UNIVERSIDADE NOVA DE LISBOA

Faculdade de Ciências e Tecnologia

Departamento de Informática

Assessment of IT Infrastructures:
A Model Driven Approach

Luís Alexandre Ferreira da Silva

(Licenciado)

"Dissertação apresentada na Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa para obtenção do Grau de Mestre em Engenharia Informática."

Orientador: Prof. Doutor Fernando Brito e Abreu

Caparica

Outubro de 2008

[This page has been intentionally left blank]

Acknowledgments

First, I would like to thank and express sincere appreciation to my supervisor Prof. Doutor Fernando Brito e Abreu for his constant assistance and support in the preparation of this dissertation. During the course of my Master's thesis studies he has been a source of encouragement and friendship, for which I am very grateful. In addition, I would like also to thank Prof. Doutor Pedro Medeiros, for the initial input in the beginning of this project.

I would like also to thank to all the people that reviewed and provided comments regarding this research work. In particular I would like to thank to the members of the QUASAR group in particular to Anacleto Correia, Raquel Porciúncula, Miguel Goulão, João Caldeira, Jorge Freitas and José Costa.

Last but not least, I am grateful to my family and in particular to my girlfriend Luzia Valentim for their support during the preparation of this thesis.

[This page has been intentionally left blank]

Resumo

Têm sido propostas várias abordagens para avaliação de arquitecturas infra-estruturais de Tecnologia de informação (TI) maioritariamente oriundas de empresas fornecedoras e consultoras. Contudo, não veiculam uma abordagem unificada dessas arquitecturas, em que todas as partes envolvidas possam cimentar a tomada de decisão objectiva, favorecendo assim a comparabilidade, bem como a verificação da adopção de boas práticas. O objectivo principal desta dissertação é a proposta de uma aproximação guiada pela modelação dos conceitos do domínio, que permita mitigar este problema.

É usado um metamodelo para a representação do conhecimento estrutural e operacional sobre infra-estruturas de TI denominado *SDM (System Definition Model)*, expresso com recurso à linguagem *UML (Unified Modeling Language)*. Esse metamodelo é instanciado de forma automática através da captura de configurações infra-estruturais de arquitecturas distribuídas em exploração, usando uma ferramenta proprietária e um transformador que foi construído no âmbito desta dissertação. Para a prossecução da avaliação quantitativa é usada a aproximação *M2DM (Meta-Model Driven Measurement)*, que usa a linguagem *OCL (Object Constraint Language)* para a formalização de métricas adequadas.

Com a abordagem proposta todos os parceiros envolvidos (arquitectos de TI, produtores de aplicações, ensaiadores, operadores e equipas de manutenção) poderão não só perceber melhor as infra-estruturas que têm a seu cargo, como também melhor expressar as suas estratégias de gestão e evolução. Para ilustrar a utilização da aproximação proposta, avaliamos a complexidade de alguns casos reais nas perspectivas sincrónica e diacrónica.

Palavras-chave

Avaliação quantitativa, infra-estrutura, *System Definition Model*, complexidade de infra-estruturas, avaliação orientada por modelos, aspectos económicos de infra-estruturas, modelação de infra-estruturas, classificação de topologias de infra-estruturas.

[This page has been intentionally left blank]

Abstract

Several approaches to evaluate IT infrastructure architectures have been proposed, mainly by supplier and consulting firms. However, they do not have a unified approach of these architectures where all stakeholders can cement the decision-making process, thus facilitating comparability as well as the verification of best practices adoption. The main goal of this dissertation is the proposal of a model-based approach to mitigate this problem.

A metamodel named *SDM (System Definition Model)* and expressed with the *UML (Unified Modeling Language)* is used to represent structural and operational knowledge on the infrastructures. This metamodel is automatically instantiated through the capture of infrastructures configurations of existing distributed architectures, using a proprietary tool and a transformation tool that was built in the scope of this dissertation.

The quantitative evaluation is performed using the *M2DM (Meta-Model Driven Measurement)* approach that uses *OCL (Object Constraint Language)* to formulate the required metrics. This proposal is expected to increase the understandability of IT infrastructures by all stakeholders (IT architects, application developers, testers, operators and maintenance teams) as well as to allow expressing their strategies of management and evolution. To illustrate the use of the proposed approach, we assess the complexity of some real cases in the diachronic and synchronic perspective.

Keywords

Quantitative assessment, infrastructure, *System Definition Model*, infrastructure complexity, model driven assessment, economic aspects of infrastructures, infrastructures modeling, infrastructure topology classification.

[This page has been intentionally left blank]

Table of Contents

[This page has been intentionally left blank]

Acronyms

ACM	The Association for Computing Machinery
APC	American Power Conversion
CA	Computer Associates International
CAPEX	Capital expenditures
CCM	Cyclomatic Complexity Metric
CCTA	Central Computer and Telecommunications Agency
CEO	Chief Executive Officer
CIM	Common Information Model
CIO	Chief Information Officer
CMDB	Configuration Management Database
CLR	Common Language Runtime
CNC	Coefficient of Network Complexity
COBIT	Common Objectives for Information and related Technology
CSV	Comma-Separated values
CSVDE	Comma-Separated values Directory Exchange
DMTF	Distributed Management Task Force
DSI	Dynamics Systems Initiative
DSL	Domain Specific Language
ERP	Enterprise Resource Planning
eTOM	enhanced Telecom Operations Map
HKM	Henry and Kafura Metric
HP	Hewlett-Packard
HIPAA	Health Insurance Portability and Accountability Act
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IMPEX	Implementation Expenditures
ISACA	Information Systems Audit and Control
ISO	International Organization for Standardization
ITAA	Information Technology Association of America
ITU-T	International Telecommunication Union Telecommunication Standardization
IT	Information Technology
ITI	Information Technology Infrastructure
ITIL	Information Technology Infrastructure Library
ITILib	The SDM Information Technology Infrastructure Library
ITGI	IT Governance Institute
ITSM	Information Technology Service Management
itSMF	IT Service Management Forum
J2EE	Java 2 Platform, Enterprise Edition
LDAP	Lightweight Directory Access Protocol

M2DM	Meta-Model Driven Measurement
MSFT	Microsoft Corporation
MOF	Microsoft Operations Framework
MPLS	Multiprotocol Label Switching
NGOSS	Next Generation Operation Support and Software
NDS	Novell Directory Services
OCL	Object Constraint Language
OGC	Office of Government Commerce
OMT	Object Modeling Technique
OO	Object Oriented
OOSE	Object-Oriented Software Engineering
OPEX	Operating Expenditures
PRM-IT	Process Reference Model for IT
RFC	Request For Change
ROI	Return of Investment
SAP	Systems Applications and Products
SDM	System Definition Model
SID	Shared Information/Data model
SBLIM	Standards Based Linux Instrumentation for Manageability
SML	Service Modeling Language
SMI-S	Storage Management Initiative - Specification
SOX	Sarbanes-Oxley
SPSS	Statistical Package for the Social Sciences
STB	Server and Tools Business Division
TAM	Telecom Application Map
TCO	Total Cost of Ownership
TEI	Total Economic Impact
UML	Unified Modeling Language
USE	UML based Specification Environment
UoD	Universe of Discourse
W3C	World Wide Web Consortium
WFR	Well-Formedness Rules
WMI	Windows Management Instrumentation
XML	eXtensible Mark-up Language
XSL	eXtensible Stylesheet Language

Table of Figures

Table of Tables

1

Introduction

Contents

This chapter starts with the motivation behind this research work and introduces the concept of ITIs and the importance and benefits that organizations can get from the ITI evaluations. Stakeholders and the importance of complexity on infrastructures and several considerations regarding the Total Cost of Ownership are also presented. Finally there is a section dedicated to benefits or contributions we expect to achieve and a brief summary of the remaining chapters, typographical conventions and document structure, to facilitate the reading.

1.1 Motivation

Organizations of all kinds are dependent of Information Technology (IT) to such a degree that they cannot operate without them [Shackelford, et al., 2006]. As defined by the Information Technology Association of America (ITAA), IT is "*the study, design, development, implementation, support or management of computer-based information systems, particularly software applications and computer hardware.*" [ITAA, 2008].

The concept of Information Technology Infrastructures, referred in this dissertation as ITIs, is a wide concept that represents the use of the various components of information technology (computers, networks, hardware, middleware and software) upon which the systems and IT services are built and run to manage and process information [Sirkemaa, 2002].

In the last few years we have witnessed a tremendous change in ITIs and they became part of every organization. Twenty years ago it was normal to have all the business and mission critical applications running on a mainframe or a mini-computer. Ten years ago, these applications were distributed over two and three-tiered systems. Now, these applications are distributed over n-tiered systems and may have thousands of components than span multiple vendors and products, with high dependencies, or some degree of relationship.

The primary purpose of the ITI is to support and enhance business processes and ITIs are the foundation upon which the business processes that drive an organization's success are based [Gunasekaran, et al., 2005]. Based on this, aspects like reliability, security, usability, effectiveness and efficiency are vital to every ITI. These infrastructures contain a complex mix of vendor hardware and software components that need to be integrated to ensure that they work well together and they distribute a variety of services both within and outside the organization, many of which are mission critical.

Historically, the biggest the infrastructure, the more difficult is to manage it, resulting in higher costs and potentially higher Total Cost of Ownership (TCO) [Kirwin, et al., 2005]. There are several approaches developed to assess and evaluate the effectiveness of IT. However there is a lack of a reliable approach that organizations could use to understand how IT investments translate into measurable benefits [Hassan, et al., 1999].

To provide guidance and help organizations to create, operate and support ITIs and processes while ensuring that the investment in IT delivers the expected benefits, several frameworks have emerged (some of them are presented in section 1.4). These frameworks define a set of standard procedures and processes that organizations should adopt to improve efficiency and effectiveness [MSFT, 2008a, OGC, 2000]. These frameworks address the domain of IT management or the domain of IT governance [Salle, 2004].

Most organizations understand the value of implementing process improvement standards and frameworks. That implementation became a worldwide trend, prompted by increasing interest and demand for greater levels of governance, audit and control [Cater-Steel, et al., 2006].

1.1.1 The importance of evaluating ITIs

IT represents one of the world's fastest-changing industries and process changes at the business level can force major changes to infrastructures [Perry, et al., 2007]. There is more pressure than ever on IT to reduce IT costs while improving service to end users [Gillen, Perry, Dowling, et al., 2007]. According to analysts, most organizations consume 70% of IT budgets managing and supporting ITIs [Weill, et al., 2002], instead of spending resources to add new business value and take the business further. As organizations grow, their ITIs grow along with them. But often that growth is uneven, driven as much by the conditions under which they operate, as by the model they aspire to.

Having the right infrastructure, at the right time, to support new business requirements is a challenging task, because most business initiatives emerge unpredictably [Pispa, et al., 2003]. Most times new business requirements require considerable changes in infrastructures that must be implemented in the shortest possible time, to meet business deadlines. In some organizations this pressure leads to wrong infrastructures, increases complexity, decreases the effectiveness and efficiency resulting in an infrastructure more difficult to manage, new components without integration with existing ones, waste of resources and delays, among other aspects.

This fusion between business and technology requires the expertise of both business and IT professionals that should support their decisions based on concrete information to better align business with infrastructures. Both should understand "what is the ITI currently?", "what they want it to be?" and turn what they have, into what they want in a disciplined way.

Having an ITI evaluation process can provide valuable information to business and IT professionals and is crucial to support their decisions regarding the growth of the infrastructures. Some examples of benefits of that evaluation are:

- Defining and maintaining ITI operations and administrative policies;
- Check if best practices are being applied across the entire infrastructure;
- Understand better the impact of changes of ITIs in other systems;
- Simplify infrastructures management;
- Evaluating emerging technologies and business potential or impact through complexity analysis and evaluation;
- Analysis and predicting of ITI growth over the years;

- Help defining an ITI strategy, planning, architecture and optimization to meet business goals and objectives.

These evaluation aspects represent the first step to get control of ITIs. Without these evaluation is difficult to control and without control it is difficult to manage [Kirwin, 2003b]. All these benefits are quantifiable and are normally perceived as positive by internal and external stakeholders.

1.1.2 Stakeholders interested in ITIs evaluation

The word "stakeholder" of a given organization is currently used to refer to a person or another organization that has an interest (or "stake") in what the organization does. The stakeholder concept can be applied to sponsors, customers, partners, employees, shareholders, owners, suppliers, directors, executives, governments, users, public, creditors and many more.

To define the role of the infrastructure to support the business and to ensure that the business is aligned with IT, it is important that IT organizations understand who its stakeholders are and ensure that they are involved in defining and reviewing IT quality and performance [OGC, 2002].

There are a number of inherent difficulties in the process of identifying key stakeholders and their needs, because they may be numerous, distributed and with different goals. The Table 1.1 summarizes some of the most common stakeholders, their job description and the "stake".

Table 1.1 — Most common organization stakeholders

Stakeholder	Job Description	Stake
Sponsors	Sponsors could be seen as business board members and are individuals in leadership roles that allocate resources like money, their own time, energy, reputation, influence and the time and energy of individuals in the groups they manage.	Return of investment in terms of increased organizational efficiency or effectiveness or improved financial performance.
Customers	Customers are the people that pay for goods or services and are recipients of the services provided by the IT organization. ITI are there to provide services and support to customers.	Commission, pay for and own IT services. They agree to service levels and allocate funding. They expect value for money and consistent delivery against agreements.
Users	Users are the people that use services on a day-to-day basis. They use IT services to support their specific business activities. Users are also widely characterized as the class of people that uses a system without complete technical expertise required to fully understand the system.	Invest energy in using the new procedures and working practices and their expected payoff is an enhanced relationship with the IT organization and improved perception in service quality to support their individual needs.

Stakeholder	Job Description	Stake
Employees / Agents	The individuals and groups who are responsible for facilitating the implementation of services in ITI, which include IT professionals, trainers, communication specialists, external consultants, human resource professionals amongst others. These individuals are asked to contribute expertise, time and energy to the ITI.	Their stake in the process is typically the expectation that their participation will lead to personally important outcomes such as recognition, learning.
Partners/ Suppliers/ Vendors	In some organizations, suppliers and vendors are stakeholders. Their investment in ITI can range from active participation in implementing new systems in their own organizations to complying with new procedures.	Their expected payoff is typically a stronger relationship with the organization leading to increased success for them.

