

# Software Support for Organ Transplant Management

Monique Calisti, Petra Funk, Patrick Brunschwig

Whitestein Technologies AG,  
Gotthardstrasse 50, CH-8002 Zürich, Switzerland,  
{mca,pfu,pbr}@whitestein.com

## Abstract

*This paper focuses on the Organ Transplant Management (OTM) process defined as the set of activities that need to be coordinated before the surgery operation itself can take place. The main goal is to understand how the different OTM tasks are interrelated, in order to build an innovative software system that aims to support medical practitioners involved in the various decision-making steps. The current work and the extensive discussions with experts in this area provided ground for the definition of the OTM system. We argue that this tool, when integrated in real hospitals and transplant centres, will facilitate many of the tasks currently performed by humans, and will allow optimisation of precious resources such as time and personnel.*

**Keywords:** Organ Procurement, Information Management, Decision Support Management.

## 1. Introduction

During the last few years, there has been a significant improvement in the area of organ transplant. Transplants are no longer the last-option kind of therapies, and recent important success is contributing to increase the number of organ transplants all over Europe<sup>1</sup>. However, despite significant improvements in the surgery process itself, the coordination of the preliminary activities involved in an organ transplant operation is still a very challenging, complex, and not yet well understood process [4][6][9].

The main complexities stem from a number of factors. First of all, the availability of the right amount of information needed to make the most appropriate patient (recipient) selection (when a specific organ becomes available), and the capability to process such data in the most rapid and effective way are two crucial aspects. Both potential recipients and donors (i.e., organs) have to be characterized by a large set of medical attributes and personal data that need to be registered to the hospital/s and involved institution/s. This information has then to be stored, maintained and distributed (when needed) in a compact and re-usable way. Unfortunately, at least from a Swiss perspective, there is no unique or standard approach to medical information representation and processing, which not only limits the interoperability between various institutions involved in the OTM process, but also slows down coordination within a single hospital. Directly related to the availability of the right information at the right time and moment, there is a need of coordinating various decision steps. There are currently a certain number of methods, criteria and rules for guiding the decision making behaviour of medical practitioners, which are partly on paper *de iure* norms, partly routinely *de facto* approaches that every hospital or even specific department is adopting, possibly depending on the good will of the various involved people. This could be improved by providing a way (1) to effectively collect the relevant required data about the available organ/s, the potential recipients, the hospital's logistics support, the medical

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<sup>1</sup> For more precise data and statistics we suggest Eurotransplant (<http://www.eurotransplant.com>).

team availability, etc., and thereby (2) to process this data by applying specific existing rules in a consistent and systematic way independently on contingent aspects. This intelligent computational supported data processing paradigm would enable pre-filtering of redundant and unnecessary information, so that important resources (e.g. time, hospital equipment, personnel, information, etc.) could be saved, and experts could take final decisions in a more effective way. Furthermore, a computer-aided approach would allow for more objective explanations about specific choices and decisions, including the capability to better control deterministic rules. This would finally leave medical staff with more time to concentrate and focus on those decision factors that can be hardly described or captured by software instruments.

This paper describes our agent-based software system for improving both the information management and the decision-making tasks. This aims, on one side, to identify the main challenges and benefits that our approach brings along, in order to validate and/or eventually modify our choices. On the other side, this hopes to stimulate discussion on the feasibility and utility of software support in today's medical environments. The paper is organized as follows: Section 2 gives an overview of the main OTM issues and presents our agent-based vision for addressing such issues. After a brief description of the main components behind the OTM system design (Section 3), we discuss some of the main challenges and benefits behind the adoption of the proposed approach (Section 4). Section 5 finally draws concluding remarks.

