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A Framework for Requirements Engineering Using System Dynamics

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Abstract

In many systems engineering activities the elicitation of requirements is regarded as a central activity for the efficient and effective functioning of the intended system. In recent years, the field of Requirements Engineering has received much attention and many research and practical approaches have been proposed. In this paper we present a Requirements Engineering framework that is motivated by the System Dynamics paradigm. The framework consists of four key activities: *ontology modelling*, *goal modelling*, *process modelling* and *scenarios generation*. It is our premise that the synergy between these four activities results in a robust way of working that provides requirements stakeholders with a systematic approach to articulating, defining, debating, and agreeing on the set of desirable functional and non-functional properties of the intended system. The approach is demonstrated with examples from a very large application and claims substantiated from experiences from this project.

1. Introduction

Since the mid-1970s when Requirements Engineering (RE) was established as a distinct field of investigation and practice, its application has evolved from, initially being concerned with software systems [IEEE-Std.'729' 1983; IEEE-Std.'830' 1984] to a broader perspective that extends to incorporate also aspects of systems and organisations [Greenspan, Mylopoulos, et al 1994; Loucopoulos and Karakostas 1995; Pohl 1996; Yu 1997; Zave 1997].

In recent years the relation of RE to the organisational context has attracted much interest not only from the software engineering community but also from researchers and practitioners working in *business process engineering* [Davenport 1993; Galliers 1993; Kavakli and Loucopoulos 1999; Yu and Mylopoulos 1996], *organisational change* [Eason 1987; Prekas, Loucopoulos, et al 1999; Rolland, Loucopoulos, et al 1999] and *design theories* [Carroll 1995; Carroll 2002; Carroll and Rosson 1990; Kyng 1995; Nardi 1995; Rosson and Carroll 2002].

This broader view of RE, is based on the premise that in designing systems, requirement engineers aim to ‘improve’ organisational situations which are seen as problematic – or, at least, as needing some change. Hence the problem of system design comes closer to addressing a wider set of problems found within organisational settings. Within this context, requirements are usually classified as *functional* requirements and *non-functional* (or *quality*) requirements. Whilst the former are concerned with the identification of intended system behaviour, the latter address issues relating to service provision for the intended usage of the system.

Requirements engineering typically deals with a class of problems that has been termed “ill-structured problems” [Reitman 1965; Rittel and Webber 1984; Simon 1984]. The problem state is not a-priori specified and there is no definitive formulation. Formulating the problem amounts, to a great deal, to solving it. The success of the requirements engineering process often depends on the ability to proceed from informal, fuzzy individual statements of requirements to a formal specification that is understood and agreed by all stakeholders. However, the process is far from deterministic and straight forward.

In this paper we propose a framework based on our research work and practical experiences in recent years (c.f. [Dimitromanolaki and Loucopoulos 2000; Filippidou and Loucopoulos 1997; Kavakli and Loucopoulos 1999; Loucopoulos 1993; Loucopoulos 1995; Loucopoulos 2000; Loucopoulos and Karakostas 1995; Loucopoulos and Zicari 1992; Prekas and Loucopoulos 2000; Prekas, Loucopoulos, et al 1999]). To demonstrate how the framework may be deployed we make use of an application from the Athens 2004 Olympic Games project. Experiences from this work also help in discussing some of our assumptions and claims. The paper is organised as follows. Section 2 gives a brief summary of the issues pertaining to requirements definition. Section 3 discusses the background to the application. Section 4 introduces the framework and provides a walkthrough the four stages of the framework using examples from the application. Section 5 concludes the paper with observations about the utility of the framework.

2. The Requirements Engineering Process

A definition of requirements in [IEEE-Std.'610' 1990] is given as:

1. A condition or capacity needed by a user to solve a problem or achieve an objective.
2. A condition or capability that must be met or possessed by a system or system component to satisfy a contract, standard, specification, or other formally imposed documents.
3. A documented representation of a condition or capability as in (1) or (2).

There are many good reasons for striving to develop a requirements specification. Firstly, it provides a focal point for the process of trying to correctly understand the needs of the customer and user of the intended system. Secondly, the specification can and should be the means by which a potentially large and diverse population of requirements stakeholders and requirements analysts communicate. The specification itself can be used for clarifying a situation about the intended system or its environment. Thirdly, the specification may be part of contractual arrangements, a situation that may become especially relevant when an organisation wishes to procure a system from some vendor rather than develop it ‘in house’. Fourthly, the specification can be used for evaluating the final product and could play a leading role in any acceptance tests agreed between system consumer and supplier.

The requirements specification lifecycle is defined as “the systematic process of developing requirements through an iterative co-operative process of analysing the problem, documenting the resulting observations in a variety of representation formats and checking the accuracy of the understanding gained”.