To get the expected "stake", sponsors know that the ITI must be "healthy" to support the business requirements. Often ITIs are the main impediment to the new business challenges [Ganek, et al., 2007], so most enterprises spend a significant part of IT budgets on ITIs [Weill, 2007, Weill, et al., 2002]. Reducing costs while improving service levels and show quantifiable value from IT investments represents a high priority for *Chief Information Officers (CIOs)* [Ernest, et al., 2007]. Evaluating ITIs is a process that can measure the "health" of infrastructures, so it is not only important to all key sponsors, but also to help CIOs to achieve their top priority. Some benefits that sponsors can achieve with an ITI evaluation are:

- **Reduction of service outages** – Most of the service outages in infrastructures are related with people and the inexistence of processes or models that describes complex technical solutions;
- **Evaluation** – Evaluate performance, processes and capabilities of the infrastructure help to assure that day-to-day tasks are executed effectively and efficiently;
- **Simplification** – Simplify the task of review and audit processes like asset management for efficiency, effectiveness and compliance;
- **Increase efficiency and effectiveness** – The efficiency and effectiveness of the systems deployed, results in productivity gains and an increase in end users satisfaction;
- **Knowledge** – Better knowledge of ITI which can help partners, suppliers and vendors, who work as virtual members of the IT staff in providing hardware, software, networking, hosting and support services.

An evaluation process can also measure some of the current key challenges of ITIs, such as complexity, which represents the root cause of problems in IT organizations [Ganek, et al., 2007].

Knowing the complexity of an ITI trough an evaluation can help to design simpler and better solutions, that are easier and faster to implement and represent a lower risk for the IT staff responsible for implementing solutions in an ITI.

1.2 Complexity

Complex ITIs are not easy to manage. In fact, organizations spend a significant part of their IT budget just to maintain ITIs [Ganek, et al., 2007]. North American and European organizations are expecting to increase 2008 IT budgets by 3%, which is the same percentage that they planned for 2007 [Bartels, 2008]. Currently CIO and IT professionals understand the importance of ITIs to the business and their main concerns and priorities are the improvement of efficiency, the improvement of IT alignment with business and helping the business to cut costs and improve productivity [Bartels, 2008]. In order to achieve those gains, the ITIs complexity must be easily determined (static perspective) and kept under control (dynamic or evolutive perspective). In both cases we need to express that complexity quantitatively.

1.2.1 Complexity metrics

Depending on the field, there are numerous complexity metrics that can be used for the purpose of evaluating complexity. In the field of ITI, complexity can be seen at several granularity levels, such as:

- **global view** where the whole infrastructure is a network of sites (e.g. a distributed multinational's intranet);
- **partial view** where the local infrastructure of the site is a network of servers and corresponding clients (e.g. an company branch in a given city).

In either case the problem of evaluating ITI complexity can be mapped to the one of evaluating network complexity and finally a network can be mapped into a directed graph.

We have performed a survey of network and graph complexity evaluation approaches, which have been proposed by different research communities, since both network analysis and graph theory are used in a broad spectrum of applications. From this survey emerged three well known complexity metrics that we will adapt, use and describe in more detail in section 5.3.2. The three well know complexity metrics are the *Coefficient of Network Complexity (CNC)* [Pascoe, 1966] which is a widely used metric for evaluating network complexity in the field of network analysis, *Cyclomatic Complexity Metric (CCM)* [McCabe, 1976] proposed by Tom McCabe, which was one of the first metrics to evaluate the complexity of flowcharts (directed graphs) representing the internal

implementation of individual software modules and the *Henry and Kafura Metric (HKM)* [Henry, et al., 1981] used to evaluate the complexity of software modules (nodes) of the so-called “call graph”, (a directed graph representation of the call relationships among those modules).

In this dissertation we will use the previously described set of metrics, enriched with a few of our own, for illustrating the feasibility of our quantitative approach in the context of ITIs complexity evaluation.

1.2.2 Comparing infrastructures complexity

There is a direct relation between ITIs and business performance. Research found that robust ITIs are a key driver of productivity and growth. The employees in organizations with better ITIs are more productive and the managers that are in organizations with better information systems, control significantly better their business [Iansiti, et al., 2006].

These conclusions create pressures on IT that can be hypothetical classified as “good” and “bad” pressures. Pressures to add business value by increasing productivity, pressures to increase end-user productivity or pressure to improve collaborations with customers are examples of “good” pressures. On the other side we have the “bad” pressures to reduce costs, improve security, keep business up and running, among others that do not necessarily push the business ahead. According to analysts, these “bad” pressures consume 70% of most IT budgets today [Bartels, 2008].

Analyzing the ITI evolution of infrastructure complexity within the organization and comparing infrastructure complexity with other similar organizations may be the first step to understand and control complexity. IT organizations that control complexity spend 15% less than their peers and operate with 36% fewer staffers [Iansiti, et al., 2006]. Through complexity analysis and comparison it will be easier to take decisions regarding IT investments to gain the most benefit and use efficient IT resources.

To evaluate the ITI complexity and be able to compare it with others, a model based approach can be used to capture ITI knowledge which can include infrastructure topology, constraints, policies, processes, best practices amongst other aspects. This knowledge can then be used to plan, test, model, deploy, operate, monitor, troubleshoot or enforce policies in ITIs.

1.2.3 Forecast of ITI complexity

The IT provides many benefits and the complexity in IT systems and in particular in ITIs must be seen as natural, since the nature of ITIs is complex (Fig. 1.1). Understanding infrastructures, tracking

changes, dealing with heterogeneous environments and solving problems are just some of the challenges that IT professionals face on a day to day basis. Because complexity is a characteristic of ITIs, it will not disappear and IT professionals must have tools and processes that they can use to deal with IT more effectively and use the strengths of ITIs to drive more strategic value.

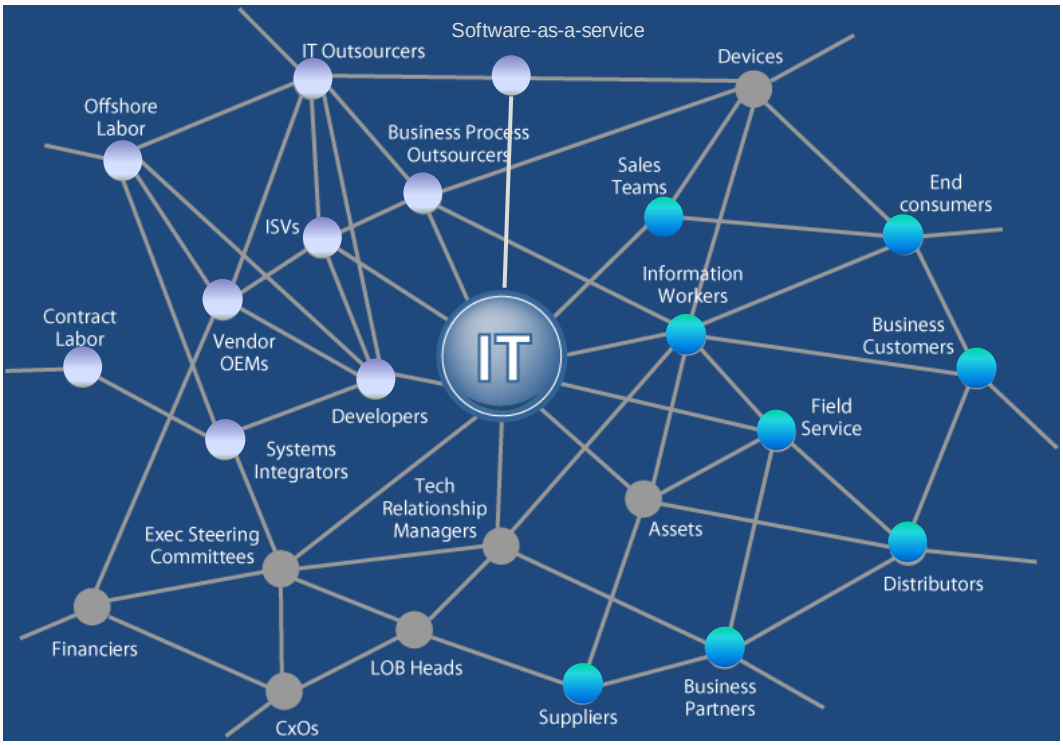


Fig. 1.1 — IT Ecosystem Is Complex (source:[Symons, et al., 2008])

To align IT with the goals of the business and to enable ITIs to function as a strategic asset to the business, complexity should be evaluated, controlled and managed. This control over complexity can help IT to move from a complex environment to a more efficient environment through actions like elimination of unnecessary redundant systems, reducing manual tasks, and more efficient use of resources, among other actions. The evaluation of ITIs and, in particular, the evaluation of the complexity can help IT professionals to deal with complexity in a productive way and help them to identify those actions.

Without control, the complexity of ITIs tends to increase due to reasons like globalization, regulations, mergers and acquisitions, systems growth and integration, security, continuous availability or business continuity among other factors. The control of complexity will enable organizations to forecast infrastructure complexity while addressing all these aspects. To be able to address new business needs and predicting infrastructure complexity, organizations, should measure their agility with focus on ITIs and then making the required IT investments [Plummer, 2005]. Agility is the ability of ITIs to adapt to business condition. Agility is typically expressed by the required time to implement a new capability or to achieve an IT goal such as increase the IT capacity by 15 percent,

deploy new features or to increase the IT capacity to support a new business application [Mertins, et al., 2008, MSFT, 2007].

1.3 Total cost of ownership

The TCO was popularized by Gartner more than 20 years ago, with the goal of clearly and reasonably address the real costs attributed to owning and managing ITIs. Currently TCO is still one of the most important concerns of IT managers [Kirwin, 2003b]. TCO identifies costs as being made of two main groups, the *direct costs* and the *indirect costs* (aka *soft costs* [Kirwin, 2003a] because they often occur outside the budget).

The direct costs are normally the capital, fees and labor costs. Indirect costs are more difficult to measure and include the costs associated with training IT professionals and users, costs associated with failure or outage (planned and unplanned), development and testing, costs associated with distributed computing, datacenters, storage and telecommunications, electricity and much more [Gartner, 2003].

The nature of indirect costs leads some organizations to underestimate their impact on ITIs. However TCO analysis often shows that the acquisition or purchase price of an asset represents only a small fraction of its total cost and indirect costs can typically represent as much as 60% of the total cost of managing and owning an ITI [Kirwin, et al., 2005].

The TCO allows the alignment of IT operational efficiency goals with business performance requirements [Kirwin, 2003a] and should not be used with the purpose of justifying IT investments, validate initiatives or increase or decrease ITIs spending. There are some frequent misunderstandings that TCO is only a way of cutting costs or that the IT platform with the lowest TCO is the best choice and indirect costs do not count [Kirwin, 2003a].

The TCO has proven to be a vital and popular framework for IT and business management decision-making and has been applied to several different technology areas. The idea of using TCO as a way to gauge IT performance is still taking shape [Kirwin, 2003b]. TCO may be used as a proxy for activity-based costing, a technique in which all costs associated with a specific IT function are measured and compared to industry averages. This comparison is sometimes more efficient than looking at IT costs at the macro level. For instance, a TCO analysis of the costs associated with managing *Enterprise Resource Planning (ERP)* applications could reveal cost disparities that would not show up if a company only considered its overall IT costs [Kirwin, 2003b].

In the field of ITIs, there has been an increasing interest in recent years in calculating the costs of ownership with the aim of helping CIOs to make better decisions as they purchase, upgrade and/or

replace their ITIs [MacCormack, 2003]. Understanding and evaluating the TCO of ITIs is a prerequisite in pursuing initiatives in ITIs [Blowers, 2006a].

1.3.1 Reducing ITIs TCO

To reduce the TCO associated with a particular infrastructure it is important, first to have a process that can analyze all the distinct aspects that an ITI is built of and calculate the real total cost of ownership. Organizations are dependent of ITIs to provide business functionality and it is essential that they understand and manage their costs [Kirwin, 2003a]. Only knowing the TCO, can help IT decision makers to focus on ITI problems and develop ways to align costs, performance and service levels with the organizational requirements, while delivering a high service quality. High service quality normally leads to a decrease in IT budgets for managing and supporting infrastructures which reduces the ITIs TCO.

There are several approaches that can be taken to reduce the TCO associated with a particular infrastructure [Aziz, et al., 2003, Conley, et al., 2007, Engels, 2006]. However, because organizations also need to preserve functionality, they need to balance between TCO and the right agility of the ITI. So, in order to reduce the TCO of an ITI, it is very important to manage the tradeoff between TCO and agility.

Complexity, by definition refers, to the condition of being difficult to analyze, understand or solve. According to [Kirwin, et al., 2005] there is a direct relationship between complexity and TCO and the more complex the IT and business are, the higher the TCO is. Complexity is acceptable if the complexity purpose is to achieve business value but unacceptable otherwise. Therefore, organizations should aim for the minimum level of complexity required to meet their business needs. In the following section, we evaluate the impact of ITIs complexity on TCO.

1.3.2 The impact of ITIs complexity on TCO

The ITI complexity is normally divided into the complexity associated with the software and complexity associated with the hardware. The complexity of any system has several drivers of which the most important are (i) size, (ii) the diversity and (iii) the mutation of its parts and of their interconnections. Often we have to drill down complexity analysis since each point of a system may itself be considered a (sub) system. We stop drilling down when a part can be considered as a *blackbox*.

An ITI is a special kind of a system. Its parts are software and hardware components. Software components range from applications down to firmware (embedded software). However, components can be computer devices (e.g. desktop, handled or mobile devices), servers, switching and communication equipment (e.g. hubs, routers, access points, repeaters) and other devices (e.g. printers, plotters, scanners).

While the size driver of ITI complexity is self-explanatory, it may not be so obvious for the diversity driver. The diversity driver of ITI components can manifest itself in different installation operations and maintenance procedures.

Consider for instance two ITIs, with the same number of servers, equipment and topology. The complexity of those two ITIs, will be much different if in one case there is no technology diversity and on the other case each component requires specific customization or operation. Just imagine that you have 10 different printers each requiring a different kind of maintenance intervention.

The mutation driver of ITI complexity has to do with its modifications throughout time. The observation period may vary depending on the characteristic being observed. For instance, while for a percentage of PCs replaced on a yearly basis would make sense, we may need to observe the maximum number of transactions per hour for balancing online versus offline services. Table 1.2 present examples of complexity drivers for hardware and software.

