Evaluating the Efficacy of Knowledge Management Towards Healthcare Enterprise Modelling

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Abstract

Driven by manifold external, internal, technological and information-driven pressures, many organisations are now turning towards the emerging domain of knowledge management to seek practical knowledge-driven solutions for acquiring premium efficiency, value-added services and business advantages. The healthcare industry—operating as an extended enterprise—owns, produces and manipulates a spectrum of knowledge. But, due to lack of systematic and formal programs/mechanisms to convert, retain and transfer healthcare knowledge one can argue that prime facie the healthcare enterprises is 'data/information rich' but 'knowledge poor'! In this paper we suggest that the healthcare enterprise need to be more conscious of its vast knowledge resources vis-à-vis the exploitation of knowledge management techniques to efficiently manage the healthcare enterprise's knowledge. The development of organisational memory, or in this case, healthcare enterprise memory, is suggested as a solution, together with a novel approach advocating the operationalisation of organisational memories leading to modelling healthcare processes for strategic planning. To demonstrate a exemplar healthcare modelling exercise we present a simulation of the workflow to achieve zero waiting time in a hospital's out-patient department.

1 Introduction

The role of information technology in healthcare is well established and its practice a time honoured tradition. The business of practising medicine is becoming ever so complex that it is consistently pushing the sophistication of information technology tools and techniques to newer frontiers. Lately, there is a growing demand from the healthcare community to leverage upon and transform the vast quantities of healthcare data and information into value-added, 'decision-quality' knowledge—a move towards a knowledge-theoretic environment.

Indeed, the healthcare enterprise is coming to terms with the prevailing sentiment (shared by many other industries) that in an IT-driven world, knowledge is one of the enterprise's most significant asset. Notwithstanding the importance of healthcare data and information (information = data + substance + purpose) [Harris, 1996], together with the gamut of IT technologies/techniques to process, analyse and operationalise them, the fact of the matter is that data and information are no longer the main focal points. Rather, considering all its functional constraints the healthcare enterprise need to work with healthcare knowledge (knowledge = information + context + experience) [Harris, 1996]. The healthcare enterprise, through medical practices and active R&D efforts, is probably one of the largest manipulator/agent of a spectrum of knowledge types and resources. Yet, *prime facie* due to the lack of systematic and formal mechanisms to convert, retain and transfer healthcare knowledge one can argue that healthcare enterprises are 'data/information rich' but 'knowledge poor'!

The task at hand now is to identify a 'knowledge environment' that supports mechanisms to not only create or even capture viable healthcare knowledge and experiences but also to operationalise them to positively impact the healthcare enterprise. This brings into relief the need to establish the role and significance of the emerging methodology/technology of *Knowledge Management* in healthcare.

In this paper, we present a case for the possible application of knowledge management techniques in the healthcare domain. In view of the current perception and complex modalities concerning the healthcare domain, we regard it as an extended enterprise, hence the term *healthcare enterprise*. Firstly, we will identify the tenets of the healthcare enterprise, illustrating how healthcare knowledge can be captured, retained, shared and transferred via a suite of healthcare knowledge bases. Note that the healthcare knowledge bases are deemed to be operated by the various players in the healthcare enterprise—providers, person, management, policy makers, etc—to meet diverse needs and services. Next, capitalising on available knowledge management services

and processes, we will put forth the concept of a *healthcare enterprise memory*—akin to organisational memories—a structure that can support the sharing and reuse of individual and enterprise-wide knowledge, experience, and lessons learnt. We will show that a healthcare enterprise memory can provide a number of knowledge-oriented services, such as automatic dissemination of knowledge, permanent knowledge encapsulation, reuse of knowledge and experience, support of intelligent knowledge management services, timely provision of knowledge and experience, transformation of information to action and above all ***healthcare modelling***. Next, we will present a case for the operationalisation of the healthcare enterprise memory, vis-à-vis, the modelling of healthcare processes—based on healthcare knowledge contained within the healthcare enterprise memory—for strategic planning and knowledge-driven decision making. To substantiate our argument we will present an ad hoc healthcare modelling exercise, whereby we will simulate the workflow constraints necessary to be addressed in order to achieve *zero waiting time* in a hospital's Out-Patient Department (OPD). We will conclude that the synergy between healthcare enterprises and knowledge management brings about a win-win situation, thereby realising a knowledge-theoretic healthcare environment.

2. A Knowledge-Centred Overview of the Healthcare Enterprise

The healthcare environment is indeed very diverse, and many factors come into play to ensure the efficiency and effectiveness of healthcare services. Before we proceed further to discuss the role of knowledge management in healthcare, it is worthwhile to examine some general characteristics of a healthcare enterprise.

- *A People Centred Enterprise*: The business of healthcare addresses both the wellness maintenance and illness management of individuals. Hence, all emanating services are targeted towards the person. Indeed, advances in IT and other technologies have yielded an array of sophisticated systems and devices for healthcare providers, yet they all are means to a common end—the improved delivery of healthcare services. So, in essence the healthcare enterprise is a people-centred enterprise.
- *An Outreaching Enterprise*: A healthcare enterprise reaches out to the community. This is in contrast to any banking enterprise, whose services are provided only at a designated location and the public need to converge at these locations to enjoy the services.
- *A Knowledge and Experience Dependent Enterprise*: The delivery of healthcare service involves an active interplay between (medical) knowledge and experience. Healthcare professionals employ their knowledge, acquired from their studies, in tandem with acquired experience to deliver quality healthcare services. Furthermore, the vitality and progress of the healthcare enterprise demands the sharing of knowledge and experiences; professionals need to both contribute to and procure from knowledge within the healthcare enterprise. Along the sideline, it must be noted that most healthcare knowledge and experience inherently belongs to healthcare professionals. Hence, there is a strong need to acquire expert medical knowledge and experience and retain it so that it can be transferred to other professionals.
- *Active Research and Development*: The healthcare environment is indeed a very dynamic one. Research and development (R&D) is being carried out all over the world and in various fields. New knowledge and experience is constantly created. The R&D findings need to be permanently recorded for future references. Presently, healthcare enterprises rely heavily on human efforts to perform tasks such as knowledge acquisition, dissemination, and storage. However, it must be noted that the task of managing such a great amount of knowledge is never easy and requires a formal methodology and a suite of knowledge management tools and techniques.
- *Resource Critical*: The availability of resources is critical for any healthcare enterprise. Resources in terms of time, personnel, medication and equipment are vital in ensuring that patients are given all that is necessary for a speedy recovery. Hence, the need for practical resource allocations.
- *Performance Based Evaluation*: The healthcare enterprise is extremely performance critical, because it is dealing with human lives. For that matter, it is imperative to determine the competence of healthcare professionals—management needs to know what they can do and not just what they know. Hence, benchmarking and the transfer of best practices are at the heart of any healthcare enterprise management system.