This reflects the view that requirements specification involves an interplay of concerns between representation, social and cognitive aspects [Pohl 1993]. Issues of representation range from informal descriptions such as natural language expressions and hypertext to formal conceptual modelling languages. In the social domain, consideration is given to the complex social process in which the communication and co-operative interaction between the stakeholders of the requirements determines the quality of the final product. Issues in the cognitive domain concern different orientations of models in terms of understanding the process itself and validating the requirements. A requirements specification is likely to change many times before proceeding to design and needs to be subjected to evaluation in order to gain confidence regarding its validity. The RE process, consists in general of four tasks [Pohl 1996]:

- requirements elicitation
- requirements negotiation
- requirements specification, and
- requirements validation

Requirements *elicitation* is about understanding the organisational situation that the system under consideration aims to improve and describing the needs and constraints concerning the system under development. The relevant knowledge about the problem (system) is distributed among many stakeholders. The objective of *negotiation* is to establish an agreement on the requirements of the system among the various stakeholders involved in the process. Requirements *specification* involves a mapping of real-world needs onto a requirements model. Finally, the *validation* task intends to ensure that the derived specification corresponds to the original stakeholder needs and conforms to the internal and/or external constraints set by the enterprise and its environment.

3. A Requirements Engineering Project

Before introducing the RE framework, we briefly outline an application that will be used in this paper to demonstrate the principles and techniques put forward in the framework. This application involved many stakeholders from different functional areas, demanding a single system that would satisfy a multitude of requirements. The system concerns the operation of competition and support venues during the Olympic Games of 2004 in Athens. At the Athens 2004 Olympic Games within a period of 16 days, 16,000 athletes from 36 different sports will take part in 300 events across 28 venues located in the Greater Athens area. They will be watched by an estimated 5 million ticketed spectators, together with over 20,000 journalists and broadcasters, and 2,500 members of international committees.

With a budget of $5billion, and a workforce of over 175,000 for the duration of the Games, one of the tasks of the Athens2004 Organising Committee (ATHOC) is to ensure the efficient and effective running of the Games in all competition venues, in a fully co-ordinated manner with non-competition venues (e.g. airport, Olympic village etc) and the city's infrastructure (transportation, city operations etc).

The purpose of the RE project was for ATHOC to develop specifications for Venue Operations that would then serve as the basis for the delivery of systems by external contractors. *Venue operations* concerns the support components that need to be put in place at each venue so that it can function according to the specifications set by the International Olympic Committee. We therefore refer to the *venue operations system* as being composed of hardware, software, people, rules and procedures or any combination of these components, interacting in space and time reflecting the dynamic behaviour of the system. The design of this system needs to address both its functional requirements (the resources and procedures for their management) and its non-functional requirements (the quality of service provision). Specifying the requirements prior to the design is the concern of stakeholders from 27 functional areas, the primary ones being accreditation, security, technology, transportation, spectator services, venue staffing, logistics, catering, sponsors, ticketing, broadcasting.

As a general rule, Organising Committees for the staging of the Olympic Games are established a few years prior to the staging of the Games. Whilst at the outset the structure of an Organising Committee is strictly hierarchical and centred around individual functional areas, this has to be gradually transformed, as the Games approach, to a venue-based process orientation in order to shift the emphasis away from internal organisational efficiency towards venue operation efficiency. While designing venue operations, members of the Organising

Committee from different functional areas form teams whose function is to manage the way that venues are run during the Games. This completes the transformation from a fully hierarchical, centralised structure to a venue-based, process-oriented and distributed structure.

Traditionally, the problem of designing venue operation specifications was approached by organising workshops, with the participation of representatives from various functional areas and experts from organising committees of previous Olympiads. These workshops were based on brainstorming sessions and focus group discussions, and the major information management tools used were text documents and architectural diagrams of the various venues. These workshops undeniably facilitated the exchange of knowledge among the functional area representatives involved, as well as the transfer of experience from one host city to the other. However, they were not sufficient for developing a common understanding among all participants, due to the lack of a common reference model and the significant variations in experience and background among the participants. The whole process under this approach is far too informal.

The closest substitutes for a common reference model available involved the use of architectural plans and representations of venue physical layouts. This practice imposed various constraints on the effectiveness of the workshops, the most important being the exclusive focus on specific operations taking place at specific venues. This fact prevented the participants from fully understanding the implications of service specifications in terms of resource requirements and resulting levels of service.