Table 1.2 — Examples of ITIs complexity metrics

	Hardware		**Software**	
	Components	Interconnection	Components	Interconnection
Size	Number of servers; Number of hubs; Number of routers; Number of printers.	Number of physical links; Number of logical links.	Application installations; Operating systems installations.	Number of dependencies on other software components; Number of configuration scripts required to allow software interoperability.
Diversity	Different end-user platforms (desktops, handled, mobile devices); Different server technologies; Different printer products.	Different link technologies (e.g. UTP, fiber optic, wireless, Bluetooth); Redundant communication links between 2 nodes.	Different applications installed; Different operating systems installed.	Different types of dependencies among software components. Different configuration scripts required to allow software interoperability
Mutation	Yearly rotation of desktops.	Hardware automatic reconfiguration to provide fault tolerance.	Application releases per year; Operating system updates per year.	Components to provide software interoperability.

Fig. 1.2, shows an estimative chart generated with a proprietary software tool (Gartner TCO Manager) of a 2.500 end-users environment where we can see the huge impact of the various complexity levels on cost. In this specific scenario the TCO per end-user doubles when maximum complexity is reached.

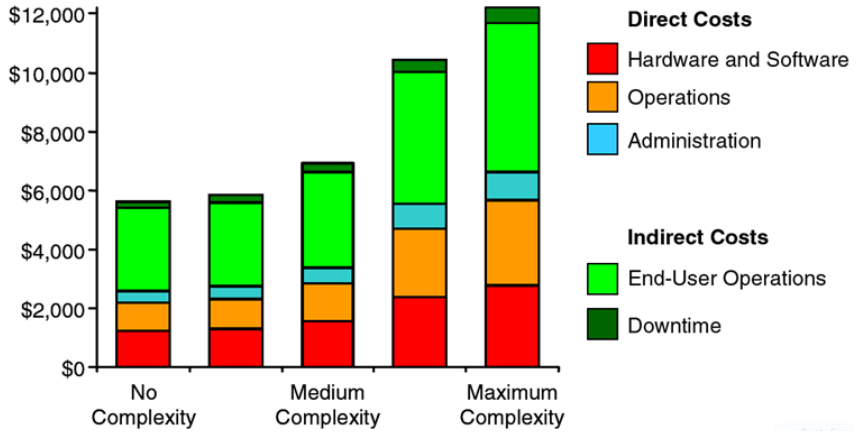


Fig. 1.2 — TCO per end user at various complexity levels (source: [Kirwin, et al., 2005])

It is very important to have a relation between the complexity and the business value and the point when the complexity exceeds the business value. Beyond that point we cannot manage the infrastructure effectively [Harris, 2005]. There is a misperception that investing on IT creates value with no limits. However, when we reach our capacity to manage the infrastructure (inflection point) the value is negative. Fig. 1.3 shows the perceived relationship between value and complexity against the real relationship, where we can see that investing in IT only brings value until the inflection point is reached.

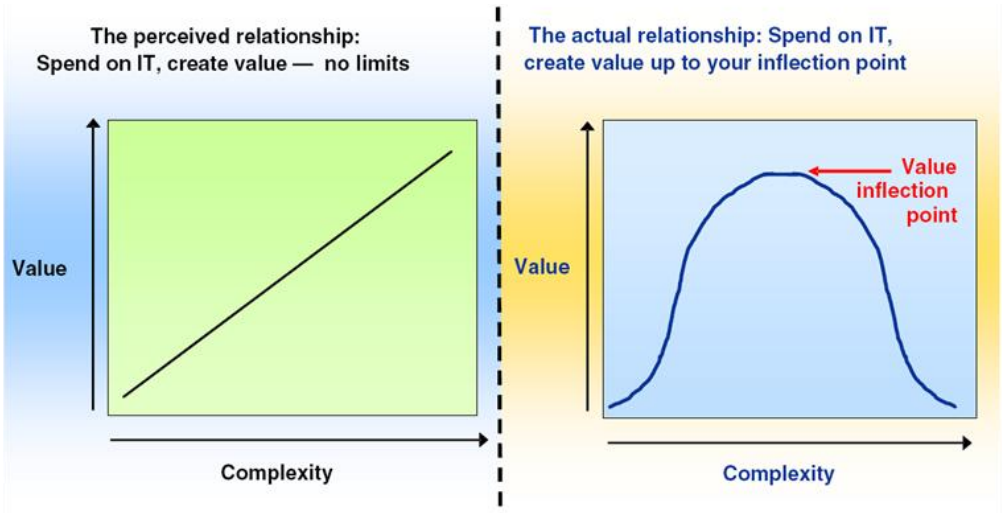


Fig. 1.3 — Complexity and the value of IT (source: [Harris, 2005])

Having a process that can continually evaluate and measure complexity of ITIs is important to understand what is the level of complexity of a particular ITI and if the value of the inflection point was reached.

1.4 IT Service Management

IT service management (ITSM) is a discipline for managing IT systems, philosophically centered on the customer's perspective of IT's contribution to the business. ITSM focuses upon providing a framework to structure IT-related activities and the interactions of IT technical personnel with business customers and users.

This dissertation proposes an ITI evaluation approach that can be used by organizations for different aspects such as the ones mentioned in the motivation section. Most of these aspects are also covered by some ITSM frameworks [Brenner, et al., 2006]. There are a variety of frameworks and authors contributing to the overall ITSM discipline. In this section we will briefly describe two of the most widely adopted frameworks: *IT Infrastructure Library (ITIL)* [OGC, 2000] and *Common Objectives for Information and related Technology (COBIT)* [ISACA, 2008b].

1.4.1 ITIL

The IT Infrastructure Library commonly referred as ITIL is one of the most widely adopted frameworks [Cater-Steel, et al., 2006], is a structured repository of best practices developed in the late 1980s by the *Central Computer and Telecommunications Agency (CCTA)* of the British Government and currently administered and updated regularly by the British *Office of Government Commerce (OCG)*. The ITIL deployment is supported by the work of the *IT Service Management Forum (itSMF)* [Bon, 2004]. The itSMF is global, independent non-profit organization with more than 100.000 members worldwide and present in several countries, including Portugal [itSMF, 2008], with the mission of development and promotion of IT Service Management "best practices", standards and qualifications.

The ITIL, currently in version 3, outlines an extensive set of management procedures that are intended to support businesses in achieving both quality and value for money in IT operations. These procedures are supplier independent and have been developed to provide guidance across the breadth of ITI, development and operations.

ITIL version 3 consists of a series of books ([OGC, 2007d, OGC, 2007c, OGC, 2007e, OGC, 2007a, OGC, 2007b]) giving guidance on the provision of quality IT services and on the accommodation and environmental facilities required to support IT. Fig. 1.4 displays a detailed look at the end-to-end ITIL v2 Model.

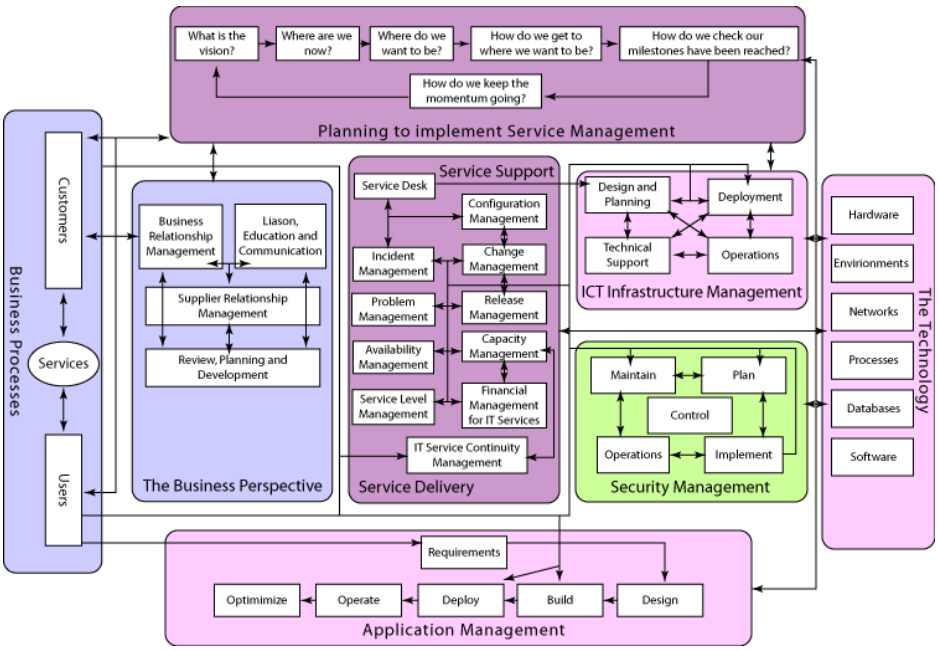


Fig. 1.4 — End-to-end ITIL process (source:[Watt, 2005])

There are other frameworks and guidelines based on the ITIL framework. These have been developed by software and hardware organizations such as the HP's Service Management Framework [HP, 2007] which is based on ITIL v3 and replaces the HP ITSM, IBM's *Process Reference Model for IT (PRM-IT)* [Ernest, et al., 2007, IBM, 2007] which in version 3 is fully aligned with ITIL v3 and Microsoft, with their *Microsoft Operations Framework 4 (MOF),* which in version 4.0 is also aligned with ITIL v3 [MSFT, 2008a].

1.4.2 COBIT

Common Objectives for Information and related Technology commonly referred as COBIT is currently in version 4.1 [ISACA, 2008b] and is another industry framework of good practices for IT produced by *Information Systems Audit and Control (ISACA)* [ISACA, 2008c] and managed by the *IT Governance Institute (ITGI)* [ITGI, 2008b]. COBIT framework allows managers to bridge the gap between control requirements, technical issues and business risks, enables clear policy development and good practice for IT control throughout organizations, emphasizes regulatory compliance and helps organizations to increase the value attained from IT. The COBIT framework is organized into four domains: *plan and organize*, *acquire and implement*, *deliver and support*, *monitor and evaluate* [ISACA, 2008a]. Fig. 1.5 presents the four domains and some of the existing IT processes.

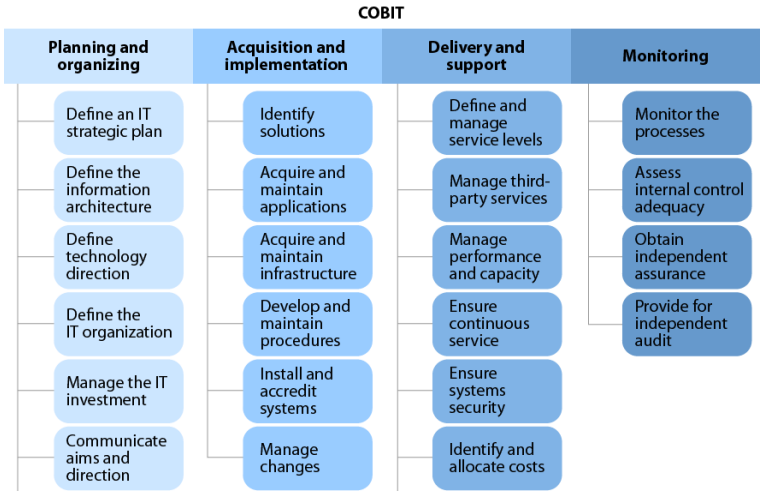


Fig. 1.5 — COBIT framework domains (source:[Symons, et al., 2006])

The *plan and organize* domain covers strategy and tactics in terms of, how IT can help the organization to achieve the business objectives. The *acquire and implement* domain addresses the organization's strategy in identifying developing or acquiring IT solutions as well as implement and integrate them within the organization's current business processes. The *deliver and support* domain focuses on the delivery of required services, which includes service delivery, management of security and continuity, service support for users, and management of data and operational facilities. The *monitor and evaluate* domain deals with the organization's strategy in assessing their quality and compliance with control requirements. This domain addresses aspects such as the performance management, monitoring of internal control, regulatory compliance and governance among others. Across these four domains, COBIT has identified 34 IT processes accompanied by high-level and detailed control objectives, management guidelines and maturity models [Haes, et al., 2005].

Regarding orientation, definition, classes of problems addressed and implementation, the COBIT and ITIL are very different, however there are some similarities between them and they are more complementary than competitive and there is a mapping comparing the components of COBIT 4.1 with ITIL version 3 [ITGI, 2008a]. Used together, they provide a top-to-bottom approach to IT governance and service management [Heschl, et al., 2006].

1.5 Research objectives roadmap

It is important to outline our long-term research objectives, since the proposals made in this dissertation are intermediate steps on the roadmap for achieving them. Those long term research objectives are then the following:

- **Propose a best practices enforcement framework** – we expect it to be helpful for ITI designers and managers;
- **Propose a TCO estimation method based upon given evolution scenarios** – in other words, we want to be able to forecast TCO evolution.

1.5.1 Best practices roadmap

As for the strategy to achieve those objectives, it will next be described by means of roadmaps, one for each long term objective. In those roadmaps, the activities with a white background represent those that were developed in the scope of this dissertation, while those with a grey background represent the ones that will be developed in future work, probably in the scope of a PhD research work.

In this dissertation we propose a model-based technique to classify ITI topologies automatically. This classification is based on a set of ITI complexity metrics that are formalized using a constraint language. We collect the values of those metrics for a set of different ITIs and then use them to prove the feasibility of the automatic topology classification technique ("AS IS (1)" state in Fig. 1.6).

We also propose in this dissertation a model-driven formalization technique for ITI best practices. Based on that formalization we perform the detection of best practices violation upon a sample of ITIs structural data ("AS IS (2)" state in Fig. 1.6).