3. Understanding Knowledge Management in a Healthcare Context

In a healthcare context, it can be argued that Knowledge Management (KM) is the formal management of knowledge for facilitating the creation, identification, acquisition, development, dissemination, utilisation, and preservation of a healthcare enterprise's knowledge using advanced technology [O'Leary, 1998a; Abecker *et al.*, 1998]. More so, KM also involves:

(a) converting knowledge from the healthcare enterprise's sources (individuals, groups, data and text), and

Figure 1: The Knowledge Management Framework [O'Dell and Jackson Grayson, 1997]

(b) connecting healthcare participants—healthcare professionals, management and patients—with that knowledge. [O'Leary, 1998b]

A typical KM framework is shown in Figure 1. In Figure 1, we note the existence of the term—*knowledge management enablers*. These are considered to be the factors that influence the development of the *knowledge management process*.

3.1. Knowledge Management Processes

Figure 1 (above) illustrates a number of KM processes that observe a cyclic arrangement, i.e. the preceding process providing input to or influencing the subsequent KM process. For our discussion, we regard *creation* as the initial process of the KM framework.

1. ***Create***: Responsible for the creation of healthcare knowledge, possibly through trial-and-error or blind variation and selective retention methods.
2. ***Identify***: Determines the existence of useful healthcare knowledge from the knowledge created in the earlier process. This can be achieved through mining efforts similar to that of data mining and knowledge discovery.
3. ***Collect/Acquire***: Once useful knowledge has been identified, next follows the process of acquiring the knowledge.
4. ***Organise/Develop/Preserve***: This can be viewed as a form of 'knowledge processing' whereby the knowledge is transformed, represented, and organised in a defined format. This process also concentrates on the explication of tacit knowledge which is supported by expert systems, issue-based information systems, best-practice databases, and lessons learnt archives. Similarly, knowledge capitalisation aims to allow the reuse of knowledge of a given domain previously stored and modelled in order to perform new tasks [Simon, 1996].
5. ***Share/Disseminate***: Provides the mechanisms to disseminate the stored knowledge to all participants of the healthcare enterprise and possibly to other healthcare enterprises.
6. ***Adapt***: This process is typically the responsibility of healthcare professionals in their practice. Upon introspection of the 'created' knowledge healthcare professionals may then need to tailor it to ensure appropriateness, currency and accuracy.
7. ***Apply/Utilise***: Knowledge when not used is equally, if not more, useless and again, this process is typically the responsibility of healthcare professionals. The success of a healthcare KM framework depends on its success in providing knowledge that is being used effectively to meet the demands of the healthcare enterprise.

3.2. Typical Knowledge Management Applications in Healthcare

In order to face the above challenges and pressures from both external and internal forces acting upon the healthcare environment, there are a number of KM-based applications that can be mobilised to facilitate the management of healthcare knowledge. Here, we mention a few relevant KM-based applications within the healthcare domain..

3.2.1. Organisational Memory

An organisational memory (OM) is an integrated solution for effective context-sensitive knowledge management. Healthcare professionals are transient entities, but to maintain the efficiency of the healthcare enterprise it is imperative to retain their knowledge and experience. Along the same lines, one can identify a number of knowledge entities within the healthcare enterprise that need to be retained for strategic purposes. An OM provides the functionality to store, share and re-use individual and organisational knowledge, experience, and lessons learnt. An OM provides the user, working on knowledge-intensive operational tasks, with all the necessary and useful information for fulfilling these tasks. Euzenat [Euzenat, 1996] defines OM as a repository of knowledge and know-how of a set of individuals working in a particular organisation. Its main function is to enhance the organisation's competitiveness

by improving the way it manages its knowledge [Abecker et al., 1998]. We suggest that in the healthcare context, a typical OM may encompass *lessons learnt archives*, *distributed case bases*, *expert systems and formal knowledge structures*, and *formal representations of argumentation*.

3.2.2. Work Process Description

Work process description (or healthcare protocols) describe the necessary steps that need to be observed in order to perform various healthcare functions, for instance the sequence of tasks/process involved in the care of patients with a particular illnesses. In a dynamic healthcare environment, work process descriptions are constantly changing and evolving—a particular protocol may render ineffective as and when certain procedural changes are applied. To maintain sanity of work process descriptions, KM provides the opportunity to employ improved methods of acquiring, maintaining, customising and re-aligning healthcare protocols [Fridsma et al., 1997].

3.2.3. Knowledge Filtering

The healthcare environment routinely produces and procures a huge amount of knowledge; it is extremely difficult to both monitor the traffic and the quality of knowledge. KM provides solutions whereby the healthcare enterprise can resort to knowledge filtering applications to identify relevant knowledge and to ensure the completeness and correctness of knowledge produced and received before including them into healthcare repositories [O'Leary, 1998c].

3.3. Knowledge Management Tools and Technologies

Whether they realise it or not, most healthcare enterprises already possess the fundamental tools necessary to initiate a reasonable KM programme. Generally, KM tools facilitate knowledge generation, codification and transfer. Typical KM tools include the WWW, GroupWare, Internet, Intranets, databases and knowledge bases [O'Leary, 1998b; Ruggles, 1997]. Figure 2 below illustrates various KM tools or technologies in use.

4. Knowledge Bases in a Healthcare Enterprise

Prime facie, the healthcare enterprise is knowledge-rich. KM techniques and tools therefore render themselves as an efficacious technological solution for the acquisition, preservation and use of an enterprise's knowledge—typically the practice of *converting* (information to knowledge) and *connecting* (people to knowledge) [O'Leary, 1998b; Grey, 1998a]. In operational terms, KM is concerned with the formal management of knowledge, vis-à-vis, the identification/creation, procurement, access, dissemination, reuse, storage, and preservation of knowledge in knowledge bases. To derive premium efficiency, knowledge encapsulated in the knowledge base(s) can be operationalised to derive a number of knowledge-driven strategic services.

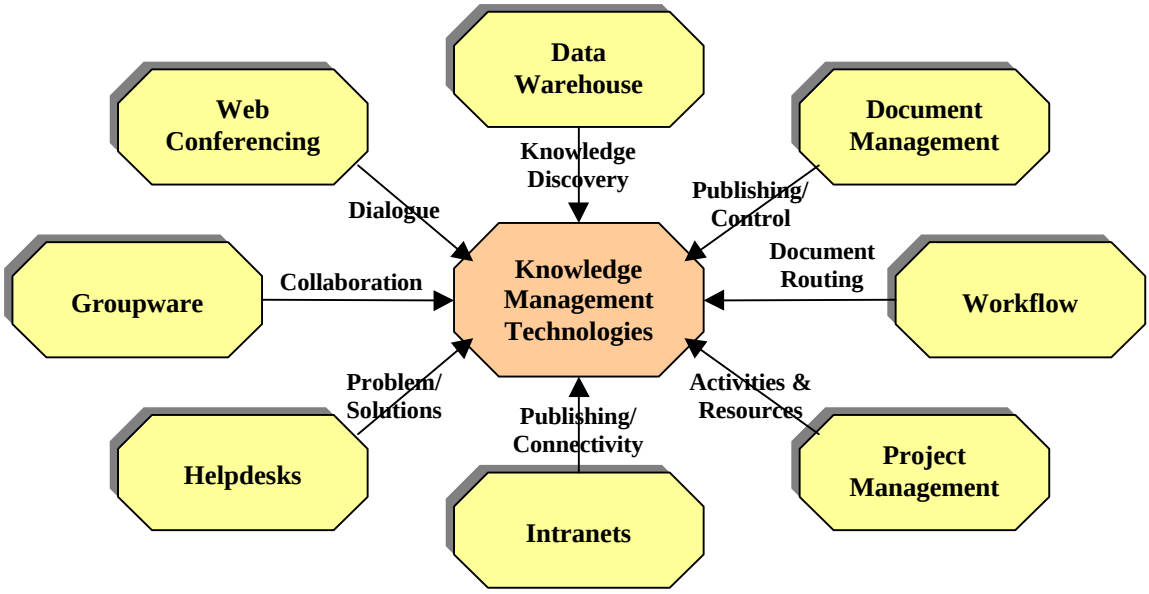

Figure 2: Knowledge Management Technologies [Grey, 1998a]