## 2. The Organ Transplant Management

The OTM process can be decomposed into two main sub-sets of activities: the *Procurement Process* (PP), which includes all activities needed to prepare the surgery operation; and the *surgery operation* process, actually corresponding to the physical transplant of the organ/s into the selected recipient. Our activity focuses on the PP, which we decompose in two main tasks:

1. *Information gathering and data management*: both, potential recipients and donors need to be characterized by a certain amount of information that has to be recorded and dynamically maintained by the transplant centres and/or the specific institution/s involved in the OTM process. This is a very challenging issue, as no common comprehensive framework to uniquely represent, store, process and visualise medical data is available.
2. *Decision matchmaking*: when organs become available, a transplant centre has to process the relevant information and verify whether there is a suitable recipient on the waiting list or not. This decision has to be taken under very strong time constraints by considering a large set of interrelated matchmaking criteria, including several deterministic medical factors (about the 80% of the total amount of data to be checked) plus a number of aspects (soft constraints) that are more difficult to quantify and estimate, but that can heavily influence the final selection of a specific patient.

The way these distinct tasks are currently performed still lacks from a comprehensive computational support and is to a great part non-coordinated. Medical experts have to match available organs to long lists of potential recipients with very weak local computerized support in processing large amount of data. Coordination is mainly achieved by telephone calls, pagers and/or other highly human-dependent means to track down suitable recipients, and contact physicians at both the extraction and insertion sites. Furthermore, the storage and the transport of organs involve a set of activities under the direct control of external and distinct organizations, which need to interact in a rapid way (available organs

cannot be preserved for more than a few hours). The so-called super-urgencies<sup>2</sup> make this even more complicated because they can drop in at any time before an organ is implanted.

A more efficient coordination of distinct activities and the automation of simple and repetitive actions would enable a better deployment of resources including time, hospital equipment, personnel, information, etc. Therefore, mainly for the increasing needs in terms of efficiency and flexibility, various traditional approaches in the health care domain are evolving from the deployment of human-centred and single-purpose systems to more automated and fully integrated applications that drive facilities and services to the end users (i.e., patient empowerment)<sup>3</sup>. In particular, this is also happening in the OTM area [3].

### **A software Agent-Based Vision**

Agent technology seems to be one of the most promising approaches for designing and implementing autonomous, intelligent and social software assistants capable of supporting human decisions [7]. The concept of an “agent” is a key abstraction used in several fields with definitions that can differ one from each other (various references can be found in [2]). In this context, we assume that an agent is an autonomous software entity able to actively and proactively interact with its environment including other components (such as humans, agents, software entities, objects, etc.) in a social way (i.e., communicating). The main idea behind the deployment of this technology is that autonomous software agents acting on behalf of medical practitioners can:

- Speed-up and automate many tedious and simple tasks currently performed by humans. The resources saved by relying upon software instruments could be re-used for more demanding and delicate tasks;
- Reduce the complexity of tasks such as multi-criteria match-making, dynamic coordination under stringent constraints by implementing smart techniques that could support the human decision making process and optimize several tasks;
- Offer value added services, such as the integration of some activities performed during the OTM with other medical services (and vice versa), or the personalization of some tasks (i.e., post-transplant therapy) for which there is currently no chance of differentiating the way patients are monitored and cured.

Although an extensive discussion on these aspects is beyond the scope of this paper, it is worth to underline that agent technology is maturing as an important software engineering paradigm. Development environments and standards<sup>4</sup> are becoming available which is likely to build confidence in agent techniques and allow more widespread experimentation. Furthermore, several companies are investing in agent technology for agent-based tools for various industrial applications<sup>5</sup>.

### **3. The OTM Software System: A Modular Architectural Approach**

In the OTM system, the interrelated procurement activities rely upon coordination mechanisms supplied by software entities. We propose a pro-active, modular and flexible approach for (1) intelligent information processing and (2) decision support (see Figure 1).