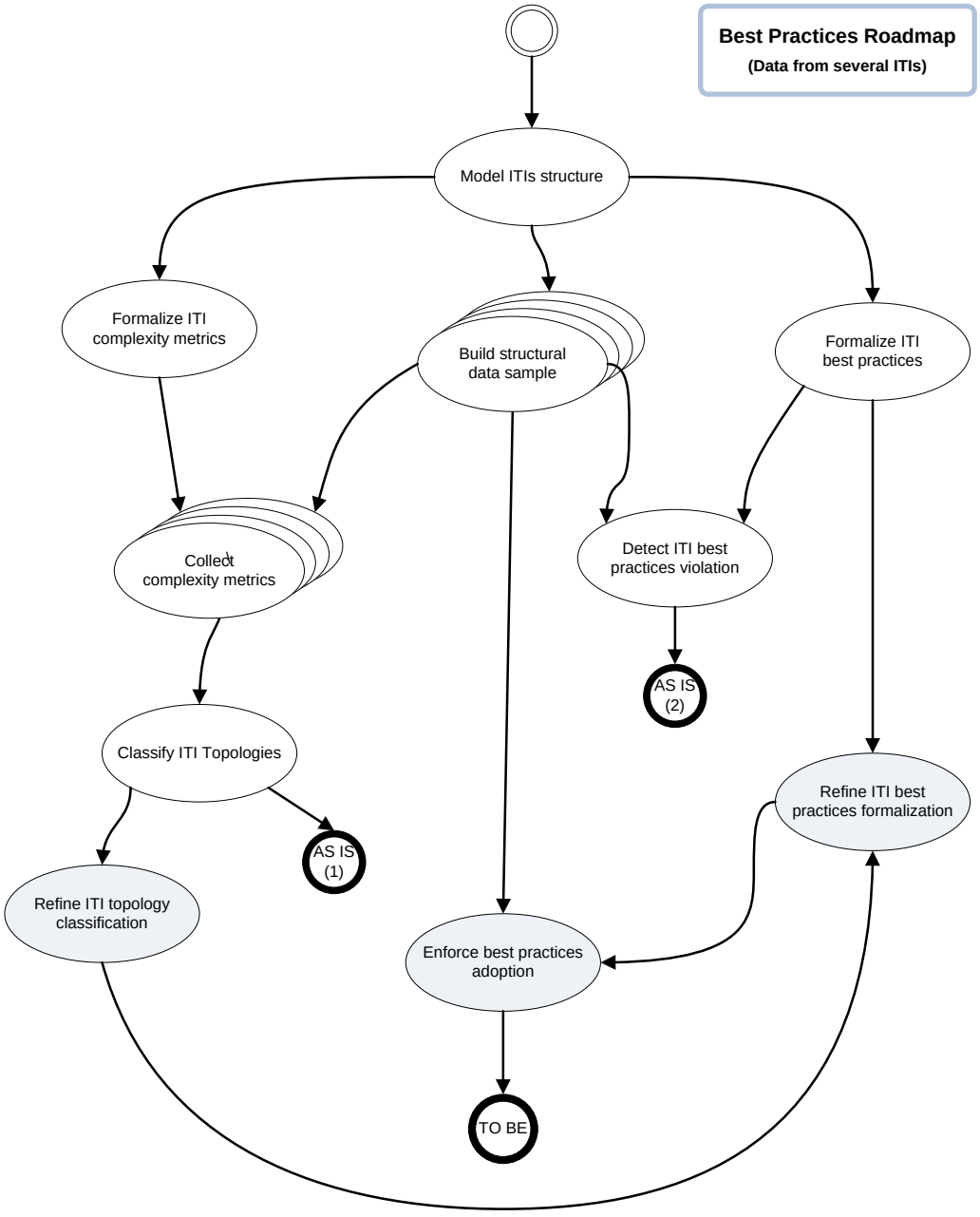


Fig. 1.6 — Roadmap (best practices)

We believe that the formalization of best practices should be targeted for specific ITI topologies. A well-formedness rule suitable for one topology may not be applicable to other topologies. Therefore, we plan to specialize best practices per topology. We will then use the automatic topology classifier to select the most appropriate rules to verify for a given ITI, in order to improve our proposed technique for detecting ITI best practices violation. We plan to test this improved version upon the previously mentioned sample of ITIs structural data, thus proving the feasibility of our proposed framework for best practices enforcement ("TO BE" state in Fig. 1.6).

1.5.2 TCO forecast roadmap

To forecast the TCO we first need to identify which are its driving forces. One of our claims is that the complexity of an ITI is one of them. Our strategy to validate this claim is to perform an analysis of variance in TCO due to ITI complexity. For that purpose we will use the sample of complexity metrics mentioned in the previous section as independent variable descriptors and a sample of ITI financial indicators (taken from the same ITIs as the ones from where the complexity metrics were collected) to compose a TCO descriptor (dependent variable). For the sake of clarity and replicability, those financial indicators will be formalized upon an ITI costs ontology. The expected outcome of this partial roadmap, represented by CVC (Cost Versus Complexity) in Fig. 1.7 is the statistical evidence that ITI complexity influences TCO and the quantification of that influence (e.g. percentage of the variation in TCO that is explained by the variation in ITI complexity).

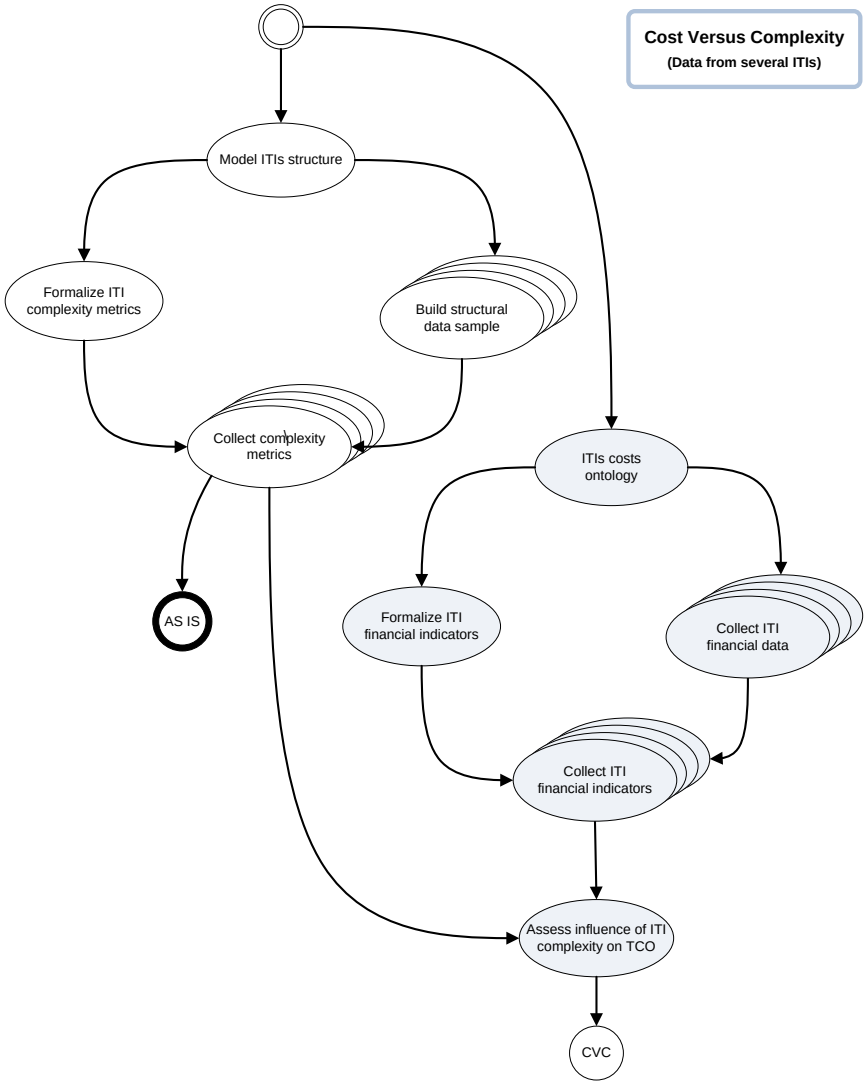


Fig. 1.7 — Roadmap (cost versus complexity)

The second part of this roadmap is represented in Fig. 1.8 and takes the CVC conclusions as input. To forecast TCO for a specific ITI we will combine a time series of the evolution of its complexity with another time series of its previously known TCOs. The latter are calculated on the basis of a set of financial indicators, using the same approach as that described in the previous paragraph, but for one ITI only, throughout time.

In the scope of this dissertation we have performed a study of the evolution of ITI complexity ("AS IS state" in Fig. 1.8). This intermediate step is in our view an interesting step forward, since TCO evolution will be influenced by ITI complexity evolution. Besides, this study has allowed us to experiment with the time series techniques that will be later required to achieve our research objective of proposing a TCO estimation method.

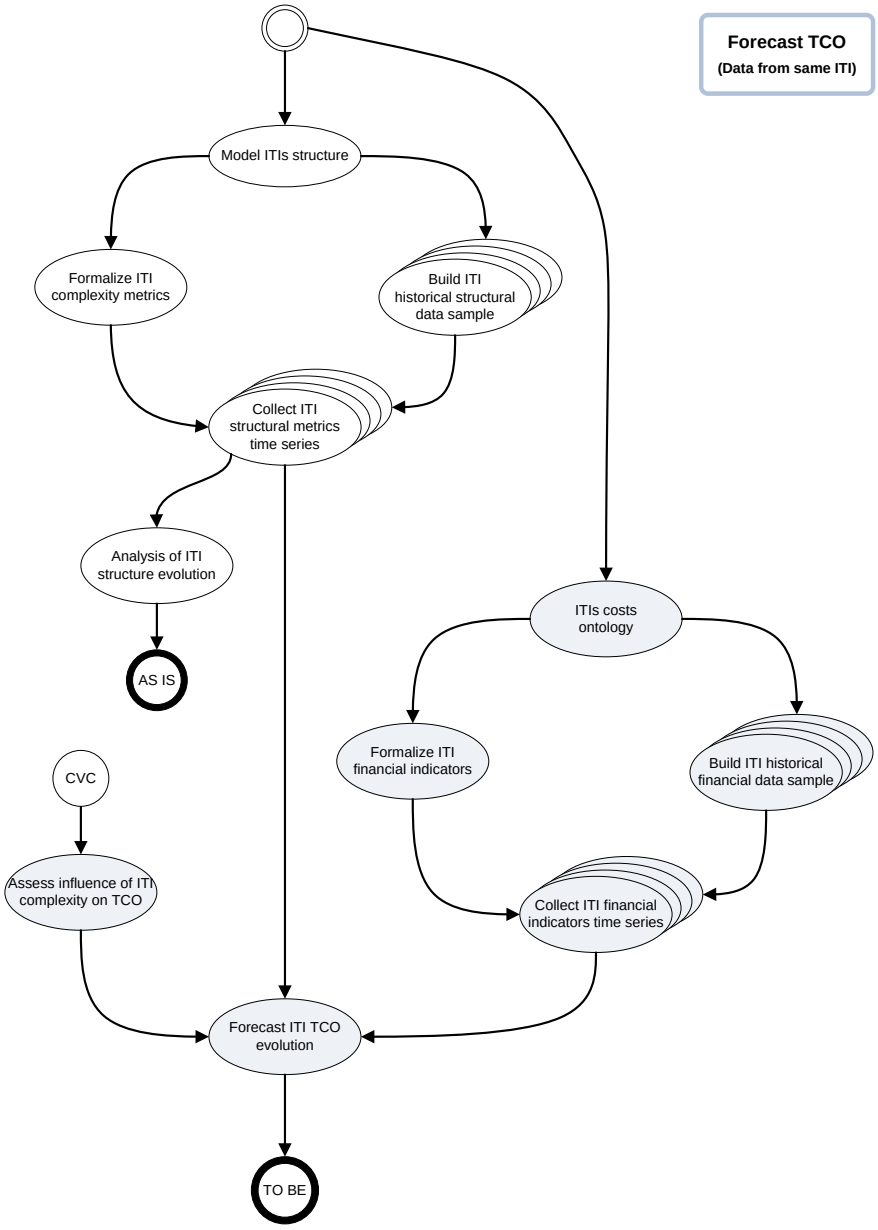


Fig. 1.8 — Roadmap (best practices)

1.6 Expected contributions

As we have seen in the previous sections evaluating ITIs is a very important concern and challenge. This dissertation is a step towards the development of a formal approach based on metamodels to evaluate ITIs. The main motivation of this work is the need to evaluate different aspects of large distributed ITIs, in order to help and support decisions of IT decision makers.

There are currently a set of commercial initiatives, processes and tools developed by IT organizations that allow the evaluation of some aspects of ITIs. However none of them supports a consistent and formal approach to evaluate these infrastructures in a quantitative way. In this dissertation we will propose an ITI evaluation methodology that can automatically capture data from a particular infrastructure and represent it upon a given metamodel. Using this approach can lead to the following benefits:

- **Represents and increase the knowledge on ITI organization** – increasing knowledge can foster the productivity of IT professionals and support and lead to better decisions regarding operation, maintenance and evolution of ITIs;
- **Metrics to measure complexity** – knowing the complexity normally reduces server proliferation which often contributes significantly to the complexity and cost of ITIs;
- **Allows comparisons of ITIs over time** – analyzing the chronological growth of ITIs allows a better understanding of the impact of policies or strategies adopted in the past and the forecast of ITIs evolution and to answer questions such what factors contribute to control the unstructured growth of the ITIs;
- **Allows comparisons of ITIs of different organizations** – the comparison process can be useful in an acquisition or merger process between organizations;
- **Check if the ITI follows organization best practices** – The implementation of a process that checks if best practices are being followed, can be useful for several reasons, such as the detection of human errors that could lead to problems such as server or network downtime. The implementation of best practices and the detection of non-compliances, can increase servers and network availability, increase staff efficiencies and check policies enforcement, for compliance with regulatory standards such as *HIPAA (Health Insurance Portability and Accountability Act)*, *Sarbanes-Oxley (SOX)*, among others;
- **Identify potential problems in the ITI** – identifying problems before they happen helps to prevent critical situations.

We propose a precise and flexible solution framework, based on metamodels, which can be used as a foundation asset for the quantitative evaluation of ITIs. We expect that this framework can help those directly or indirectly involved with ITIs to do a better job in what concerns the management

and evolution of ITIs. The proposed approach is based on metamodels, and defines how we can capture ITIs objects and their settings, and instantiate them on models. With the ITI information available on models, we present an approach that can be used to extract the required information from the ITI, facilitating the task of understanding the various components of the ITI and how they are related.

We have formalized the definition of several complexity metrics and successfully collected them from large real world ITIs. Those metrics can be used in calculating and estimating several ITI aspects such as their size, their complexity, their evolution, or used in combination with other indicators to calculate the TCO.

This approach contributes to productivity gains, through the possibility of running queries against ITIs. We also provide an approach, where organizations can write their own best practices, in order to help them to detect infrastructural non-compliance configurations. In summary, we expect that with an approach to quantitative evaluate ITIs we can increase the efficiency and effectiveness of ITIs, reducing costs, simplifying day to day management activities and making ITIs more robust and more agile.

1.7 Document structure and typographical conventions

To facilitate and simplify the reading of this document, the structure is organized in eight chapters, each with a context. The content of each chapter is as follows:

Chapter 2 describes related work relevant to the understanding and evaluation of distributed ITIs. For that purpose this chapter presents taxonomy, and a survey built of eight documents related with evaluation studies and evaluates these eight documents using the created taxonomy. Finally this chapter presents a comparative analysis of these evaluations and presents some findings.