Types of Knowledge	Types of Knowledge Bases	Types of Knowledge Services
• Medical Knowledge • Organisational Structure • Operational Workflow • Protocols/Guidelines • Medical Procedures • Business Rules • Medical Knowledge • Patient/Community • Staff Profile • Resource Inventory (Human, Equipment, Building, Etc.)	• Domain Knowledge • Protocol Knowledge • Workflow Knowledge • Policy Knowledge • Lessons Learnt Knowledge • Admission Knowledge • Delivery Knowledge • Performance Knowledge • Discussion Knowledge • Business Knowledge • Change Adaptation • Communication Knowledge • Enterprise Documentation	• Healthcare Entity Modelling • Transfer of Best Practices • Benchmarking • Audit Trails • Resource Scheduling • Product/Service Evaluation • Product/Service Accreditation • Policy Revisions • Workflow Revisions • Training Programs • Business Ventures • *Strategic Knowledge Services*

Table 1: A view of healthcare knowledge, knowledge bases and knowledge services

Table 1 shows a sample of the various types of knowledge that we have identified to exist in a healthcare enterprise and hence can be captured using KM techniques. Furthermore in Table 1, we identify the different types of knowledge bases that can be created and administered within a healthcare enterprise; and finally, we suggest (in Table 1) the kind of knowledge-driven services that can be derived from the available knowledge bases.

4.1. The Need for Sub-Knowledge Bases

An informed look at healthcare knowledge reveals that it is extremely complex with multiple inherent relationships with other knowledge entities. Healthcare knowledge purports a broad scope that ranges from generic to highly specific—i.e. bringing into relief the possibility of a taxonomy of knowledge-bases. We propose that for the purpose of clarity of perspective and context, it is useful to further classify the typical healthcare knowledge bases (as shown in Table 1) into more specialised and well defined ***'sub-knowledge bases'*** (or child knowledge bases). We posit that sub-knowledge bases may contain specialised knowledge, but at the same time exist and operate in the same manner as their parent knowledge bases. For instance, if we take the knowledge base for healthcare enterprise protocols, it can be further categorised into more specialised protocols: for the OPD, the emergency unit, the dental clinic, admissions and discharges, and maintenance. With regards to the hierarchical taxonomy of knowledge bases, the OPD protocol sub-knowledge-base can be further partitioned into a number of sub-knowledge bases, such as medical protocols, medical check-up protocols, medical consultation protocols, and inventory requisition protocols. Figure 3 illustrates the hierarchical representation of knowledge bases. The proposal for sub-knowledge bases is still in its infancy and we are working towards the definition and implementation of the same.

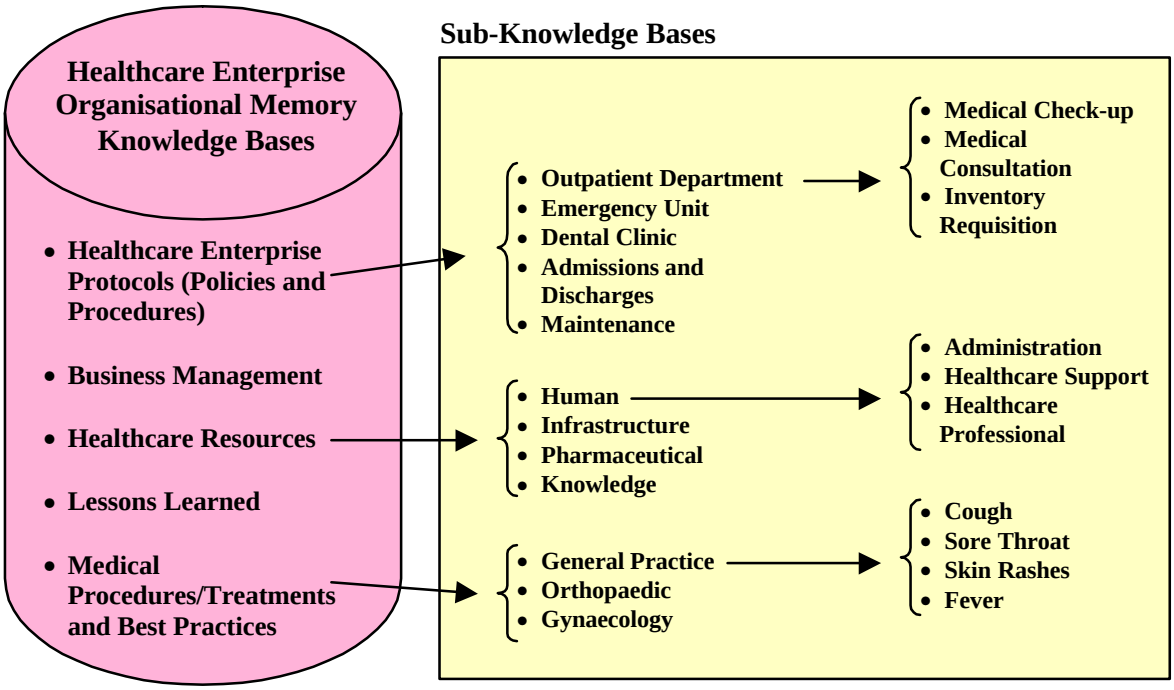

Figure 3: Organisational Memory Knowledge Bases

With regards to the proposal of implementing healthcare knowledge bases in a hierarchical manner, the issue of inter-knowledge base consistency is of extreme importance and we briefly discuss this issue.

4.2. Inter-Knowledge Base Consistency

We posited earlier that each knowledge base (existing at whatever level of the knowledge base taxonomy) is to be perceived as being independent and as a self-contained entity. Nevertheless, to address higher-level concepts and knowledge, it is possible that multiple knowledge bases, or at a more specific level the contents of the knowledge bases, may be formally inter-related with each other. We agree with the anticipated efficacy of this approach. However, at the same time, we deem necessary to impose certain constraints whereby:

1. Inter-knowledge base relationships need to be well defined and should in no way contradict or confuse the global knowledge schema.
2. Besides being accessed, knowledge bases are also reviewed and/or updated regularly. In case the contents of multiple knowledge bases are inter-related, the accuracy of one knowledge base will depend on another. Hence, there must exist 'autonomous' mechanisms in order to check the consistency of the knowledge bases when any one of them is to be updated.

