventory costs, shelf life, demand mean and deviation, etc.). Look back approach is more popular than the other ones but it brings to higher inventory levels. Moreover, forecasts on aggregate data about consumptions recorded by pharmacy are influenced by medical unit management techniques. Look-ahead methods, instead, need for careful and punctual information about requirements forecast.

As Nicholson et al. (2004) claim, the most traditional servicing approach is the periodic review par level (or order-up to level), that requires to set the review interval and the optimal security stock (base stock level). While the second depends on therapeutic and medical constraints set by taking into account demand variability, the first has to be defined according to resources involved.

Some examples of re-ordination strategies come from Kalmeijer et al. (2003), who promote the extensive use of Information Systems to manage requirements considering the default medication database as the local stock. Non-stock items are automatically ordered from pharmacy, instead.

In what follows, the description of the two activities composing the Medical Unit Inventory management process is reported:

(b.1) Medical unit stock management and replenishment (handling of incoming and wasted materials, dispensing and keeping the warehouse management system up-to-date; defining replenishment requests);
(b.2) Pharmacy requirements assessment.

4.3 Centralized Inventory Management (c)

This process (Fig. 4) is triggered by a medical unit requirement. The centralized inventory management can be interpreted as substitutive with respect to the medical unit inventory management or in line with it. Both of these representations are given, but a distinction between them is needed because, if pharmacist knows the medical unit real patients’ needs in a period of time (expressed in terms of unit doses), he can authorize the transport of the net requirements rounded up in drug packages. If not, the decision can be taken by the medical unit nurse manager but, without sharing the punctual information about needs and their timing, no availability considerations can be carried out by pharmacists in case of urgency.

The sub-processes involved are:

(c.1) Pharmacy stock management, order disposition and supplying activities (N frame of Fig. 4, comprehensive of budget reconciliation and O frame, that reports the design of the urgent deliveries management process (condition (1) or (3) are not met));
(c.2) Internal distribution (in the Q frame, the storekeeper is provided by a list of withdrawals for each medical unit while urgent deliveries are managed by their own. In both cases, a bin is given to the transporters to be consigned. They are also in charge of taking wasted materials to hospital warehouse);
(c.3) Materials Admission, Quality control and Payment (P frame).
5. Conclusions

This paper proposes an integrated and detailed analysis of the hospital materials management processes and translates this knowledge into a business process model formalization, merging clinical and managerial objectives. In the clinical perspective, it allows to enhance patient safety through clinical risk reductions and limiting, among others, time consuming tasks of all actors, to be ready in case of recall and to efficiently manage drug shelf life and expiration dates. From the management point of view, it lays the foundations for optimising the HMM because an exhaustive, robust and flexible basis of information can allow (as an option of the model) the execution of all logistical activities by a centralized function (the hospital pharmacy), living medical staff to its clinical activities and programming replenishment and supply tasks on the basis of the real materials needs of patients.

This study provides researchers and practitioners with a useful guide to the various technology-related, management and business issues that can arise during the design or reengineering of the HMM and the related information system.

Moreover, the concept behind business process languages (as the BFMN here used) is to make a process executable, and hence, amenable to quantitative analysis (in primis the simulation, as the most frequently proposed in literature (Vergidis et al., 2008)), being a useful method to evaluate the organizational expected impact on performances of the HMM.

Finally, modeling the data sharing and the integration and coordination among actors and activities, the proposed HMM gives the guidelines for the design of a common and distributed information platform that can be used, besides, to collect data, identify key performance indicators and compare them in different management techniques scenarios, carrying out performance evaluations; moreover, it can be used to implement accurate activity based costing systems, also time-driven, as in line with the recent publications by Kaplan and Porter (2011).

References