Chapter 3 introduces the Meta-Model Driven Measurement approach, presents several modeling languages and performs a comparative review of three different ITIs modeling languages. The remaining of the chapter is dedicated to the selection of a modeling language to work throughout this dissertation and to present several considerations regarding the chosen modeling language.

Chapter 4 describes how the chosen modeling language will be applied using the M2DM approach and introduces important concepts such as metamodel semantics enforcement and the ITILib. The last section of this chapter is dedicated to a step-by-step description of every component of our approach to evaluate ITIs.

Chapter 5 applies the approach described in chapter 4 to evaluate different perspectives of an ITI. There is a section dedicated to the evaluation from a sizing perspective with a real case study, another section dedicated to the evaluation of complexity with five different case studies and a last section dedicated to the application of best practices to ITIs. There is also a formalization of rules for best practices compliance verification with the OCL constraint language.

Chapter 6 is dedicated to the detection of network topologies based upon logistic regression techniques. In this chapter with the help of the multinomial logistic regression we created a model that can be used to detect the network topology ITIs. To ilustrate this in the last section presents we applied the created model to ten real ITIs collected from different organizations that were slightly modified to guarantee the confidentiality of the data.

Chapter 7 presents the conclusions and the future work. It starts by summarizing the contributions of this dissertation, present some threads to their validity and outlines several directions for future research work.

To clearly distinguish semantically different elements and provide a visual hint to the reader, this dissertation uses the following typographical conventions:

- *Italic script* highlights important key words, scientific terms, methods and tools carrying special meaning in the technical or scientific literature;
- **Bold face** denotes table headers and items in enumerations.

2

Related Work

Contents

This chapter is dedicated to related work in the area of quantitative evaluations. There is a taxonomy to support a survey of eight evaluation documents and a comparative analysis of the findings.

2.1 Taxonomy for supporting the survey

In this section we will describe related work relevant to the understanding and evaluation of distributed ITIs. To allow comparisons among different studies we require a set of comparison criteria. The first three chosen criteria (*complexity evaluation*, *evolution analysis* and *best practices assessment*) correspond to three possible views in assessing ITIs that are further explored in this dissertation. The *modeling* and *characterization* criteria intend to cover the aspects related to the description of the domain concepts. The next two criteria classify how the ITIs *data collection* process was conducted and the resulting *sample* representativeness.

2.1.1 Complexity evaluation

As discussed in chapter 1, the complexity of an ITI should be taken into consideration for managing important aspects such as TCO evaluation or evolution analysis. That complexity is related with software, hardware or network components. The categories that have been identified for classifying this criterion are the following:

Strong – All components affecting the complexity of an ITI are considered in the assessment;

Moderate – The majority of components affecting the complexity of an ITI are considered in the assessment;

Weak – Only a few components affecting the complexity of an ITI are considered in the assessment;

None – There is no explicit reference of complexity assessment being performed.

2.1.2 Evolution analysis

In order to accommodate future changes and align ITI with business we must analyze it in a chronological perspective. There are several advantages of performing an ITI evolution analysis such as the understanding of past growth, predicting the future growth, performing comparisons or documenting ITIs, among other aspects. While performing an evolution analysis, we must consider that ITIs have an associated lifecycle, with a set of phases that includes acquisition, deployment, and maintenance, until being decommissioned. The categories that have been identified for classifying this criterion are the following:

Strong – The conducted assessment takes the full ITI lifecycle into consideration and the individual contributions of each phase are clearly described;

Moderate – The conducted assessment takes the full ITI lifecycle into consideration but few details are provided regarding the individual contributions of each phase;

Weak – The conducted assessment only covers a part of the ITI lifecycle, although some kind of evolution is discussed;

None – The conducted assessment does not perform any kind of evolution analysis.

2.1.3 Best practices assessment

Several frameworks suggesting best practices for ITIs have been proposed in the literature. However, from the evaluation point of view, we would like to assess if their application is being followed in practice (e.g. in a given ITI). The categories that have been identified for classifying this criterion are the following:

Strong – Best practices are formally defined and the assessment of their adoption is carried out automatically, based upon that definition;

Moderate – The use of best practices is envisioned and their specification is clearly expressed or evidence is provided on the way that is (or can be) used to assess their adoption;

Weak – The use of best practices is envisioned but their specification is not clearly expressed and no evidence is provided on the way that is (or can be) used to assess their adoption;

None - There are no references to best practices in the study.

2.1.4 ITI modeling

To perform any kind of evaluation we should be able to describe as objectively as possible the semantics of the entities being evaluated, their interrelationships and constraints. For that purpose we should use a description language (usually using a diagrammatic notation), preferably with a well defined metamodel that enforces models' well-formedness. Those description languages can range from domain specific ones (a DSL for ITIs) to general purpose description languages. The corresponding categories that have been identified for classifying this criterion are the following:

Strong – the assessment is performed upon a DSL for ITIs with a formalized metamodel;

Moderate - the assessment is performed upon a general purpose description language with a formalized metamodel;

Weak - the assessment is performed upon a description language without a formalized metamodel;

None - the assessment is performed without an explicit support of a description language.

2.1.5 ITI characterization

To allow performing any kind of causal analysis, hypothesis testing or forecasting, we need to identify and describe the different attributes or characteristics that describe an ITI. That description should be as objective as possible to allow the comparability and replication of evaluations. Preferably, that description would support the automatic collection of values of those attributes. The proposed categories for this criterion are the following:

Strong – the attributes or characteristics of the ITI are defined with the use of a formal description language (e.g. using an algebraic notation or first order predicate calculus) upon the metamodel, therefore with no ambiguity;

Moderate – the attributes or characteristics of the ITI are defined using a formal description language but with no clear reference to the underlying metamodel;

Weak - the attributes or characteristics of the ITI are defined using natural language only;

None - the attributes or characteristics that are relevant for assessing the ITI are not explicitly.

2.1.6 Data collection

Data collection aims at instantiating the adopted metamodel. In other words we need to reify the concepts that are expressed in the chosen ITIs' modeling language. Unless it is automated, data collection will probably be the most costly activity in ITI assessment. We propose the following categories:

Strong – The collection process is largely automated;

Moderate – The collection process was at least partly automated;

Weak – The data collection process was entirely manual (e.g. based on user surveys, questionnaires or interviews);

None – There are no references to the data collection process used.

2.1.7 Sample

Assessment is an issue that can be discussed conceptually, but in the end it will only make sense if is applied to real world case studies. Therefore, it is important to categorize the kind of samples that have been used in related works. The proposed categories are the following:

Strong – The use sample includes data from multiple ITIs throughout time;

Moderate - The used sample includes data from multiple ITIs in a given moment in time or from a single ITI throughout time;

Weak - The used sample includes data from a single ITI in a given moment in time;

None – There is no evidence that data collection upon an ITI was conducted.

2.1.8 Results validation

All assessment exercises are finalized by presenting their conclusions. However, the techniques used to derive and validate those conclusions can have very distinct levels of preciseness. We have considered the following categories:

Strong – Independent teams have cross-checked the presented results (external validation);

Moderate – Assessment hypothesis are tested against a sample and threats to validity are identified;

Weak – Conclusions are based upon descriptive statistics on a sample;

None – Informal conclusions are drawn based upon direct observation and "gut feeling".

2.2 Survey

In the last years there was a significant growth in terms of the number of papers, reports, meetings, books and studies that performed evaluations and analysis in organizations with the aim of helping CIOs to make better decisions regarding the way they purchase, upgrade or replace their ITIs.

To understand, what is the current state of the art with these evaluations, we collected seventy public documents from different sources and available in Internet to analyze (the complete list is available in Appendix D). From this list we decided to perform a deeper analysis with the taxonomy presented in section 2.1. To perform the analysis we decided to consider only documents no older than 2004, with references to concepts related with this dissertation (such as complexity and best practices, TCO) and with information regarding the methodology used to perform the evaluation. The selected documents are available in Table 2.1.

It is important to point out, that our objective in reviewing these documents was not to attempt to draw conclusions about the relative merits of the measured aspects but instead assessing the evaluation methodology using the previous defined taxonomy.

Table 2.1 — Documents selected for analysis

Nº	Evaluation document	Name	Performed by
1	[Juurakko, 2004]	Measuring and Management TCO for Tetra Networks	Nokia Corporation
2	[DiDio, 2004b, DiDio, 2004a]	Linux, UNIX and Windows TCO Comparison	Yankee Group Corp.
3	[Cybersource, et al., 2004]	Linux vs Windows - Total Cost of Ownership Comparison	Cybersource Pty
4	[Wang, et al., 2005]	TCO Research in Enterprise Computing (Linux, Windows NT and Windows 2000/2003)	CCW Research
5	[CIOview, 2005]	The Business Value of Migrating from Oracle to SQL Server 2005	CIOview Corporation
6	[Wipro, et al., 2007]	Reducing TCO with Windows Vista - Quantified Savings for Mobile PCs	Wipro Technologies GCR Custom Research
7	[Jutras, 2007]	The Total Cost of ERP Ownership in Mid-Size Companies	Aberdeen Group, Inc.
8	[Troni, et al., 2007]	PDA and Smartphone: 2007 Update	Gartner, Inc.

To better understand these studies, the sections 2.2.1 to 2.2.8 give an overview of every document in Table 2.1 and summarize the results achieved. Finally, we classify each document using the defined taxonomy.

2.2.1 Evaluation 1 – [Juurakko, 2004]

This study is focused on measuring and managing the TCO for Tetra Networks. This study details how capital, implementation and operational expenditures contribute to TCO and how to optimize Tetra Network's TCO.

This study concludes that the costs associated with capital expenditures (CAPEX) such as the network solution, infrastructure or terminals and the costs associated with implementation expenditure (IMPEX) such as building the network are not the biggest elements of TCO. The costs associated with keeping the network up and running or operating expenditures (OPEX), account for 50% to 80% of the costs in a ten years period.

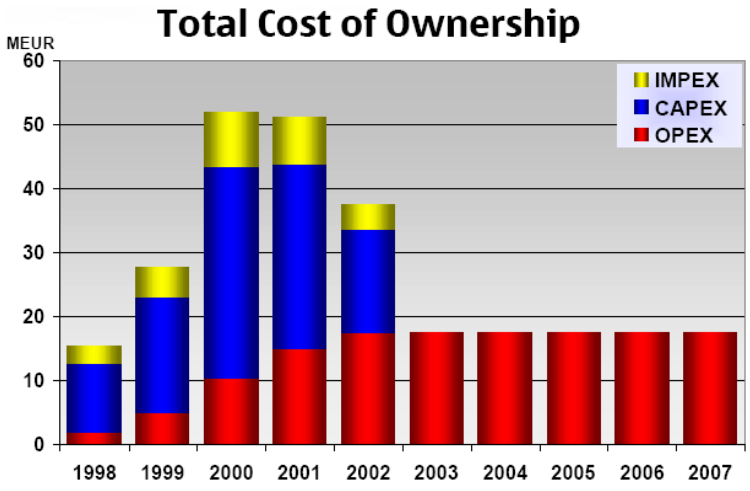


Fig. 2.1 — Total Cost of Ownership for TETRA networks (source:[Juurakko, 2004])

The study also mentions that the network economy comes from optimized CAPEX, OPEX and IMPEX. However it makes no references regarding how the application of best practices can influence the TCO. During the study several networks are presented. However the impact of network complexity on the TCO is also not presented. In terms of life-cycle costs, there is a separation of costs per categories (CAPEX, OPEX, IMPEX), but there is no detail in terms of the costs that are measured in each category. The study provides side-by-side comparison with six different networks. However little or no detail is provided in terms of the TCO assessment methodology, such as how was the data collected or how the values were obtained.

Table 2.2 — Classification of study 1

Category	Classification
Complexity evaluation	None
Evolution analysis	Moderate
Best practices assessment	None
ITI modeling	None
ITI characterization	Weak
Data collection	None
Sample	Strong
Results validation	Moderate

2.2.2 Evaluation 2 – [DiDio, 2004b, DiDio, 2004a]

This study was created by Yankee Group and is divided in two reports. The purpose of the study is to determine the TCO and ROI of Linux compared with Windows and UNIX in specific corporate user scenarios.

This study concluded that there is no operating system that can fulfill the needs of all companies. Each company should make a realistic assessment of existing operating systems and decide whether the current infrastructure meets the goals and business needs. According to the Yankee Group's extensive research, Linux distributors are growing monthly. Linux, UNIX and Windows platforms are mature and many large enterprises made significant investments in them. There is no technical advantage in switching platforms according to this study. Only a small minority (4 percent) of UNIX users and about 10 percent of Windows users has the desire to switch platforms. The study makes no references to the impact that the application of best practices to Windows, Linux or Unix operating systems may have on TCO. There are some references to "hidden" costs such as the interoperability, integration and the cost of deployment application. However there are no references to the impact that the operating systems complexity can have on TCO. In terms of the methodology the Yankee

Group performed a set of surveys to obtain the data and most of the categories regarding the life-cycle costs are presented. However their study does not present information regarding the operational costs of operating systems over a period of time.

Table 2.3 — Classification of study 2

Category	Classification
Complexity evaluation	None
Evolution analysis	Moderate
Best practices assessment	None
ITI modeling	None
ITI characterization	Weak
Data collection	Weak
Sample	Weak
Results validation	Moderate

2.2.3 Evaluation 3 – [Cybersource, et al., 2004]

This study was created by Cybersource in 2004 and compares the TCO of running Linux versus Windows in the enterprise. The study represents an update of a previous study also from Cybersource in 2002.

This study reported that Linux was 36% cheaper than Windows, when taking into account the software cost as well as service, support and upgrades. This study also indicated some issues to the study 2 [DiDio, 2004b, DiDio, 2004a] regarding how the surveys were performed and that the mailing list used was operated by a Microsoft Partner. In terms of the methodology, the results were obtained from a small size organization and encompass two scenarios (existing hardware and purchased new hardware). Most of the Life-cycle costs are presented in the study and the saving achievements by using one solution are also presented. There are no references to the impact of complexity or the application of best practices to the TCO.

Table 2.4 — Classification of study 3

Category	Classification
Complexity evaluation	None
Evolution analysis	Moderate
Best practices assessment	None
ITI modeling	None
ITI characterization	Weak
Data collection	Weak
Sample	Weak
Results validation	Moderate

2.2.4 Evaluation 4 – [Wang, et al., 2005]

This research calculates the TCO in several workloads in enterprise and medium size organizations in china. The study compared the comprehensive sets of costs for systems running Linux, Windows NT and Windows 2000/2003.