As an example to the first constraint, the *healthcare protocols knowledge base* has a sub-knowledge base for *medical consultation protocols*. The details of medical consultation protocol may state that the healthcare enterprise will need at least 1 healthcare professional, 1 healthcare support staff and 2 administration staff to accomplish the designated tasks. Now, we may have another sub-knowledge base in the *healthcare resources knowledge base* that stores knowledge on human resources. Inter-knowledge base consistency will be reflected by the fact that both these sub-knowledge bases will quote the same number of staff for medical consultation duties.

As an example to the second constraint, the *general practice sub-knowledge base* may state that for headache, the standard drug to prescribe is Paracetamol. The same information is contained in the *pharmaceutical sub-knowledge base*. Now, if the *general practice sub-knowledge base* is updated, following a recommendation to make Aspirin the standard drug for headache, it is important to reflect this change in the other knowledge bases related to the *general practice sub-knowledge base.*

Figure 4 below illustrates the possible inter-relationships between various knowledge bases. Here, we propose the implementation of 'autonomous' mechanisms that follow the inter-relationships between knowledge bases to perform consistency checking and updating.

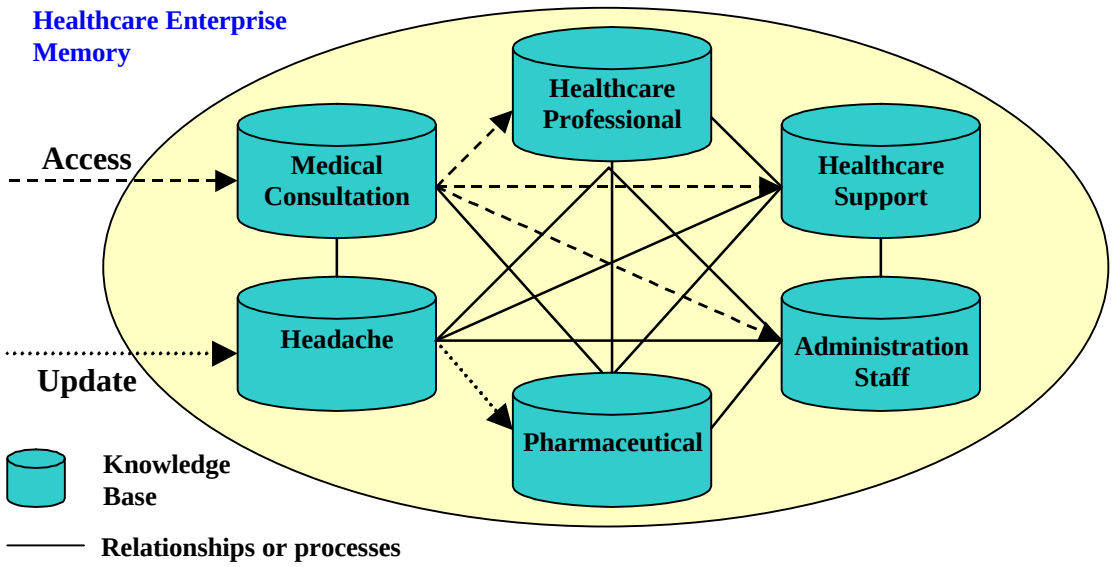

Figure 4: An environment supporting multiple inter-related knowledge bases

5. Healthcare Knowledge Management Using Healthcare Enterprise Memory

Central to most practical, context-sensitive knowledge management solutions is the Healthcare Enterprise Memory (HEM)—a structure similar to an organisational memory. HEM can be envisaged as a systematic confluence of various knowledge bases, managed by a common infra- and info-structure, that can be operationalised to deliver a variety of knowledge-driven strategic services. HEM provides the functionality to store, share and re-use individual and organisational knowledge, experience, and lessons learnt. Figure 5 shows the various knowledge-related actives that emanate from an HEM.

Below, we highlight the efficacy of HEM towards effective healthcare knowledge management:

5.1. Automatic Dissemination of Knowledge

By design, an HEM are out-reaching systems—equipped with a wide variety of knowledge bases, they can serve as a medium to disseminate knowledge to various clients. For instance, medical domain knowledge to healthcare providers, workflow or performance knowledge to healthcare administrators, performance/benchmarking knowledge to healthcare policy makers and wellness oriented knowledge to the public.

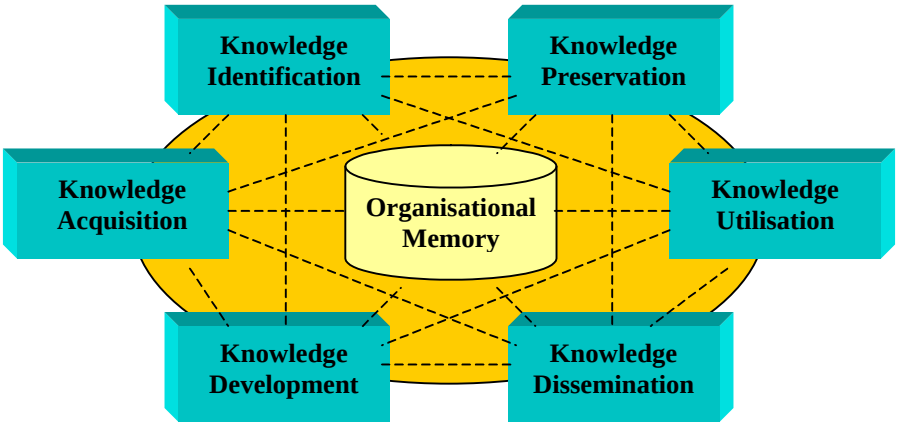

Figure 5: Healthcare Enterprise Memory and Knowledge Management services [Abecker *et al*., 1998]

5.2. Reuse of Knowledge and Experience

The healthcare enterprise is a dynamic one, with its knowledge mass always in a flux. It may enhance its knowledge mass with the arrival of knowledge workers or it may endure a loss to its existing knowledge mass with the departure of knowledge workers. HEMs are designed to retain, share and re-use individual and enterprise-wide knowledge [Abecker et al., 1998] for future use and reference—mimicking a kind of environment that learns or builds on its experiences. In this regard, HEMs also promote enterprise-wide learning and adaptation to avoid the repetition of mistakes committed in the past. Knowledge about past cases (medical protocols, documentation of experiences, etc.) all serve as stimulants for learning, leading to 'expertise transfer' and 'cross-project fertilisation' within and across enterprises [van Heijst *et al*., 1996; Nagendra Prasad and Plaza, 1996].

5.3. Support of Intelligent Knowledge Management Services

We know that the healthcare environment is greatly dependent on R&D efforts, hence there must exist an efficient mechanism to manage the knowledge that comes out of these efforts. HEMs can provide healthcare professionals working on knowledge-intensive tasks with all the information necessary for R&D activities and in turn also store the findings in a defined knowledge-base (for sharing and future reference purposes).