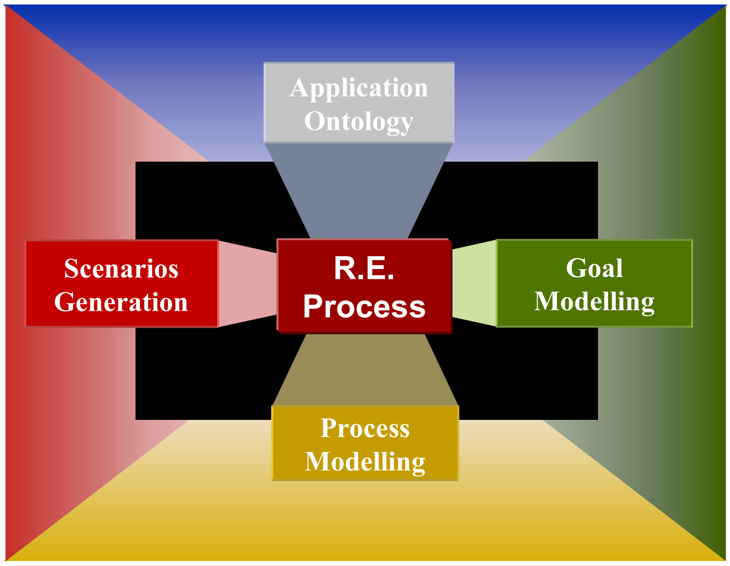


Figure 1: A Requirements Engineering Framework

4. The Requirements Engineering Framework

In order to support the process of RE, we adopt an approach that involves four interrelated activities, as shown in Figure 1. Each of these activities corresponds to one of the four main RE tasks identified in Section 2. *Application ontology modelling* covers the greatest part of requirements elicitation. *Goal modelling* covers part of requirements elicitation and the requirements negotiation task. *Process modelling* is the activity through which we produce a requirements specification, and finally *scenario generation* is used in support of requirements validation. We will demonstrate the way in which the framework can be applied in an industrial case through the ATHOC project. This particular application presents many unique characteristics and therefore was approached in an individual way, however it is ideal for demonstrating the flexibility of the framework and the expressive power of the system dynamics paradigm.

4.1 Application Ontology Modelling

The starting point for our study of the venue operations system was the application ontology, which is concerned with the definition of the main entities that are found in the problem space. We were interested in addressing the following questions:

1. What is the boundary of the system?
2. Who are the 'beneficiaries' of the system? In other words, who uses the system and to what purpose?
3. What are the different types of support that these users need in order to achieve their goals?

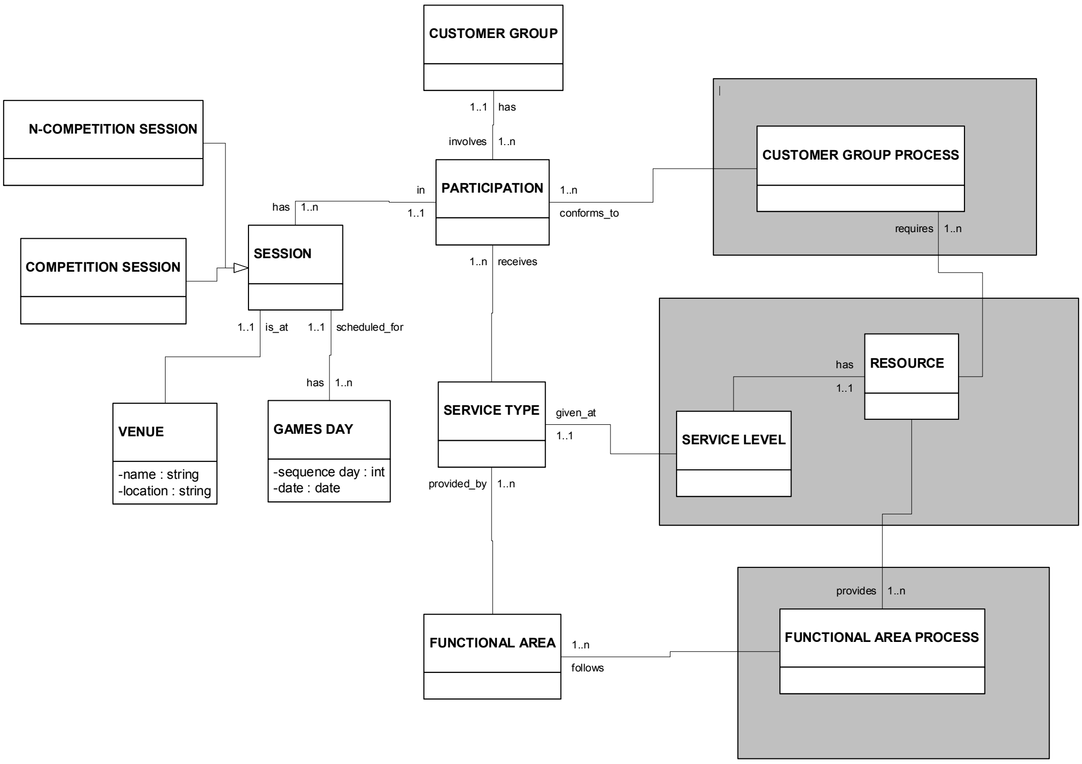


Figure 2: The ATHOC RE Project Boundary

In terms of the Olympic Games application, the answer to the first question defines the RE project space, which is presented as a conceptual model in Figure 2. This model defines unambiguously the main concepts of the system, and states that we are interested in defining the processes that the various functional areas will have to establish (lower shaded rectangle). These processes will manage resources established in order to provide a level of service previously agreed and that the implementation will have to achieve (middle shaded rectangle). The purpose of these resources is in supporting customer processes (upper shaded rectangle).

This brings us to the second question, namely defining the 'beneficiaries' of the system, the different customer groups of venue operations. A *customer group* is a specific category of Games participants, with a well-identified role and, therefore, characteristics that distinguish them from any other group. One such group is that of spectators, by far the most voluminous and with a wide variety of needs, ranging from transportation to/from a venue to the ability for on-site purchase of tickets, food and memorabilia. Another important customer group is of course that of athletes and team officials, a group that is at the focus of attention during the Games and whose needs have a very high priority. There are 12 customer groups in total, including among others broadcasters, paid staff, volunteers, international federations, and the International Olympic Committee.