This research concludes that organizations can beneficiate with the use of Windows 2000 Server and Windows Server 2003 over Linux. According to the calculations hardware acquisition is responsible for 35,4% of TCO while operation and administration costs are responsible for 33% of TCO. The study also shows that the TCO of using Linux for database, file and print services or mail is higher than in Windows, lower for web servers and similar for networking servers. This research also concludes that complexity of IT systems has a significant impact on TCO and that comparable to Linux, there are TCO advantages in using Windows 2000 and Windows 2003.

Table 2.5 — Classification of study 4

Category	Classification
Complexity evaluation	Strong
Evolution analysis	Strong
Best practices assessment	Strong
ITI modeling	None
ITI characterization	Weak
Data collection	Weak
Sample	Strong
Results validation	Moderate

2.2.5 Evaluation 5 – [CIOview, 2005]

This research outlines the advantages of migrating databases from Oracle to SQL Server. It provides side-by-side Total Cost of Ownership (TCO) comparison between Oracle and SQL Server 2005 for a variety of the most common database situations.

The study found that the hidden costs of doing nothing with an existing Oracle database may exceed the costs of acquiring an entirely new hardware and software architecture. According to this study SQL Server 2005 offers significantly improved price/performance and reliability over previous versions. In terms of the methodology, the TCO study represents a period of three years and the amount of savings in migrating to SQL Server 2005 is calculated. Most of the Life-cycle costs are presented in the study with detailed values for each category. In terms of complexity there is a scale of 1 to 10 regarding database complexity and the impact of complexity is calculated in terms of

migration effort. There are some references to the application of best practices, however potential saving of applying best practices are not calculated as part of the TCO.

Fig. 2.2 — Extending Oracle 8i or migrating to SQL Server (source: [CIOview, 2005])

Table 2.6 — Classification of study 5

Category	Classification
Complexity evaluation	Moderate
Evolution analysis	Strong
Best practices assessment	Weak
ITI modeling	None
ITI characterization	Weak
Data collection	Moderate
Sample	Moderate
Results validation	Moderate

2.2.6 Evaluation 6 – [Wipro, et al., 2007]

This study objective was to quantify savings for mobile PCs (notebook PCs, Tablet PCs and Ultra-Mobile PCs) using Microsoft Windows Vista Operating System.

The study found that with the adoption of Windows Vista the potential TCO savings per mobile PCs per year is $605. This is achieved through the utilization of Windows Vista benefits (security, desktop engineering, service desk, user labor, hardware and software), the implementation of best practices through the use of "infrastructure optimization" and the use of Microsoft Desktop Optimization Pack (MDOP). The study provides side-by-side comparison with Windows XP. The TCO methodology to collect information was based on surveys to 131 organizations from four different industries.

Table 2.7 — Classification of study 6

Category	Classification
Complexity evaluation	Weak
Evolution analysis	Moderate
Best practices assessment	Strong
ITI modeling	None
ITI characterization	Weak
Data collection	Weak
Sample	Weak
Results validation	Weak

2.2.7 Evaluation 7 – [Jutras, 2007]

This study is intended to analyze the TCO of six different ERP solution providers in terms of software, services and maintenance of mid-size companies with revenues between $50 million and $1 billion.

The study found that as the company grows, the number of users goes up along with total cost of software and services, however the maintenance costs did not growth in a linear fashion as the others. The study presented the average costs per user by company size, the software and services costs as well as the total cost by vendor. This study also found that TCO proven to be a significant factor in software selection however is also strongly recommended to estimate ROI.

Table 2.8 — Classification of study 7

Category	Classification
Complexity evaluation	None
Evolution analysis	Weak
Best practices assessment	None
ITI modeling	None
ITI characterization	Weak
Data collection	None
Sample	Weak
Results validation	Moderate

2.2.8 Evaluation 8 – [Troni, et al., 2007]

This study analyzes the TCO for personal digital assistants (PDAs) and smartphones and is an update to other similar study performed in 2004. This study aims to help organizations to understand the cost implications associated with procuring and supporting mobile devices, to plan their deployments more effectively and to investigate areas for potential costs saving

The study found that PDA and smartphone TCO declined by 15% comparing with 2004. The study also found that acquisition costs of the mobile devices represent only 10% of the overall TCO with communication costs representing more than 35%. The costs associated with hardware and software increase, while the costs associated with operations, administration and end-users decrease, mostly because organization have more mature processes in place and implemented best practices. This study also mentions that the TCO is highly dependent on the complexity of applications.

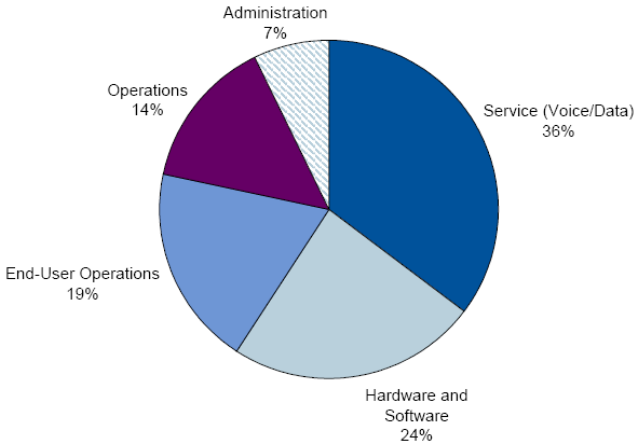


Fig. 2.3 — Average PDA and Smartphone TCO (source: [Troni, et al., 2007])

Table 2.9 — Classification of study 8

Category	Classification
Complexity evaluation	Weak
Evolution analysis	Strong
Best practices assessment	Weak
ITI modeling	None
ITI characterization	Weak
Data collection	None
Sample	Weak
Results validation	Weak

2.3 Comparative analysis

To perform the comparative analysis we decided to create a table where the rows represent the categories for evaluation identified in taxonomy and columns are the selected evaluations. The intersection between rows and columns are a symbol correspondent to the category (according to legend). One of the deliverables of this dissertation that will be detailed in chapter 4 is a methodological approach to perform ITIs evaluations. Later we will classify our evaluation approach using this taxonomy. Table 2.10 presents the comparative analysis.

Table 2.10 — Comparative analysis of ITI evaluations

Survey	Complexity evaluation	Evolution analysis	Best practices assessment	ITI modeling	ITI characterization	Data collection	Sample	Results validation
[Juurakko, 2004]	—	⦿	—	—	○	—	●	⦿
[DiDio, 2004b, DiDio, 2004a]	—	⦿	—	—	○	○	○	⦿
[Cybersource, et al., 2004]	—	⦿	—	—	○	○	○	⦿
[Wang, et al., 2005]	●	●	●	—	○	○	●	⦿
[CIOview, 2005]	⦿	●	○	—	○	⦿	⦿	⦿
[Wipro, et al., 2007]	○	⦿	●	—	○	○	○	○
[Jutras, 2007]	—	○	—	—	○	—	○	⦿
[Troni, et al., 2007]	○	●	○	—	○	—	○	○

Legend: ● Strong ⦿ Moderate ○ Weak — None

Based upon the analysis and classification of these documents we can conclude that evaluating an ITI is a complex activity. We found that the majority of the evaluations:

- **Have different methodologies** – there is no consistency among studies regarding the used methodology. The processes used to collect information, the duration of the processes, the type of analysis, the number of years of the study, are just some examples. For example we found that some studies considered a period of three years while others considered a period of five years. Some studies do not mention the process used to obtain the data, some mention questionnaires or surveys, others face to face interviews, others telephone interviews others market research and some a mix of these;
- **Do not cover the entire life-cycle of costs** – there is some consistency in the understanding that the acquisition costs are only part of the costs in the majority of the studies. However the other costs collected and analyzed differ from study to study. Not all separate direct costs from indirect costs and present detailed descriptions of each cost as presented in the Gartner "Chart of Accounts" [Gartner, 2003]. We also found that most do not cover the impact of complexity on TCO and those who cover do not mention if the complexity is associated with ITI as a whole, with software, hardware, network or others aspects. The same applies to other aspects such the adoption of best practices among others;
- **Have different processes to perform comparisons** – the process used to perform comparisons also differ from study to study. There are a substantial number of studies that

perform comparisons based on average, others based upon estimations and others do not perform comparisons at all.

With the analysis of these studies that range between 2003 and 2007, we observe that based upon another review between 1997 and 2002 [MacCormack, 2003], the state of practice for these evaluations continues to be poor.

All these findings regarding the measurement of TCO suggests a clear need for an TCO evaluation methodology that can clear define rules and guidelines regarding how the whole process should be performed. Creating a TCO evaluation methodology to allow organizations of any kind to perform TCO analysis based upon the same categories using the same processes and methods are a very interesting and challenge task, which solves or minimizes most of problems identified.

With the ITI evaluation methodology that we will introduce in chapters ahead we will not provide a TCO evaluation methodology, but we expect to simplify the TCO calculation with the data and information that we can gather from infrastructures trough the various analyses that we will be able to perform in ITIs.

3

ITI Modeling

Contents

The chapter 3 describes what M2DM is and performs a comparative review of three different ITIs modeling languages, evaluated with the purpose of selecting one to work with. The rest of this chapter is dedicated to provide more information regarding the chosen modeling language and the work performed.

3.1 Introduction

To evaluate infrastructures, there has to be a way to represent all components that are part of an ITI and their relations. To represent all the components we need a common language that we can use to create models that capture all the relevant knowledge of the ITI in a readable, searchable and reusable way.

Since several model driven approaches specifications have been proposed, we evaluate some of them to choose the one that best fulfills the goal of performing ITI evaluations.

3.2 Meta-Model Driven Measurement (M2DM)

To perform a quantitative evaluation we must be able to express some descriptive variables on a more than ordinal scale on our domain of discourse (DoD). In order to achieve that, we must agree on what we are talking about, that is, we need a well understood representation of our DoD. This is where ontologies come to the rescue.

Ontology is the science of what is, of the kinds and structures of the objects, properties and relations in every area of reality [Smith, 2003]. However, in Computer Science, we use the word "ontology" in a more loosely way, to designate an abstract representation of the relevant concepts and their relationships in a given domain. If that domain is the one of modeling then, instead of talking about a "modeling ontology", we simply call it a "metamodel". There are several ways of formally defining an ontology and generic languages, as well as domain-specific ones, such as OWL [McGuinness, et al., 2004], have been proposed for this task. In the scope of metamodeling, the most widely used ontology language is UML, by using meta-class diagrams enriched with *Object Constraint Language (OCL)* constraints [Cranefield, et al., 1999], as happens with all *MOF (Meta-Object Facility)* based metamodels published by the Object Management Group (OMG).

Since we have identified the need for a metamodel, we turn our attention to the metrics definition and collection problems. Metrics should be formally defined to avoid subjectivity in their interpretation and in the implementation of collection instruments. In this dissertation, we will use the *Metamodel Driven Measurement (M2DM)* technique in which metrics are defined as OCL expressions upon the adopted metamodel. In addition to the formality granted by the use of this constraint language, OCL expressions can be automatically evaluated upon the instantiated metamodel using an ITI evaluator component. The M2DM technique was originally proposed in [Brito e Abreu, 2001] upon the GOODLY metamodel [Brito e Abreu, et al., 1997]. The M2DM technique was used in several distinct contexts, such as the ones of defining object oriented (OO) design metrics based upon the UML 1.x metamodel [Baroni, et al., 2002, Baroni, et al., 2003], expressing object-

relational database schema metrics based upon the Common Warehouse Metamodel (CWM) [Baroni, et al., 2004], evaluating components reusability upon the UML 2.0 metamodel [Goulão, et al., 2004b, Goulão, et al., 2004a] or assessing components composition using the CORBA Components Metamodel (CCM) [Goulão, et al., 2005b, Goulão, et al., 2005a]. In the following section we outline some modeling languages and we discuss how we have selected the metamodel for the purpose of evaluating ITIs.

3.3 Modeling languages

Picking on previous considerations, a metamodel is a modeling ontology and as such it should describe the constructs used in the modeling process, their properties and relations. In other words, a metamodel describes the grammar and semantics of a modeling language.

There are several metamodels constructed with different purposes and it will not be accurate to assert that one approach is better than another in all circumstances. The concept of using models for the management of IT services and infrastructures is not new. In this section with discuss some of these existing modeling languages that can be used for different purposes in the ITIs field such as the *Unified Modeling Language (UML) [OMG, 2007a]*, *System Definition Model (SDM)* [MSFT, 2004] and *Service Modeling Language (SML)* [Dublish, et al., 2006].

3.3.1 Unified Modeling Language

The UML is a visual language for specifying, visualizing, constructing and documenting software-intensive systems, as well as for business process modeling, systems engineering modeling and representing organizational structures. UML is a general-purpose modeling language that represents a collection of best engineering practices that have proven successful in the modeling of large and complex systems of a wide range of domains. Under the stewardship of the Object Management Group (OMG), the UML has emerged as the software industry's dominant modeling language. UML started from the unification of efforts of Grady Booch, Jim Rumbaugh and Ivar Jacobson in the late 90's. All of them published books on their own object-oriented methodologies: the Booch method [Booch, 1994], *Object Modeling Technique (OMT)* [Rumbaugh, 1996] and *Object-Oriented Software Engineering (OOSE)* [Jacobson, 1995], respectively. This unification of efforts succeeded and UML became a *de facto* standard in the modeling community both in industry and academia. With this unification, concepts from several OO methods were integrated in UML, what makes UML rich, but also large.

3.3.2 System Definition Model

The *System Definition Model (SDM)* was created by Microsoft and is the central component of an industry wide initiative called *Dynamic Systems Initiative (DSI)* [MSFT, 2005], to simplify and automate how customers design, deploy and operate distributed systems. The SDM was created to simplify the process of modeling complex IT distributed systems and it was not intended to replace the standard *Common Information Model (CIM*) [DMTF, 2007] or other CIM implementations such as the WMI [MSDN, 2008]. It provides a modeling layer, which can describe interconnected relationships and management policies of the distributed system.