5.4. Timely Provision of Knowledge and Experience

For a healthcare delivery system to be effective, healthcare professionals must receive relevant healthcare information at the right time without being overwhelmed with a flood of irrelevant knowledge [Abecker et al., 1998]. An HEM can be put to use to facilitate the timely and pro-active delivery of knowledge from relevant knowledge base(s) to healthcare providers.

5.5. From Information to Action

An HEM is not to be perceived as a static knowledge storage system, rather they incorporate mechanisms that can help transform stored knowledge into action procedures. HEM-based *Intelligent Assistant*s [Abecker *et al*., 1998] can co-operate with healthcare professionals to jointly solve healthcare-related problems by firstly supplying the necessary knowledge without the user submitting retrieval queries to the system and then processing the knowledge to execute the task at hand.

6. Building a Healthcare Enterprise Memory: A Model

The term 'building' here refers to the modelling of an HEM with emphasis on knowledge representation, ontologies and creation of knowledge bases. In simple functional terms, an HEM can be created through the process of identifying, capturing and leveraging formal (e.g. texts and documents) and informal (e.g. experience and lessons learnt) medical knowledge from internal and external sources (see Figure 6).

According to Figure 6, the healthcare knowledge bases are to be populated by the abstraction of internal and external healthcare information/knowledge based on certain content identification criteria. The synthesis process transforms the abstracted knowledge into a formal representation scheme that renders it operable by computer systems. Finally, the emergent knowledge bases undergo a process of review or update to ensure the validity and consistency of the extracted knowledge.

For our purposes we propose a four-layer HEM model:

1. **Object Layer**: Consists of various healthcare information and knowledge sources. The sources may have both formal (machine-readable) or informal (human-readable) representations.

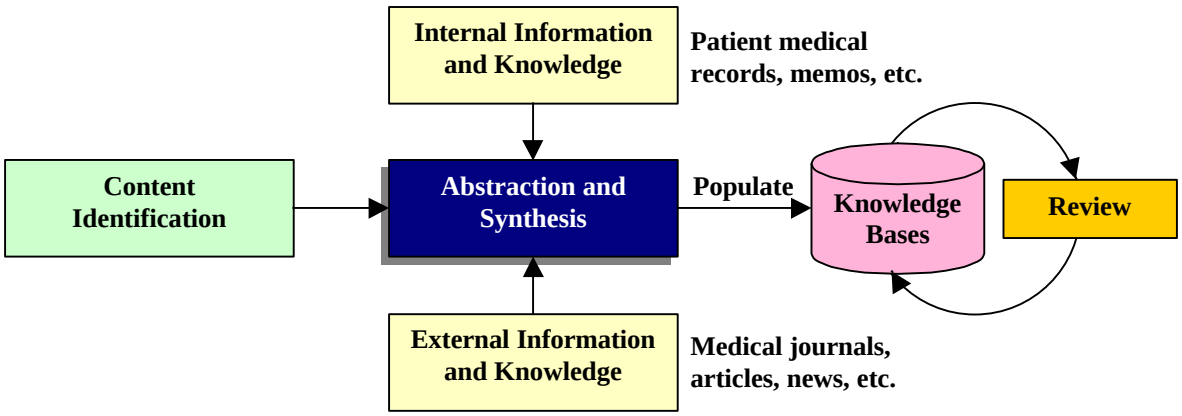

Figure 6: A Knowledge Base Creation Environment [O'Leary, 1998a]

2. **Knowledge Description Layer**: Enables uniform and intelligent access to object-level resources. The main purpose of this layer is to facilitate accurate selection and efficient access to relevant healthcare knowledge in a given task context and application situation.
3. **Application Layer**: Models and executes processes and tasks. The HEM's services can be realised in different ways, ranging from dedicated programs (which perform a well-defined task) to flexible query interfaces. These include medical protocol models and healthcare work processes management systems.
4. **Services Layer**: Providing specialised services to healthcare professionals or the public through the use of various applications.

A complete scheme of an HEM together with peripheral technologies and services is illustrated in Figures 7a and 7b, whereby we show a mapping of our four-layer HEM model to KM processes, to KM technologies and to various AI technologies.