The answer to the third question defines the various *types of service* that ATHOC must put in place so that each customer group can successfully complete its mission in the Games. These services vary depending on the customer group for which they are intended, the time and location at which they are provided, and so on. One such service is security checking, which all customer groups must undergo before they can access any venue area. Because of the importance accorded by ATHOC to security issues, this is considered to be a key service and its successful implementation essential for the smooth functioning of the venue operations system. While security checking is uniformly provided to all customer groups, there are services that can be specific to one group only. The check-in of paid staff upon their arrival at a venue is such a service; it enables the implementation of the defined shift schedule and is therefore necessary for venue staff, yet it is invisible by all other customer groups.

The notions of customer group and service type are closely interlinked because *the one helps define the other*. Each customer group is primarily characterised by its needs and by the services that satisfy these needs, while the requirements (both functional and non-functional) of each service type are defined with reference to the respective customer group. The notion of customer, in particular, should not be perceived as purely passive. As all categories of Games participants are by definition involved in various activities, it is possible for a customer group to be a service receiver at a specific instant and subsequently become a service provider. Paid staff, for instance, are *serviced* during their check-in, while later on they *service* spectators at various points inside the venue.

4.2 Stakeholders’ Goals Elicitation

Goal modelling is about describing the causal structure of a system (be it a business system, or a software system, etc.), in terms of the *goals-means* relations from the “intentional” objectives that control and govern the system functions to the actual “physical” processes and activities available for achieving these objectives. Goal modelling aims at providing the means for describing the *purpose* of the system under consideration, why it came into being.

In eliciting the goals for the venue operations system, the aim was to understand what determined the successful operation of the system. This involved helping the various stakeholders externalise the (sometimes implicit) goals that they had, capturing these goals, and synthesising that knowledge with information from other sources, such as existing documentation, abstract descriptions of various systems and procedures, and so forth. Stakeholders’ goals were thus an initial, high-level expression of system requirements viewed from the perspective of ATHOC, i.e. the *service provider* (as opposed to that of the *user*).

With respect to goal categorisation, we found that it was often relatively straightforward to capture goals about the functions that the system should provide (i.e. the functional requirements), while in most cases it was difficult to accurately define goals regarding the quality of venue operations. In both cases, the multitude of stakeholders (i.e. functional areas) involved in the requirements specification often resulted to competing, and sometimes clearly conflicting, goals about the system. Furthermore, it was especially difficult for stakeholders to express their goals in specific (i.e. measurable) terms. Indeed, while each functional area found it relatively easy to identify distinct functional/quality aspects of the system, it was much more difficult to quantify each of these aspects. This difficulty unfailingly complicates subsequent stages of system design because it has a decisive influence on the type and amount of resources required, and by extension on the final cost of the system.

To deal with the complex situation of goal elicitation we progressed in a stepwise, cyclical manner, starting from high-level, sometimes fuzzy, goals. We then elaborated on these goals with the help of the functional areas affected by them. By modelling the processes that the venue operations system comprises, and by testing different scenarios on how quality goals can be implemented in each of these processes, we could identify different ways of refining goals into specific quality requirements on the basis of which the system could be developed.

An example of a high-level goal that all functional areas invariably expressed was related to the quality of service provision to various customer groups. Irrespective of customer group and service type, the goal was usually expressed in this form: 'Minimise the time that a customer has to wait in order to get serviced'. With reference to the examples previously mentioned, this translates into goals such as 'minimise the time that a spectator has to wait in order to go through security checking' or 'minimise the time that a staff member has to wait in order to check in upon arrival to the venue'.

This type of goal does not translate very well into operational terms because it does not specify a concrete target for the waiting time. To complicate matters further, there is not a single acceptable waiting time as that depends on the service type and the customer group for which it is intended. What is acceptable for spectators or staff, for instance, may not be acceptable for members of the Olympic family or for athletes. Therefore, the first question we had to ask in order to refine this goal was: failing to provide enough resources so that nobody ever has to wait in a queue, what is an acceptable waiting time? In other words, what is the *level of service* that each functional area is aiming to offer to the customers it is going to service? Should we be happy with 30 seconds waiting time or with 15 minutes? In some cases even that answer was not ready, so it had to be negotiated.

A different type of high-level goal was expressed with respect to the overall presence of spectators in a venue. Given that a venue may hold more than one event (e.g. competition session) during a day, at any time there may be spectators arriving at the venue area for one of the upcoming sessions, spectators leaving the venue from one of the past sessions, and spectators participating in a current session. The total number of spectators present has to be somehow controlled for practical reasons such as the availability of resources (e.g. space), but also due to safety concerns. This translates into the goal 'manage the total presence of spectators in the venue area'. Again this is an abstract goal that needs to be made more specific; to refine it, the stakeholders examined the factors influencing the presence of spectators in the venue and their distribution in the various areas of which it consists. These factors include the competition schedule at each venue, the transportation capabilities to/from the venue, the availability of open spaces and/or service areas within the venue, and so forth. Addressing issues such as those concerning these two high-level goals was the first step towards visualising an operational system.