In the first case, the focus is on acquisition, representation, and structuring of the required medical knowledge, including patient records/organ profiles. Here the usage of formally specified *ontologies* as *structured data repository* provides a powerful, well-structured ap-

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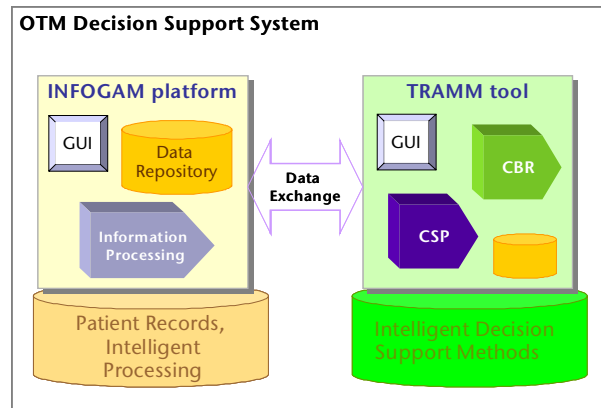
<sup>2</sup> Zero-urgencies are (in Switzerland) patients in danger of life with the highest priority in the waiting lists.

<sup>3</sup> A number of existing projects and initiatives involving hospitals, IT oriented companies and research groups are enforcing this trend (see Section 4). See also <http://www.medscape.com/viewprogram/1919>

<sup>4</sup> Standardization in the agent area is done by the non-profit organization FIPA (more information at <http://www.fipa.org>).

<sup>5</sup> Many references and relevant links can be found from <http://www.agentlink.org> and <http://www.agentcities.org>.

proach (possibly also in terms of semantics underpinning) to organize information in a flexible, re-usable, distributable, and maintainable way. Intelligent information processing methods filter, classify and organize the data in order to make it usable and visible for the users on the screen. *The Information Gathering and Management platform (INFOGAM)* provides a repository of ontologies characterizing the hospital, the medical experts, the hospital infrastructure and the waiting list. It can be mainly accessed with a set of methods and functions that can be either triggered through a friendly graphical user interface (GUI) or can be pro-actively started by the “intelligent” processing entities behind this interface.



**Figure 1: OTM– a component-based information gathering and decision support system.**

The second set of issues concerns the decision support tasks, especially with regard to the multi-criteria matchmaking of available organ/s characteristics with the patients’ profiles (waiting list) for the final selection of the best recipient. Here a combination of *constraint solving problems (CSP) techniques* [10] and *case-based reasoning (CBR) methods* [8] are integrated within an agent system for an effective search of the problem space (i.e., decision making choices). *The Transplant Multi-criteria Matchmaking (TRAMM)* system integrates existing CSP and CBR algorithms and reasoning methods for effective decision support. An easy and user-friendly interaction is enabled through a specific GUI.

This modular architecture allows for a clear separation of the information management related tasks from the actual reasoning and decision support methods, facilitating the implementation of the tool, and enhancing the chances of re-usability of such components for other services within a transplant centre. Modularity also provides a better control of the flow of information and use of resources, especially with regard to the performance of each single system component. Interoperability between the two components is an essential part of this work. For this reason, the technologies adopted in the OTM context are standard FIPA agent mechanisms, and standard instruments for data representation (i.e., XML<sup>6</sup> based ontology, DAML-S<sup>7</sup> service description and medical formatting such as LOINC, ICD or SNOMED) and transport (e.g. HL7<sup>8</sup>). This is also a strategic approach in building components that interact with other software tools for solving various hospitals’ tasks such as personnel scheduling and resources planning.

<sup>6</sup> XML is the Extensible Markup Language. More information can be found at <http://www.xml.com>

<sup>7</sup> DAML-S is a markup language devoted to describe Web services. More information at: <http://www.daml.org/services/>

<sup>8</sup> HL7 is an information exchange standard for hospitals and clinics, further information: <http://www.hl7.ch>

#### 4. Related Work and Discussion

During the last years, several projects, researchers and practitioners have addressed the problem of improving the way the OTM is performed<sup>9</sup>. We tried to analyse several existing software systems in order to better understand the potential of our agent-based approach.

*INFOGAM related systems:* The Clinical Vision (CV) approach<sup>10</sup> addresses the information management needs in the transplant domain from the transplant centre perspective. The goal is to provide a set of tools facilitating practitioners in the data management tasks. Similarly, the TPL<sup>11</sup> solution offers information management facilities by providing graphical interfaces for the visualization and manipulation of transplant relevant data. Although, some information is publicly available, it was not possible to find out whether besides friendly database wrapping, the TPL system enables proactive notifications of the system toward the human users. The CV approach seems a more complete tools package covering visualisation, monitoring and reporting of a more complete set of OTM related information and events. However, also in this case it does not seem to cover decision-making support or proactive notification services.