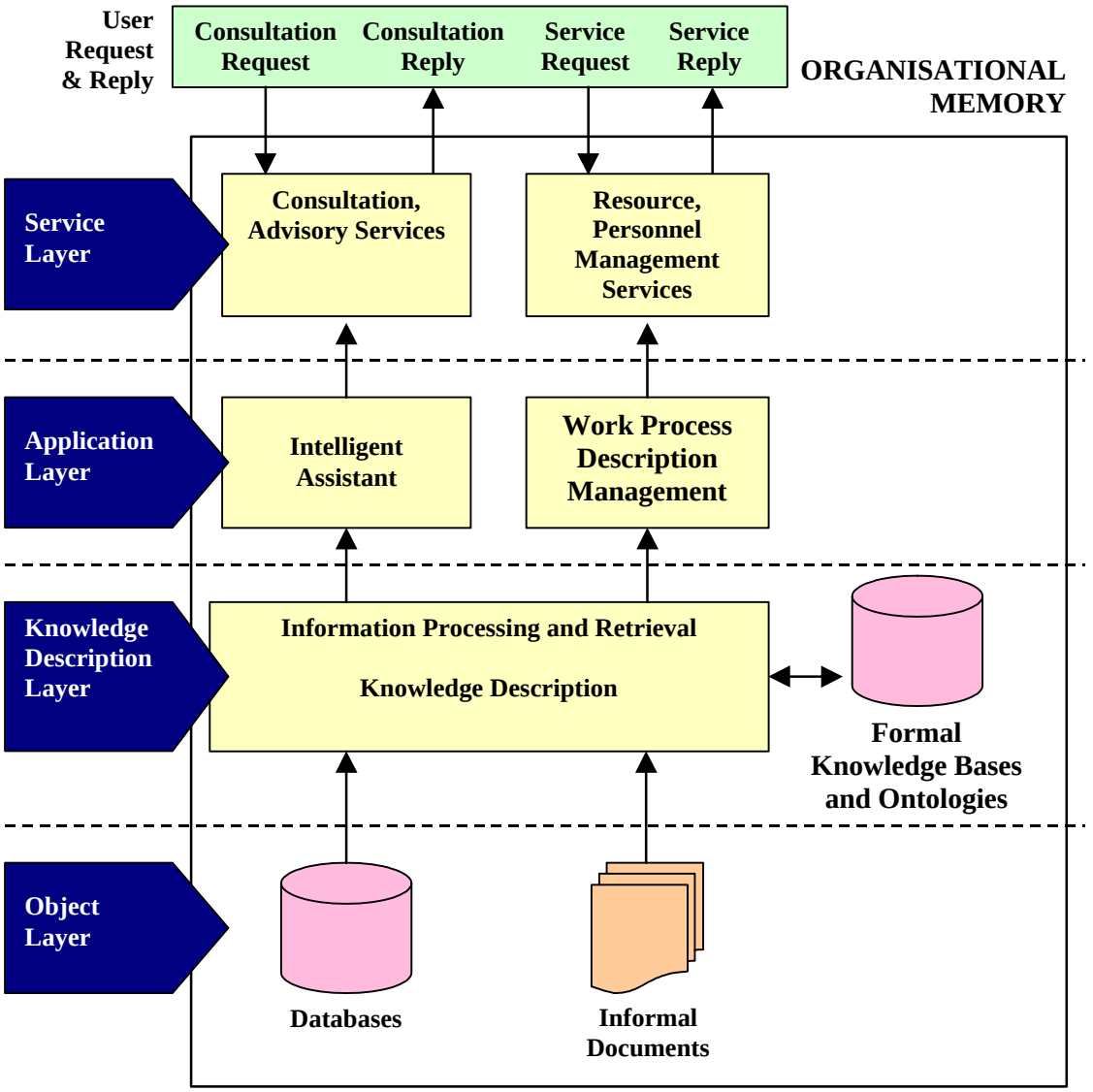

Figure 7a. A four-layer model of the Healthcare Enterprise Memory

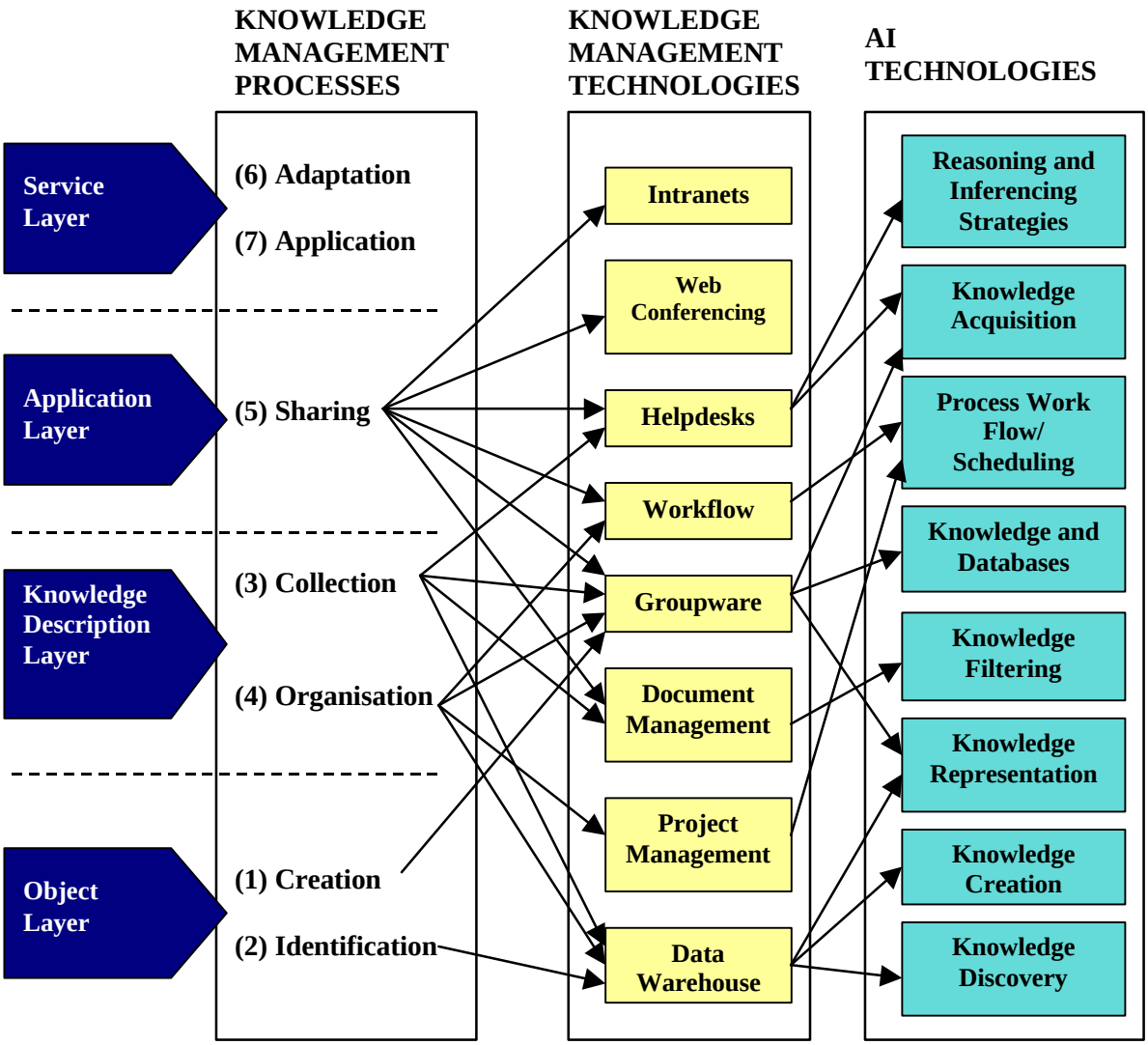

Figure 7b. The mapping of the four layers to KM Processes, to KM Technologies, and finally to AI Technologies

7. Operationalising Healthcare Enterprise Memory

Traditionally, healthcare policies are derived by taking into account on-the-ground information, resource constraints, lessons learnt and domain knowledge. However, the effects of any devised policy cannot be ascertained until it is applied and data (spanning over a considerable period of time) concerning its effects is collected and analysed. We propose a novel and knowledge-driven approach to healthcare policy making whereby the knowledge encapsulated within the HEM is operationalised to simulate specific scenarios pertaining to proposed or under-study policies. The knowledge acquired from the simulation results is anticipated to provide an idea of the effects of the proposed study. We term this approach as Healthcare Modelling.

Healthcare modelling entails the development of a *healthcare process model* (addressing a specific goal or task). The modelling aspect entails the submission of different (experimental) values to the various parameters of the healthcare model and noting the influence of the parameter values towards the efficacy of the task/process being modelled. This strategy is akin, to some extent, to traditional simulation and modelling activities, however the value-added aspect of our approach is that the healthcare model is derived from the manipulation of vast medical knowledge and outcome data contained within the HEM. Hence, it can be argued that healthcare modelling involving HEM is more informed, context sensitive, aware of relationships between disparate knowledge entities and realistic. Figure 8 identifies the process of healthcare modelling by operationalising healthcare knowledge, i.e. an HEM.