4.3 Process Modelling

The concept of process is a key issue in a process-centred paradigm. In summary a business process demonstrates the following characteristics:

- a business process has well identified *products* and *customers*, such that business objectives are matched through the (product offering) business process and delivered in the form of the product; customers may be external or internal to the organisation;

products may include finished goods or services;

- a business process has *goals*, i.e., it is intended to achieve defined business objectives aiming to create value to customers;
- a business process involves several *activities* which collectively achieve defined business process goals and create value to customers;

During the RE stage, process modelling concerns the analysis of high-level goals into operational requirements. In our approach, this analysis engages the use of System Dynamics in describing the business processes and relating them to the stakeholder goals (as discussed in section 4.2) [Loucopoulos 2003].

To demonstrate the approach, consider again the example application.

There was a wide range of process-related problems to be studied while addressing the issue of venue operations. At one end of the spectrum, there were problems with 'local' impact, i.e. affecting a single customer group, a small area of the venue, and a small part of venue resources (workforce, machinery, consumables). At the other end of the spectrum, there was the problem of the 'behaviour' of an entire venue as a complex, interconnected system. This corresponds to process models focusing on the dynamic profiling of all venue components, over an extended time frame (e.g. an entire day of the Games), possibly with respect to the needs of more than one customer group. A distinguishing feature of this type of situation is the large number of different service types that the model must represent, since the behaviour of the venue operations system is affected by each of these service sub-components. As a result, the degree of complexity in the resulting process model rises dramatically.

Examples of the problems studied while addressing the issue of venue operations include:

- Staff arrival at venue site and check-in
- Verification of accredited personnel at various sites
- Printing and distribution of competition results
- Transportation of athletes from the Olympic Village to various venue sites
- Spectators' profiling at the main Olympic Complex

The first facet of the venue operations system, i.e. the behaviour of specific components of the system is examined by model components like the one presented in Figure 3. This fragment is about the various types of service facilities that are available to the spectators' customer group inside the Olympic Complex. These facilities service needs such as buying food or memorabilia, withdrawing money from an ATM etc.

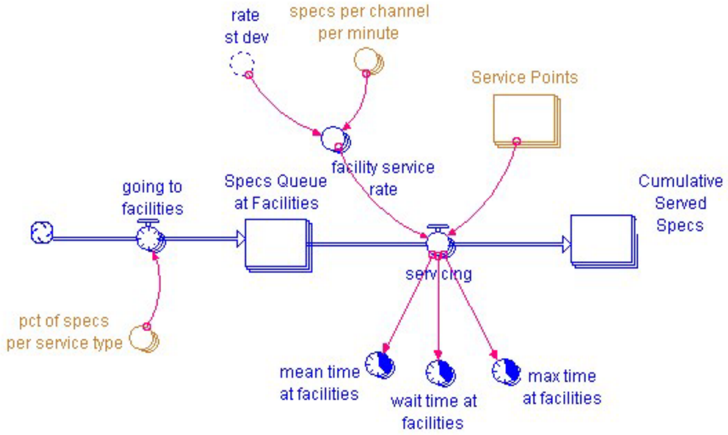


Figure 3: Model fragment regarding spectators' service facilities

The behaviour of the services component is determined by two issues: the *demand* for each type of service and the *supply* offered by the service provider. The demand is determined in part through the **'pct of specs per service type'** variable, which expresses the number of customers expected at each type of service facility per unit of time as a percentage of total spectator presence. Total spectator presence depends on overall spectators' behaviour in the venue area, which interacts with this model fragment through a number of feedback loops (not shown here due to the complexity of the complete model).

The supply is determined by two parameters: the number of **'Service Points'** available (e.g. 10 stands selling food), and the **'specs per channel per minute'** service rate (e.g. two spectators serviced per service point per minute). According to this representation, spectators arrive at the service facility ('**going to facilities**'), queue there for a while if no service point is available ('**Specs Queue at Facilities**'), and eventually get serviced ('**servicing**').

Using this model fragment we can elaborate on the way that stakeholder goals were refined through the use of process modelling. We previously mentioned the high-level goal 'Minimise the time that a customer has to wait in order to get serviced'. The realisation of this goal for a given type of service facility, and for a given demand, depends on the availability of supply for that facility. Supply is composed of two independent factors, the number of service points and the service rate. Therefore, the initial goal was decomposed into two complementary (i.e. non-competing) goals: 'Maximise the number of service points' and 'maximise the service rate'. These goals are more accurate than the initial one, however they need to be analysed further in order to become quantifiable.

The second facet of the venue operations system, i.e. the overall behaviour of the system, is the result of composing smaller system components (such as the services component) so as to build the complete system model. For instance, a summarised version of the model describing spectators' behaviour at the Olympic Complex is presented in Figure 4. The full version of the model contains a significant number of feedback loops and its behaviour is controlled by about 600 equations.