The SDM is an XML-based language and modeling platform through which a schematic "blueprint" for effective management of distributed systems can be created. SDM started as a research project in *Microsoft Research* and the original idea was to create a modeling language for the next generation of distributed dynamic computing. As the project became matured, SDM moved from *Microsoft Research* to *Microsoft Server and Tools Business Division (STB)* where it was integrated into Microsoft's development tools, its management solutions and the Windows platform itself. The first practical implementation of SDM was in Visual Studio 2005 Team System and the main goal was to facilitate the design of distributed systems through design time validation of SDM models. Because the definition of the underlying SDM language is an evolutionary process, the version that shipped with Visual Studio 2005 Team System is known as the first version of SDM or SDMv1. The latter was extended to cover more of the lifecycle and some Microsoft products started supporting the SDM platform concepts, what originated the second version of SDM or SDMv2. Products associated with this version included *System Center Operations Manager*, which is able to build up a logical description of each application it manages, the relationships between the application components and what dependencies each application component has on other software, operating system services and even hardware. SDMv2 was never publicly documented, because Microsoft started to work on SDMv3, also known Service Modeling language.

3.3.3 Service Modeling Language

The *Service Modeling Language (SML)* represents an evolution of SDM and is an open industry-wide specification that defines a common language for expressing information about IT resources and services [Dublish, et al., 2008b]. Using the *eXtensible Markup Language (XML)*, SML defines a consistent way to express how computer networks, applications, servers and other IT resources are described, which can solve the problem of the numerous ways to represent the same IT resource. In

multi-vendors environments, SML simplifies IT, because it provides a way to share information across different tools and applications and allows the creation of a complete picture of an IT environment.

The SML is an XML-based language for describing and constructing ITI models, aiming to promote the interoperability between heterogeneous components. It allows building models than can be used across infrastructures components from different vendors [Dublish, et al., 2006]. Customers investments in models that, for instance, capture their best practices, are preserved. SML does not prescribe a specific IT model or set of models. Instead, it defines the syntax and semantics that all SML models must follow: their base vocabulary, the rules of composition, the grammar and the syntax. The SML was created by the SML working group and is based on standards like XML Schema [Fallside, et al., 2004] and Schematron [ISO/IEC, 2004]. The SML working group was formed by some of the key IT industry leaders organizations (BEA, BMC, Cisco, Dell, EMC, HP, IBM, Intel, Microsoft and Sun) which are working together to standardize this modeling language.

The working group published the first draft publication on 25 July, 2006 [Dublish, et al., 2006]. In addition to the publication of the SML specification, the companies also announced their intention to develop a library of core models to describe generic resources such as network elements, operating systems, storage devices, desktops, server systems, web servers, a directory service and more. SML defines a consistent way to describe computer networks, applications, servers and other IT resources so that businesses can more easily manage services built on these resources.

The SML is still under development and on the 3rd, March, 2008 the working group submitted the third public working draft of SML version 1.1 for review by W3C members and other interested parties [W3C, 2008b].

3.4 Modeling language selection

To be able to evaluate ITIs in a distributed system environment we decided to select a set including the most recent or well known model-driven approaches, which can be used to achieve this goal with less effort. That set includes the *Unified Model Language* [OMG, 2004], the *System Definition Model* [MSFT, 2004] and the *Service Modeling Language* [Dublish, et al., 2006].

The purpose of this section is to evaluate the chosen metamodels based on some characteristics or criteria that we found relevant for the evaluation of ITIs and choose the most appropriate modeling language to this domain.

To highlight the characteristics of the various modeling approaches we choose the following list of evaluation criteria to evaluate metamodels:

- **Expressiveness** – The modeling language should provide relevant universe of discourse (UoD) concepts such as client and server computers, network devices, physical and logical connections, middleware and application components;
- **Relevance** – The modeling language should be supported by a well known organization committed to its evolution;
- **Models availability** – We should have access to real-world ITI models expressed in the modeling language, or be able to reverse engineer them;
- **Metamodel instantiability** – From existing or reverse-engineered models, we must be able to instantiate the corresponding metamodel;
- **Understandability** – The required effort to learn the notation and to recognize the modeling and their interrelationships concepts should be as small as possible;
- **Extensibility** – The metamodel can be extended with new concepts or existing concepts can be further detailed/adopted. Extensions should not cause revisions of existing definitions.

Each of these characteristics will be applied to the selected modeling languages to allow a comparison to be made.

3.4.1 Unified Modeling Language

The application of the previous characteristics to UML is as follows:

Expressiveness: UML allows the representation of ITIs by using Deployment Diagrams. This kind of diagram has a limited number of abstractions (physical nodes, software components, associations and dependencies). To increase the representation richness we must use stereotypes and tagged values. This option limits models portability, namely if we intend to use some ITI's models capture tool.

Relevance: The OMG has been committed in the standardization and evolution of UML. After a sequence of minor revisions that ended in version 1.5, UML went through a major revision, which resulted in version 2.0. The latest published version is 2.1.2. [OMG, 2007a, OMG, 2007b].

Models availability: Although an XML based format for UML models portability has been proposed [OMG, 2007c] and is supported by several tool vendors, the examples of XMI files found in the web are few and relate mostly to toy examples and to other diagrams (mostly class and use case ones) rather than deployment diagrams.

Most UML tools now support at least some features of UML 2.0. However, we could not find tools to capture UML deployment diagrams out of existing ITIs.

Metamodel instantiability: The UML 2.0 metamodel is fragmented across many packages, which hampers its understandability. Furthermore, the M2DM approach requires some metamodel flattening, since known ITI evaluator components do not support the package construct.

Understandability: The concepts of UML, the language and notation are aspects easy to recognize. However due to UML expressiveness, it may be complex and difficult to read and understand.

Extensibility: The UML metamodel has three extensibility mechanisms, which are tagged values, stereotypes and constraints. Tagged values allow arbitrary information to be attached to model elements. This extensibility mechanism allows users to define new element properties for any model element. Stereotypes allows sub-classification of model elements. Stereotypes can be used to introduce additional distinctions between model elements that are not explicitly supported by the UML metamodel. Constraints allow new semantic restrictions to be applied to elements.

3.4.2 System Definition Model

The application of the previous characteristics to SDM is as follows:

Expressiveness: SDM provides a rich set of constructs to model ITIs, such as systems, resources, endpoints and different kinds of relationships (containment, communication, hosting, reference or delegation). Since the SDM scope is much more focused than the one of UML, its metamodel is much less complex as a whole.

Relevance: The SDM was a key component of a Microsoft strategy called the *Dynamic Systems Initiative (DSI)*, with the objective of reducing the total cost of IT operations and infrastructure management. Microsoft is committed to achieve this objective trough the utilization of a modeling language like SDM and incorporate it in a subset of products.

Models availability: Although some simple models are included for exemplification in Microsoft products that support SDM, we also could not find examples of realistic models in the Internet. However, we can easily generate them from any existing ITI, using the *CSVDE (Comma-Separated values Directory Exchange)* tool, available on Microsoft server operating systems, that allows us to use a batch process to bulk export ITI objects and their relations from an *Lightweight Directory Access Protocol (LDAP)* [Zeilenga, 2006] repository (e.g. Active Directory) into a *CSV (Comma-Separated Values)* file format.

Metamodel instantiability: We have reverse engineered the SDM metamodel, out of the XML DTD of SDM models made available by Microsoft. We could realize that this metamodel is much less complex than the UML 2 one.

Understandability: The concepts of SDM, the language and notation are aspects easy to recognize and SDM models are easy to read and understand.

Extensibility: The SDM metamodel is extensible through the software development kit (SDK) and allows the creation of new SDM resources as additional properties on any logical server or application. These new resources can be associated with any existing types. SDM supports also the ability to define new SDM types, like *systemdefinitions*, *endpoints* or *relationships* amongst others.

3.4.3 Service Modeling Language

The application of the previous characteristics to SML is as follows:

Expressiveness: SML provides a rich set of constructs for creating models of complex services and systems. Depending on the application domain, these models may include information such as configuration, deployment, monitoring, policy, health, capacity planning, target operating range, service level agreements and so on.

Relevance: SML is a recent joint effort of major players in the IT industry (BEA, BMC, CA, Cisco, Dell, EMC, HP, IBM, Intel, Microsoft and Sun), being promoted through the World Wide Web Consortium (W3C) [W3C, 2008a], an industry forum that develops interoperable technologies (specifications, guidelines, software and tools).

Models availability: Due to its very recent proposal, it is natural that we cannot yet find available SML tools or model examples.

Metamodel instantiability: Although the SML metamodel can be obtained by reverse engineering the XML DTD of SML, made available at the W3C site, we cannot instantiate it since we do not yet have available models or tools to capture them.

Understandability: The concepts of SML, the language and notation are aspects easy to recognize and SML models are easy to read and understand.

Extensibility: To provide extensibility and ensure accurate and convenient interchange of the documents that make up an SML model or a portion of an SML model was defined an implementation-neutral interchange format that preserves the content and interrelationships among the documents. The SML specification defines a standard format called the SML Interchange Format (SML-IF) that does that and allows that elements in SML can be extended to contain additional content and/or attributes from other XML namespaces [Dublish, et al., 2008a].

3.5 Comparative analysis

To compare the previous characteristics of the modeling languages and choose the one that best fulfills our needs, we will summarize the evaluation using an ordinal scale for grading each criteria, using the following scale of satisfaction:

- Very Dissatisfied **(1 point)**
- Dissatisfied **(2 points)**
- Somewhat satisfied **(3 points)**
- Very Satisfied **(4 points)**

To facilitate the comparability process we specified a value (ranging from 1 to 4). The criteria and languages are presented in Table 3.1. According to this scale the modeling language with an higher value will be the chosen.

Table 3.1 — Candidate ITIs modeling languages

Criteria / language	UML	SDM	SML
Expressiveness	2	3	4
Relevance	4	3	4
Models availability	2	4	1
Metamodel instantiability	3	4	3
Understandability	2	3	3
Extensibility	4	3	4
Total	**17**	**20**	**19**

According to the total results presented in Table 3.1 the SDM appears to be the modeling language that better fulfills our objective since it has the higher number of points. However since SML is an evolution of SDM and it was created to model complex IT services and systems, including their structure, constraints, policies and best practices it may sound strange why it has a lower number of points. The main reason for this is related with the criteria *Models availability* that was classified with 1 point due to the fact that when we started this work, the SML was under development, we did not have much information about this language.

According to the results we will use the first public available version of SDM shipped as part of *Visual Studio 2005*. Another important aspect regarding SDM is that we had access to tools that allowed us to instantiate the metamodel.

In the next sections we will present the SDM structure with "toy" examples to explain the main SDM definitions. More details regarding the structure of SDM can be found in appendix A.

3.6 The chosen metamodel structure

The structure of the SDM is based on three core types or object definitions (*system*, *endpoints* and *resources*), five relationship types (*containment*, *communication*, *hosting*, *reference* and *delegation*) and some optional additions that can be added to the core types (*settings*, *flows* and *constraints*) each of these are described below and with more detail in appendix.

The *system* is the "heart" of the SDM and in its most basic form, a system is an independently configuration of *resources*. In the field of software, these resources can represent directories or files, scripts, XML files and so on, In the field of hardware they can represent servers, sites, connections, power supplies and other components. In the next sections we will use *systems* to represent the servers and the sites of a distributed ITI.

The *systems* normally have *resources* and they allow access to its resources or access to resources on other systems via *endpoints*. For example, a web service endpoint provide a means for an application to expose or consume web services or a server located in one site replicate data with other server trough endpoints.

In SDM systems can be atomic or composite. An atomic system is composed directly of resources, while a composite, system is composed of other systems. In a distributed ITI, each site is a composite since each site is composed of one or more servers.

In a composite system an endpoint represents a proxy for an endpoint in other system. Every time that a system needs to communicate with another system it uses this proxy that will communicate with a remote proxy endpoint of the other system.

Fig. 3.1 shows the application of these core types to an ITI. The ITI presented has only one site with the name *Lisbon*, one subnet and two servers, which communicate trough endpoints.

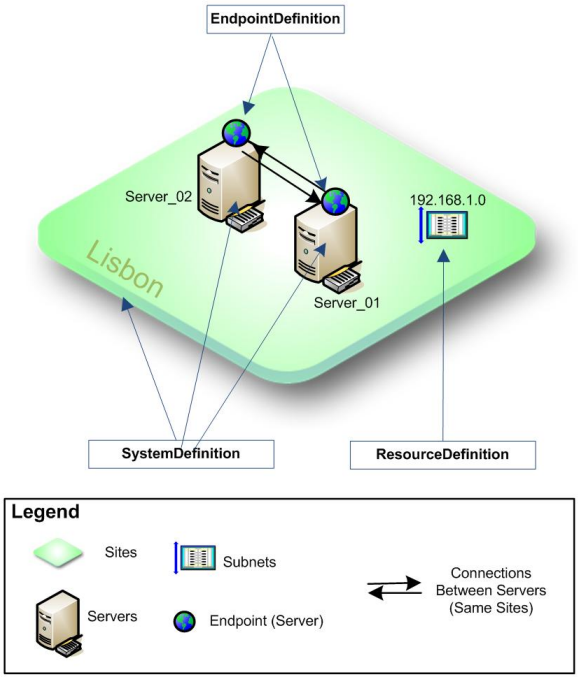


Fig. 3.1 — Application of SDM core types

Table 3.2, summarizes the core types of SDM used later to describe elements and to capture important semantics of ITI.

Table 3.2 — SDM core types

SDM Core Types	Description
System	Represents standalone entities that perform well-defined tasks in the physical world and are independently deployable. Systems may make use of other SDM building blocks, including other systems. Interactions among systems are explicitly modeled using communication relationships.
Resource	Represents a software or hardware element that is not independently deployable in the physical world. A resource must be deployed as part of a system. Resources can contain other resources but not endpoints or systems. Resources within an SDM system cannot express dependencies on resources outside the system.
Endpoint	Represents a communications interface on a system. Endpoints allow SDM systems to form communication relationships with other systems. Endpoints are used to model the interaction of a system with other systems.

The relationship definitions are used to allow the definition of associations among SDM systems, resources and endpoints and are refined into *communication*, *delegation*, *containment*, *reference* and *hosting* relationships.

The *communication* relationship allows the interaction between two systems or endpoints. If a communication relationship does not exist between endpoints, then a connection cannot be established between those endpoints. For example, to represent the communication among servers

trough endpoints, we can use the communication relationship. The *delegation* is used to represent a proxy or delegation relationship between two endpoints. For example an HTTP server, exposed by a web application, delegates all communication to the HTTP server endpoint.

The last three SDM relationships (*reference*, *containment* and *hosting*), referenced by the three key relationships [MSFT, 2008b], can be organized in a hierarchy from least specific to most specific, with the hosting being the most specific and reference being the less specific. That is, a containment relationship is a more specialized version of a reference relationship and a hosting relationship is a more specialized version of a containment relationship.