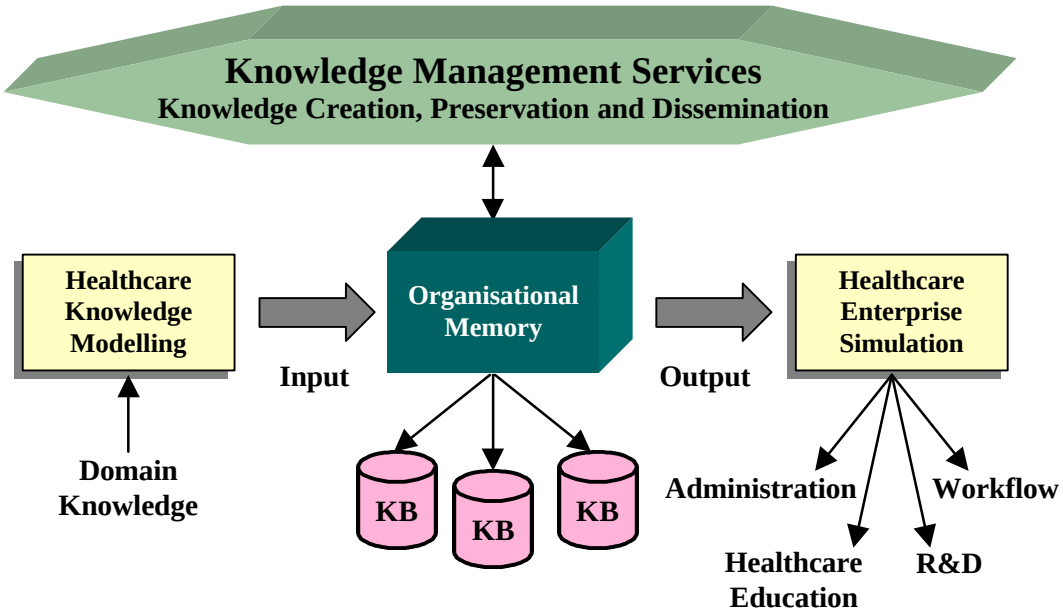

Figure 8: Illustrating the process of operationalising organisational memories

To substantiate our proposal for operationalising an HEM, we illustrate below a healthcare modelling exercise. The subject of the modelling exercise is the evaluation of resources allocation and associated workflows in order to improve the time-taken to service patients at an Out-Patient Department (OPD) of a government-based healthcare enterprise, serving an average of about 180 outpatients daily.

Consider the following scenario: In the OPD of a healthcare enterprise, an important factor in determining the efficiency of healthcare service provided is S*ervice Delivery Time* (SDT). Many OPDs are advocating the concept of *'Zero Waiting Time'* or pledging to deliver its services within a specified time period starting from the time of a patient's registration. We now demonstrate how to operationalise the HEM in order to determine procedures/protocols/resource allocations to achieve minimum SDT.

7.1. Workflow Analysis

First, we need to examine the existing workflow of the OPD for a patient seeking medical consultation (see Figure 9 below). Note that in an HEM the workflow will be stored in the OPD knowledge base.

The OPD workflow (shown in Figure 9 below) states that on average, it takes the OPD 30 minutes to service a patient. The average time is a consequence of the fulfillment of a set of *standard requirements* stored in the OPD knowledge base.

7.2. Standard Requirements

A sample of the standard requirements for this particular task is as follows:

1. 3 healthcare professionals, 6 healthcare support staffs (nurses) and 4 administration staffs (collection of fees and record keeping) are available for 8 hours daily.
2. 2 electrocardiograph (ECG) machines are available for doctor's use at all times.
3. 3 dressing sets are available in the injection/dressing room at all times.
4. 10 vacant beds are available throughout the hospital daily for admissions.

To determine different SDTs, one can simulate the OPD workflow by varying the parameters in the OPD's standard requirements found in the knowledge base. Such simulations can identify the peculiarities of various standard requirements and the bearing of the various parameters in the eventual SDT. For instance, a simulation may yield that insufficient resources in terms of healthcare personnel and facilities are the main causes of workflow bottlenecks. We posit that this is a major undertaking and at present, we are working on tools and techniques to formulate simulation models for defined tasks.

7.3. Eliminating Workflow Bottlenecks by Modelling

Assuming that a simulation of the OPD workflow have identified certain workflow bottlenecks. Now, healthcare management can focus on the problem areas, suggest possible solutions and again simulate the suggested solutions to determine the effects of the proposed solutions. For example, assuming that a common bottleneck identified in an OPD is the insufficient number of available healthcare professionals thereby causing patients to wait in the waiting room for long periods. The simulation may involve changing the number of healthcare professionals (based on availability and expertise) to improve SDT. A solution drawn from

the simulation results may propose an increase in the number of healthcare professionals from 3 to 6. This will ensure that the current waiting time is reduced by half, i.e. the rate at which patients are called into the doctors' rooms is doubled.

More precisely, modelling the above solution with respect to the OPD workflow (shown in Figure 9) together with other functional constraints yield an *Estimated Waiting Time* (EWT) of 13 minutes as opposed to the usual 15 minutes, thereby producing a SDT of 28 minutes. In this manner, further solutions to the above workflow bottleneck can be simulated by experimenting with different number of healthcare providers and noting the estimated EWTs and SDTs. Table 2, shows ad-hoc estimates of waiting times, SDTs and constraints pertaining to number of available and needed healthcare professionals. Indeed, with the OPD receiving, on average, 180 patients daily, 'zero waiting time' is theoretically possible with the availability of 180 healthcare professionals. This is, however, highly impractical for obvious reasons. Nevertheless, with proper healthcare modelling based on an HEM, we argue that it is possible to determine an optimum number of healthcare professionals needed, based on available resources, in order to produce an acceptable EWT.