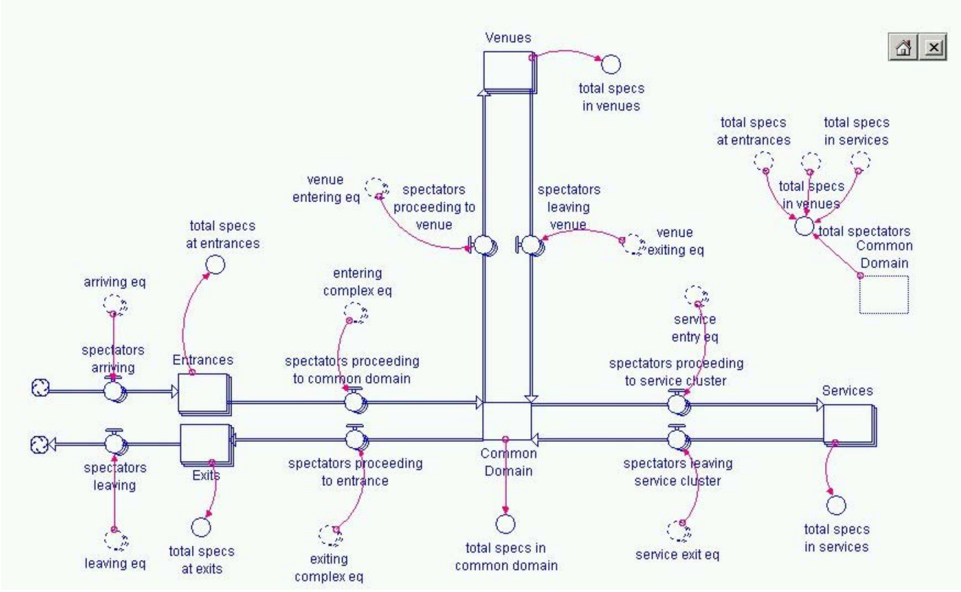


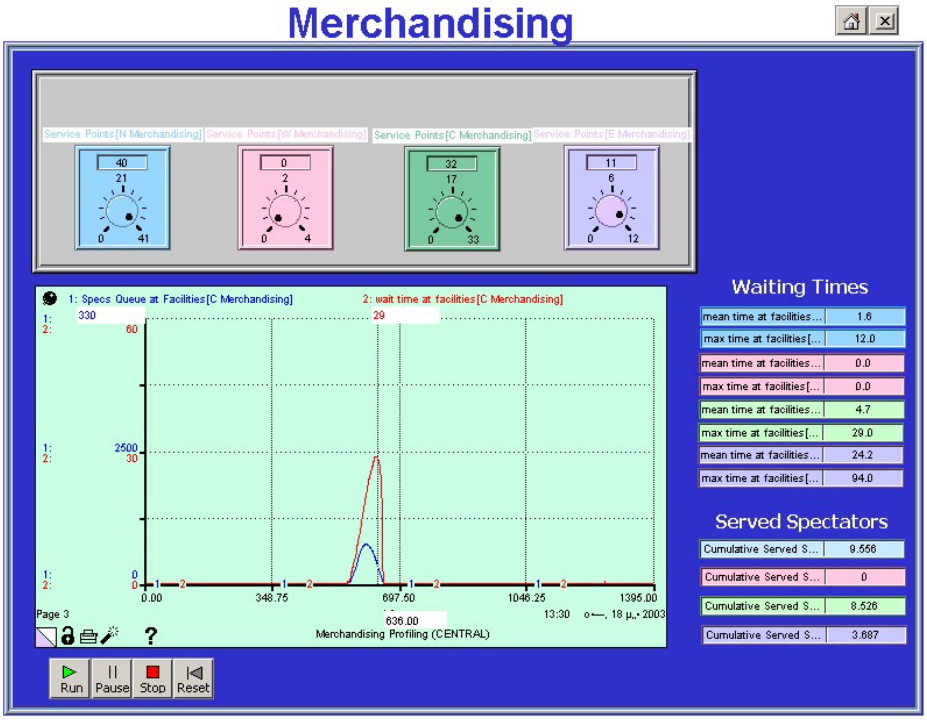
Figure 4: Model regarding overall spectators' behaviour in the Olympic Complex (summary)

Each of the main stages of the process ('**Entrances**', '**Venues**', '**Services**' etc.) corresponds to a detailed model component like the one presented in Figure 3, describing the sub-processes taking place at the respective venue area. One can see the interactions between these sub-processes. The behaviour of the **'Services'** component, for instance, (i.e. its servicing capacity) influences the system as it determines the number of people that are queuing there and thus not participating in activities elsewhere. As another example, it is clear from the model that spectator arrival rate at the '**Entrances**' and departure rate at the '**Exits**', determines the number of people circulating in the common domain of the complex. Moreover, these rates affect the availability of spectators to fill the venues, and they also affect the demand at the service facilities. Therefore, the high-level goal 'manage the total presence of spectators in the venue area' could be achieved (partly at least) through the more specific goal 'manage the arrival and departure of spectators in the venue area'.