*TRAMM related systems.* The UNetsm<sup>12</sup> Internet-based transplant information database has been created by UNOS for the US organ transplant institutions to register patients for transplants, match donated organs to waiting patients, and manage the time-sensitive, life-critical data of all patients, before and after their transplants. This platform is the closest one (in terms of available procedures and functionality) to the OTM system. Such system, tailored to the US transplant model and system, might need several modifications and changes in order to be applicable in other transplant contexts. The OTM system could be considered a modular complementary system enabling the re-use of already existing UNetsm components by means of flexible agent interactions. However, we believe that the deployment of autonomous software agents as the key enabler technology makes the major difference of our approach in comparison to other solutions.

From a more research-oriented perspective, the SMASH<sup>13</sup> project considered the applicability of multi-agent systems for improving transplant services of hospitals in Catalonia (Spain). The developed Carrel/ UTCx [3] system's main objective was to automate and speed-up the process of distributing organ and tissues to the proper recipients in a fair way. Despite important achievements, various aspects need further work, especially with regard to the time-critic and structural requirements of the OTM domain. Furthermore, the coordination of the various Carrel entities is based upon automated negotiations of software agents acting on behalf of medical experts. We believe that for an effective use of support tools in the health care domain, full automation is not feasible (at least for many crucial processes), and negotiation is not necessarily the most appropriate coordination protocol. In addition, there is in such context no solid approach to the definition of standard and reusable information models and ontologies. The ontology provided with OntHos[1] is a good step towards formal representations similarly to our framework. However, their main focus of the conceptualisations is on scheduling of hospital resources<sup>14</sup>. The specific knowledge about organ transplant has not been covered.

The ambition behind the development of our system is to come up with a compact framework covering all important OTM steps, including both the information management and decision making steps. The idea is not to duplicate existing frameworks and tools, but to

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<sup>9</sup> For paper's length limitation we cannot give a detailed analysis of all relevant works. We only give some main pointers.

<sup>10</sup> For more information; [http://www.ccl.com/products/clinical\\_vision/transplant\\_solutions.asp](http://www.ccl.com/products/clinical_vision/transplant_solutions.asp)

<sup>11</sup> For more information <http://www.medconsulting.ch/tpldoku.htm>

<sup>12</sup> For more information <http://www.unos.org/whatWeDo/technology.asp>

<sup>13</sup> More information about the SMASH project can be found at: <http://www.iiia.esic.es/Projects/smash/>

<sup>14</sup> An ontology for hospital scenarios: <http://16-spike-dos.informatik.uni-wuerzburg.de/Ontologie>

complement them (when necessary and appropriate). By its intrinsic modular agent-based nature, our system offers innovative characteristics in terms of flexible personalisation of the working environment for medical practitioners, proactive notification services from the system to the human users, and powerful decision making support by combining powerful reasoning techniques with modern and leading software engineering technologies. As this effort combines knowledge and expertise from different disciplines, it is important to have a close interaction of various organizations (hospitals, research organizations and IT players). Furthermore, in order to ensure legal and ethically responsible choices, public acceptance and an efficient broad deployment of new technologies in the OTM context, it is fundamental to promote active involvement of regulators, coordinators, medical experts, users and.

## 5. Conclusion

In the health care scene, while the automation of some activities and the deployment of auxiliary software tools have partly enabled to address pressing requirements for more effective information management and decision-making, there is still a strong need for addressing the complexity of integrating new solutions within existing hospitals' infrastructures (i.e., pervasive health care). This requires taking into account users' needs and various existing constraints (medical, legal, etc.) in a more flexible, dynamic and personalized way, in particular in the OTM context. We strongly believe in the potential of our agent-based approach to be used as a distributed software support tool that would enable a better taking care of the individuality of the patients, saving precious resources and would finally facilitate the tasks of physicians and coordinators.

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