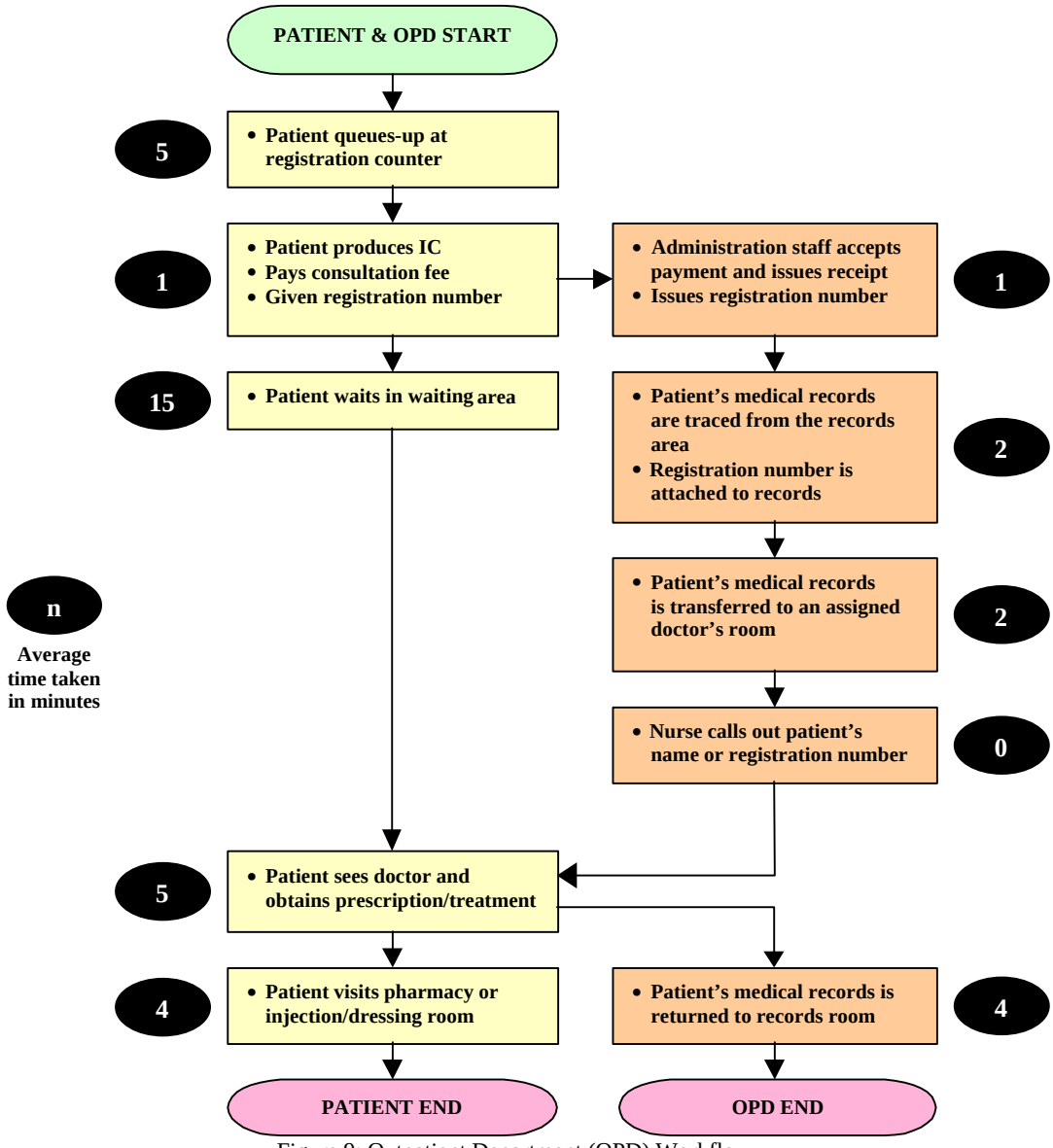

Figure 9: Outpatient Department (OPD) Workflow

Number of healthcare professionals	EWT (minutes)	SDT (minutes)	Constraints
0	∞	∞	At least 1 healthcare professional needed.
1	25.00	40.00	3 healthcare support staff available.
3	15.00	30.00	6 healthcare support staff available.
6	13.00	28.00	10 healthcare support staff available.
12	11.50	26.50	18 healthcare support staff available.
180	0.00	15.00	240 healthcare support staff available.

Table 2: Ad-Hoc modelling results for EWT and SDT with respect to the number of available healthcare professionals.

No. of available ECG machines	Simultaneous ECG machine usage	Is 'Zero Waiting Time' Possible?	Constraints
1	1	Yes	1 healthcare support staff is available.
	> 1	No	> 1 ECG machine needed.
2	1 or 2	Yes	1 or 2 healthcare support staff is available.
	> 2	No	> 2 ECG machines needed.
3	1, 2 or 3	Yes	1, 2 or 3 healthcare support staff is available.
	> 3	No	> 3 ECG machines needed.

Table 3: Ad-hoc modelling results suggesting the possibility of achieving 'Zero Waiting Time' by taking into account multiple resource constraints.

We present another modelling exercise that addresses the issue of resource allocations, in particular the effects of the simultaneous usage of resources. For example, a simulation of the OPD workflow has assessed that with 2 ECG machines available, 'zero waiting time' is still achievable if healthcare professionals require them for no more than two patients simultaneously. However, 'zero waiting time' would not be possible should more than 2 patients require an ECG taken at the same time. Table 3, shows the simulation results pertaining to the possibility of achieving 'zero waiting time' whilst satisfying multiple constraints—number of available ECG machines and rates of simultaneous ECG machine usage. In Table 3, the Constraints column indicates the number of healthcare support staff needed to operate the ECG machines.

The above examples attest the efficacy of operationalising the HEM for healthcare modelling towards policy making. We have shown that operationalisation of OPD knowledge (stored within the HEM) provides the opportunity to formulate healthcare policies, to estimate average SDT for different scenarios, the feasibility of achieving 'zero waiting time' and so on. More attractively, these policies will be grounded in insights gained throughout the modelling of the healthcare knowledge.

8. Concluding Remarks: Exploiting the Healthcare Enterprise Memory for Healthcare Management: A Win-Win Situation

The healthcare environment is generally perceived as being 'information rich' yet 'knowledge poor'. With advances in the domain of knowledge management and the effectiveness of organisational memories (as demonstrated earlier), we suggest that a joint effort involving healthcare professionals and knowledge management experts need to venture towards the realisation of a 'knowledge rich' healthcare environment to enhance the effectiveness and efficiency of healthcare enterprises.

Indeed, this paper has identified the possible role of knowledge management technology in healthcare. Subsequent efforts need to focus on in-depth practical issues and applications of knowledge management techniques for meeting the ever-growing healthcare delivery demands. It is our contention that the healthcare domain can gain a lot by leveraging on existing and up-coming knowledge management tools and techniques. To conclude, we present a few factors that support the case of a possible synergy between healthcare enterprises and knowledge management, leading to a win-win situation.

- *Acquisition and organisation of knowledge*: In general, healthcare knowledge is sparsely dispersed throughout the healthcare enterprise. The use of OMs can not only collect and retain healthcare knowledge, but it can also serve as a centralised, well-structured information depository. Such a scheme will not only ensure the existence of a healthcare knowledge depository but more attractively it will assist in the systematic evolution of healthcare knowledge, thereby rendering 'intelligence' to the HEM and in turn to the healthcare enterprise [Grey, 1998b].
- *Minimisation of technological cost and risks*: The implementation of an HEM is a low-cost solution and can be developed both rapidly and relatively cheaply using available IT technologies. This suits the dynamic nature of the healthcare enterprise as it will benefit from the quick and proven solutions.
- *Exploiting patient and professional feedback*: Feedback is an integral component of healthcare practice. Healthcare professionals receive feedback or critique from patients on the effectiveness on medication and treatment, etc. Such feedback can be channelled into the HEM and vice versa in order to permanently store feedback knowledge and in turn assist to improve the quality and currency of knowledge contained within the HEM. This is in line with the notion of knowledge evolution within an HEM and the healthcare enterprise.
- *Integration into existing healthcare environment*: Functionally, an HEM can tap into the enterprise's existing flow of information via a direct interface with tools commonly used by healthcare professionals (e.g. word processors, spreadsheets, etc.) [Abecker et al., 1998]. Most computerised healthcare enterprises already use word processors, spreadsheets and even databases for their daily operations, this feature can lead to the pro-active development of the HEM.
- *Active presentation of relevant information*: An HEM can actively remind professionals and staff of helpful information and serve as an *intelligent assistant* [Abecker *et al*., 1998].

Finally, we realise that the healthcare enterprise owns huge volumes of diverse knowledge and it is a major endeavour to convert this knowledge into an HEM. Nevertheless, keeping in view the advantages of the given proposal, it is appropriate to postulate that, in view of the dynamic and resource stringent and demanding nature of the healthcare enterprise, it is inevitable that the healthcare industry will refer to knowledge management techniques for ensuring a continuum of premium healthcare services. The ideas reported here are now being implemented as a suite of KM tools for HEM.

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