4.4 Scenario Generation

The generation of different scenarios concerning each problem studied, and the simulation of these scenarios with the help of the process models developed, is an essential part of requirements definition. In our experience, scenarios are an indispensable tool for truly understanding the implications of stakeholders in their deliberation of requirements. In our application, as the models were being developed and the stakeholders were becoming more aware of the different factors influencing each problem, the range of possible values for each of these factors became more evident, thus creating the initial ideas for different scenarios.

In the model of Figure 3, for instance, scenario formulation focused on the three variables defining demand and supply for each service facility, namely the percentage of spectators expected for each type of service (demand), the number of service points per service type and the respective service rate (supply). Other relevant factors, such as spectators' arrival and departure patterns, were taken into account. The stakeholders involved in scenario generation investigated the range of probable values for each of these parameters, as well as some 'extreme' values that were less probable but worth investigating nonetheless. Each scenario was characterised by the values of *all* independent variables; the number of possible scenarios thus depended on the number of their feasible combinations.



Service Points[N Merchandising]: 40 (0–41)
Service Points[W Merchandising]: 0 (0–4)
Service Points[C Merchandising]: 32 (0–33)
Service Points[E Merchandising]: 11 (0–12)

Waiting Times

mean time at facilities... 1.6
max time at facilities[... 12.0
mean time at facilities... 0.0
max time at facilities[... 0.0
mean time at facilities... 4.7
max time at facilities[... 29.0
mean time at facilities... 24.2
max time at facilities[... 94.0

Served Spectators

Cumulative Served S... 9.556
Cumulative Served S... 0
Cumulative Served S... 8.526
Cumulative Served S... 3.687

Figure 5: Simulation results for the 'Merchandising' service

Figure 5 presents the results of the simulation for a scenario concerning the **'Merchandising'** service in one of the four areas of the Olympic Complex. The demand is set at **15% of spectators** using merchandising services, while supply is provided by **32 points of service**, and a service rate of **1.5 minutes per customer**. Graphical results include total spectators waiting to be serviced at each moment (blue curve), and the corresponding waiting time (red curve), while numerical results include the mean and maximum waiting times, as well as the number of spectators served throughout the day. In this particular scenario, a total of **8526 spectators** were serviced, with **a mean waiting time of 4.7 minutes** and **a maximum waiting time of 29 minutes** (numbers shown in the green numerical indicators). The results of scenario simulation helped the stakeholders realise the implications of their design choices in terms of the service level provided to customers. This realisation in turn contributed to a quantification of the goals that each functional area set for the final system, e.g. 'achieve a total of 85 service points for merchandising in the Olympic Complex' or 'achieve a service rate of one customer per minute'.

Simulating the behaviour of the venue operations system overall yields results like those presented in Figure 6. The screen shows the profile of spectators' behaviour for the entire day at four key points of the complex: arrival, presence in the common area, presence inside venues and, finally, departure. According to the scenario presented here, spectators arrive to the Olympic Complex during the **two hours preceding** each competition session and leave the complex during the **two hours following** the session. This gives spectators time to stroll in the common domain of the complex, to visit service facilities, to be at a specified venue in time for the corresponding session, and to leave the complex in an orderly fashion. At the same time, the total number of spectators in the common domain of the complex was kept at a relatively comfortable level. In other words, the goal 'manage the arrival and departure of spectators in the venue area' was quantified in terms of the two goals 'distribute spectator arrival in the two hours preceding each session' and 'distribute spectator departure in the two hours following each session'.

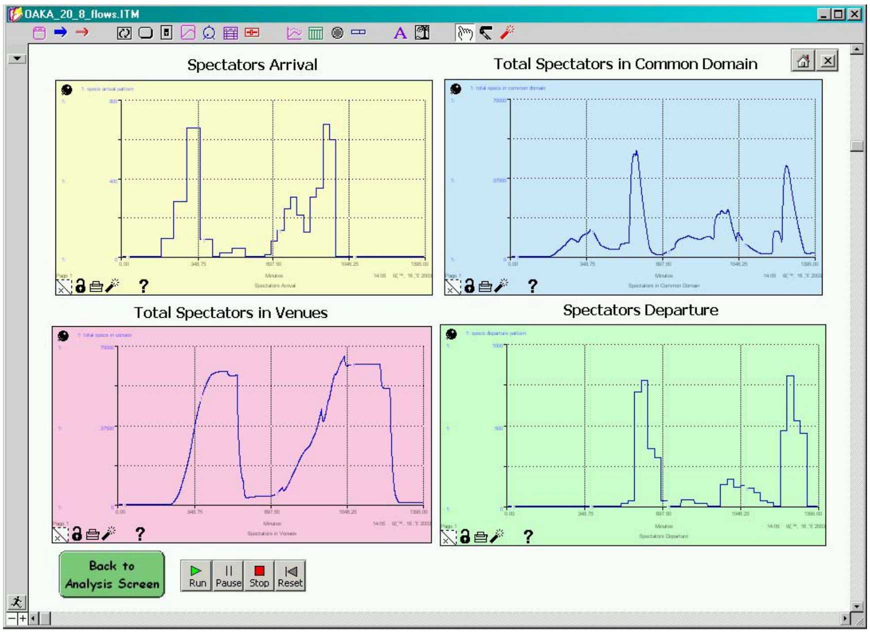


Figure 6: Overall spectator profiling at the Olympic Complex

The models were subjected to testing through simulation sessions, in workshops involving from 5 to as many as 40 participants. In all workshops the models were presented to project stakeholders together with the corresponding scenarios and simulated runs. As most of the participants were not familiar either with RE methodologies or with the system dynamics way-of-thinking, their initial reactions ranged from excitement to disbelief. However, even sceptical participants soon realised the advantages of a visual yet operating model consisting of interacting components, and the power of rapid scenario development and simulation. These features enabled stakeholders to reach a consensus about the underlying processes and the implications that each choice would have on overall system behaviour. The first type of result, i.e. results concerning specific components of the system, helped to answer operational questions concerning the rational allocation of resources and the resulting service provision capabilities of the system. The second type of result proved useful for understanding the overall behaviour of a venue, thus answering higher-level, management questions concerning customer presence and distribution, arrival and departure patterns etc.

5. Observations and Conclusions

Requirements engineering is considered by many as the most critical of all development activities for socio-technical systems. In most cases, different stakeholders are involved with different experiences, backgrounds, goals for the system etc. The work presented in this paper is based on the premise that, in order to achieve consensus as to the combined set of requirements for the intended system, there is a need to deploy a systematic approach that encourages all stakeholders to understand the issues at hand and collectively progress towards a desired solution.

In particular, informal and textual descriptions need to give way to conceptual modelling languages with clear semantics and intuitive syntax so that an application can be defined at an appropriate level of abstraction. This would greatly enhance visualisation of processes that in turn will contribute to a more informed discussion and agreement between stakeholders.

We found that prior to our work for venue operations design, stakeholder workshops, facilitated on the basis of past experience, were only partially helpful. Architectural and topological designs imposed constraints on thinking about customer-oriented service provision. Textual requirements specification resulted in voluminous documentation with little chance for proper agreement, estimation of resources and planning for a co-ordinated implementation. However, eliciting and developing maps of stakeholders' mental models were not sufficient by themselves for achieving stakeholders' agreement. Models needed to be subjected to 'testing' in order to understand the implications of changes to a system component on the overall behaviour of the system. Such a testing was achieved through simulation activities. Simulation of models was a necessary component for developing scenarios, and this way of working proved to be invaluable in experimenting with alternative solutions and to encourage co-operative design in multiple workshop sessions.

The field of *scenarios* has been a fertile one for many types of application, from industrial decision making [Chindemi, Manca, et al 1998] to medical applications [Dangerfield, Fang, et al 2001; Georgantzas, Batista, et al 2000], finance [LaRoche and Kohn 2000], human computer interaction [Carroll 2000], software development [Abdel-Hamid and Madnick 1991] and requirements engineering [Carroll 2002; Filippidou and Loucopoulos 1997; Potts, Takahashi, et al 1994]. A common feature of scenarios in all these domains is their use in examining alternative future situations. According to Carroll, scenarios support the way of working of experts working on ill-structured problem settings such as planning and design [Carroll 2002]. In our application, scenarios proved to encourage group brainstorming through which participants could focus on alternative solutions and to envision potential behaviour of the system prior to its implementation. Using scenarios in our RE project, the problem of defining desirable levels of service for venue operations was solved by a process that resulted in the actual definition of the service levels. In other words, following many different experimentations, stakeholders arrived at an agreed set of requirements with respect to their aspirations about service provision. Furthermore, the requirements from each stakeholder were in conformance with the requirements of all other stakeholders. This supported the process-orientated perspective adopted in the framework and also confirmed the findings of a number of empirical studies on the cognitive nature of design that have shown that expert designers develop sub-solutions in their effort to understand the problem [Darke 1978; Malhotra, Thomas, et al 1980; Rowe 1987]. In our participative design approach, stakeholders first defined what they thought might be important aspects of the problem. They subsequently developed tentative designs in their scenario analysis sessions to ascertain whether anything else can be discovered about the problem. The design paradigm resembled that of 'generator-conjecture-analysis' paradigm [Hillier, Musgrove, et al 1984]. Analysis guides design and design guides analysis -and all in an effort to gain an understanding of the problem, of the situation at hand.

The effect of this was a fundamental change to the way that stakeholders were working. The gradual shift of emphasis from informal to reflective was based on the realisation that there is no well-founded route from problem setting to problem solving but there is a continuous interaction between the two.

In this paper we have argued for the need to engage four essential modelling activities during the RE phase of a project:

- *Ontology modelling* in order to define the problem context, boundaries and essential application concepts.
- *Strategy modelling* in order to capture all stakeholders' goals and to define the potential areas of synergy or conflict regarding the intended system.
- *Process modelling* in order to express the collaborating set of activities that define the dynamics of a system.
- *Scenarios modelling* in order to develop hypotheses about the proposed system behaviour and test these hypotheses against realistic situations.

Methodologically, the framework supports a 'solution-first strategy' [Carroll 2002] to requirements definition. Analysis guides design and design guides analysis -and all in an effort to gain an understanding of the problem, of the situation in hand.

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