The *hosting* relationship should be used when the lifetime of one object is dependent of the lifetime of the other. For instance if we consider a folder with files then, if we delete that folder all the files contained will also be deleted. Other characteristics of the hosting relationship are:

- The hosted object can be hosted by only one other object;
- The hosted object cannot host the hosting object;
- The hosting relationship can be nested hierarchically.

The *containment* relationship differs from hosting because an object can contain multiple other objects; an object can be contained by multiple other objects; a contained object cannot contain the containing object. If for instance, we consider a group of servers belonging to a site, deleting the site does not mean that the servers no longer exist.

The *reference* relationship is used when one type of object uses or works with another, but does not host or contains the other. For example, a web application may use other web application but they are not hosted or contained.

The Fig. 3.2 shows the application of two relationship types (*communication* and *containment*) to an ITI with two sites, named *Lisbon* and *Paris*.

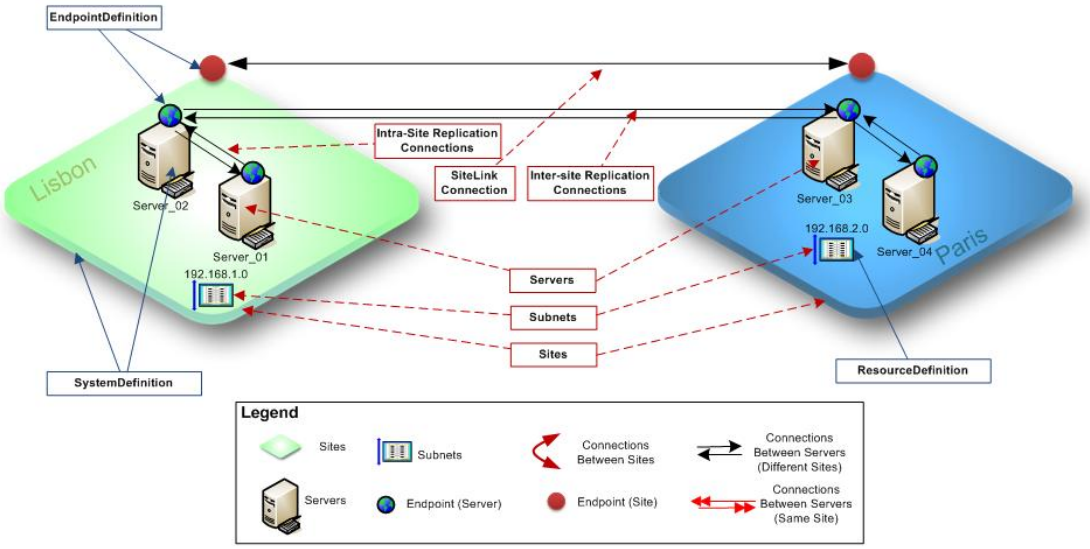


Fig. 3.2 — Application of SDM relationship types

According to the characteristics of ITIs and the existing objects presented in Fig. 3.2 we summarize in Table 3.3 the mapping between ITIs and the SDM metamodel objects.

Table 3.3 — Mapping between ITI objects and SDM abstractions

ITI objects	SDM objects	Description
Server	*SystemDefinition*	The *SystemDefinition* object will be used to represent objects of "Server" kind.
Site	*SystemDefinition*	The *SystemDefinition* object will be used to represent objects of "Site" kind.
Subnet	*ResourceDefinition*	The *ResourceDefinition* object will be used to represent objects of "Subnet" kind.
Endpoint	*EndpointDefinition*	The *EndpointDefinition* object will be used to represent objects of "Endpoint" kind.
Connection	*CommunicationDefinition*	The *CommunicationDefinition* object will be used to represent relationships among objects.
Belong	*ContainmentDefinition*	The *Containment* object will be used to represent relationships when we need to express that an object belongs to another object.

Table 3.4, summarizes the relationships of SDM used to describe elements and to capture important semantics of ITIs.

Table 3.4 — Relationships of SDM

Category	Description
Containment	Specifies ownership of an SDM object.
Communication	Models an interaction between SDM systems. This relationship is expressed between endpoints on each system. The relationship may also be between endpoints on the same system.
Hosting	Identifies the execution environment for an SDM object (called the guest). At any given time, a guest may have exactly one host.
Reference	Captures dependencies between resources. The dependency is usually known only to the resource that has the dependency. The SDM v1 does not support the creation of reference relationships.
Delegation	Exposes endpoints from nested SDM systems or a resource from a host.

These relationships amongst objects allow that a system can be hosted or contained in another system what creates a layered model. For example, an ASP.NET application is hosted on web server, which is hosted on the operating system, which is hosted in a server. These hosting relationships allow the model to be layered, so that different concerns can be addressed in different layers. Each layer can be represented in discrete models or SDM documents making the system easier to build and understand. The SDM was designed to support four layers, as illustrated in Fig. 3.3.

This four-layered model lets us represent all aspects of an distributed ITIs, such as the structure of applications systems, the application hosting environment, the network and operating systems environment and finally the hardware. The SDM allows us to define constraints that constrain systems being hosted on one another. Constraints can be defined on an SDM system type for example to restrict the kinds of systems which it can host. In a distributed infrastructure with servers

and sites, it could make sense to host a server in a site, but does not make sense to host a server in another server. Objects in each layer can describe constraints on the layers above or below.

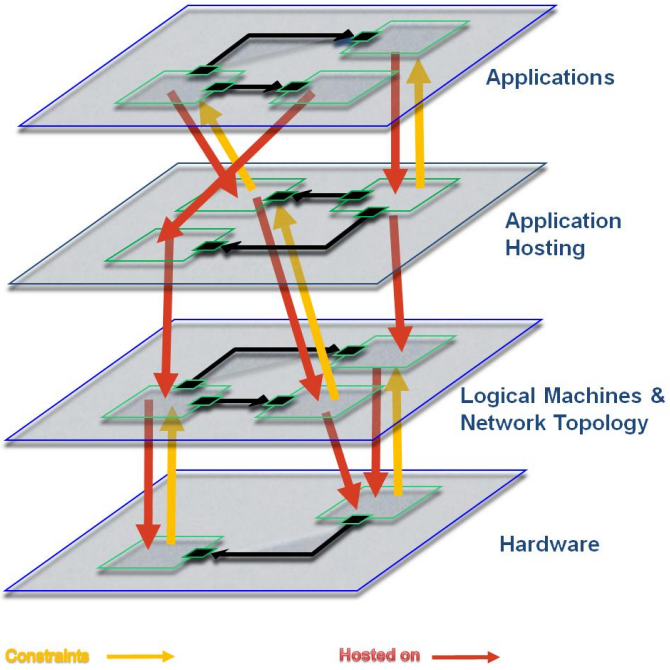


Fig. 3.3 — The four layers of SDM

The use of constraints, settings and flows represents optional additions that can be added to systems, endpoints and resources. Each of these additions is described on Table 3.5.

Table 3.5 — Settings, flows and constraints in SDM

Term	Description
Settings	Create simple value elements, which can then be used to store configuration information. All definitions can expose settings members, which are called setting declarations within the SDM schema.
Flows	Flow passes settings values among members of an object definition and among participants in relationships.
Constraints	Capture detailed requirements that depend on the configuration of SDM objects involved in a relationship. For example, a constraint may be used to ensure that sites cannot host other sites.

3.7 Modeling using SDM language

To illustrate the feasibility of our approach, in this section we will show how to instantiate the site with the name *Lisbon* presented in Fig. 3.1. The hypothetical example of the ITI has only one site with two servers and one subnet. Later, we will use real ITIs with hundreds of servers, sites and subnets.

This section starts with an UML meta-object diagram to illustrate the relations among the objects of the site *Lisbon* using the SDM language described earlier and next we wrote an SDM document using SDM syntax.

For understandability sake and also due to the naming constraints in OCL, we have performed a few transformations on the original names of the meta-objects in Table 3.6:

Table 3.6 — Transformations on original object names to be compliant with OCL rules

Object/meaning	Replaced	Description
"."	"_"	**Purpose:** Eliminate dots in identifiers, since those are not allowed in OCL **Example:** Subnet id 172.27.226.128 → 172_27_226_128)
"/"	_Mask_	**Purpose:** Eliminate slashes in identifiers, since those are not allowed in OCL **Example:** Subnet mask 172.27.226.128/25 → 172_27_226_128_Mask_25
Resources	SN_	**Purpose:** To clearly distinguish a subnet from other objects in OCL **Example:** Subnet 172.27.226.127/25 → SN_172_27_226_128_Mask_25
Endpoint Server	EPSE_	**Purpose:** To clearly distinguish a server endpoint from other objects in OCL **Example:** Server_Lisbon_01 → EPSE_Server_Lisbon_01
Endpoint Site	EPSI_	**Purpose:** To clearly distinguish a site endpoint from other objects in OCL **Example:** Site_Lisbon → EPSI_Site_Lisbon
Containment	_Contains_	**Purpose:** To identify objects of type containment from other objects in OCL **Example:** Site *Lisbon* contains Server_Lisbon_01 → Lisbon_Contains_ Server_Lisbon_01

The Fig. 3.4 shows the SDM document, using SDM syntax to describe the *Lisbon* site. The definition of *Lisbon* Site using the SDM represented in Fig. 3.4 consists of a document file with extension *.sdm* using a set of XML instructions representing SDM object definitions, that must conform with the SDM schema to be compiled. The SDM schema is specified in the *SystemDefinitionModel.xsd* file available in *Microsoft Visual Studio 2005 Team Edition for Architects*. Every document file must have at least the following items:

- Root element called *SystemDefinitionModel* with a name attribute (Line 1 and 2, of Fig. 3.4);
- Version which contains the version of the *.sdm* file (Line 3, of Fig. 3.4);
- Document language attribute which contains the default language for the descriptions found in the model (Line 4 of Fig. 3.4);
- Information attributes which provide details about the owner of the *.sdm* file (Line 6 to 11 of Fig. 3.4).

System Definition Model: SDM syntax to represent a the site with the name *Lisbon*.

```
<SystemDefinitionModel
  Name="ITInfrastructure"
  Version="1.0.0.0"
  DocumentLanguage="en"
  xmlns="http://schemas.microsoft.com/SystemDefinitionModel/2005/1">
  <Information>
   <FriendlyName>Lisbon Site</FriendlyName>
   <CompanyName>Universidade Nova de Lisboa</CompanyName>
   <Copyright> Copyright (c) Universidade Nova de Lisboa. All rights reserved. </Copyright>
   <Description> Small organization </Description>
  </Information>

  <SystemDefinition Name="Lisbon">
  </SystemDefinition>
  <SystemDefinition Name="Server_01">
  </SystemDefinition>
  <SystemDefinition Name="Server_02">
  </SystemDefinition>

  <ResourceDefinition Name="SN_172_27_226_128_Mask_25" />
  <ResourceDefinition Name="SN_172_27_226_0_Mask_24" /

  <EndpointDefinition Name="EPSE_Server_01_d2" />
  <EndpointDefinition Name="EPSE_Server_02_d2" />
  <EndpointDefinition Name="EPSE_Server_02_fd" />
  <EndpointDefinition Name="EPSE_Server_01_fd" />

  <ContainmentDefinition Name="Lisbon_Contains_Server_01"
              ParentDefinition="Lisbon" MemberDefinition="Server_01" />
  <ContainmentDefinition Name="Lisbon_Contains_Server_02"
              ParentDefinition="Lisbon" MemberDefinition="Server_02" />
  <ContainmentDefinition Name="Lisbon_Contains_SN_172_27_226_128_Mask_25"
              ParentDefinition="Lisbon" MemberDefinition="SN_172_27_226_128_Mask_25" />
  <ContainmentDefinition Name="Lisbon_Contains_SN_172_27_226_0_Mask_24"
              ParentDefinition="Lisbon" MemberDefinition="SN_172_27_226_0_Mask_24" />

  <CommunicationDefinition Name="EPSE_Server_01_d2_EPSE_Server_02"
               ServerDefinition="EPSE_Server_01_d2"
               ClientDefinition="EPSE_Server_02_d2"/>
  <CommunicationDefinition Name="EPSE_Server_02_fd2_EPSE_Server_01"
               ServerDefinition="EPSE_Server_01_fd"
               ClientDefinition="EPSE_Server_01_fd" />
</SystemDefinitionModel>
```

Fig. 3.4 — SDM definition for *Lisbon* site

With the basic structure of an SDM file defined, we can create the *Lisbon* site and servers *Server_01* and *Server_02* which are objects of type *SystemDefinition*. To define these systems on our System Definition Model, we have to add the required XML instructions to the SDM document file as presented in lines 13 to 18 of Fig. 3.4.

These set of XML instructions defines the *Lisbon* site and both servers (*Server_01* and *Server_02*). With the definition of *Lisbon* site in lines 13 and 14, we can move forward and add the subnet *192.168.1.0/25* to the site, which are an object of the type *ResourceDefinition*. This resource is defined in line 20 of Fig. 3.4.

To make the communication possible between objects of type *SystemDefinition*, endpoints must be created for each *SystemDefinition*. Endpoints are created when a system needs to communicate with other systems. In our example the *server_01* needs to communicate with *server_02* and *server_02* need to communicate with *server_01*. For each communication or connection, we must have two endpoints. One endpoint is considered the client and represents the system that initiates the communication or the consumer and the other is the server or the provider and represents the destination of the communication.

Fig. 3.5 — *Client* and *Server Endpoints*

To specify that *Server_01* communicates with *Server_02* and also that *Server_02* communicates with *Server_01*, we need to define four endpoints (lines 23 to 26 of Fig. 3.4)

With all objects defined, we can create relationships between them. To establish these relations we will use the relationship *ContainmentDefinition*. To accomplish this task we start by adding both servers to *Lisbon* site (line 28 to line 31) and then the subnet to *Lisbon* site (line 32 and 33).

Notice that in the relationship *ContainmentDefinition*, there is the concept of parent definition and member definition. *ParentDefinition* is the instance that contains the member, which is the site in our example. *MemberDefinition* is the instance that is contained, which are the servers or the subnet.

Now that we have all objects and their relationships instantiated we can establish communications among them. In our example we have two different connections, one that starts on *server_01* and ends at *server_02* and another that starts at *server_02* and ends on *server_01*. This communication between systems can be expressed in SDM, with the relationship *CommunicationDefinition*. To be able to communicate between systems we have to use the

endpoints created earlier. In the communication definition there is the concept of *ServerDefinition* and *ClientDefinition* as represented in Fig. 3.6 to identify the source and destination of the information.

Fig. 3.6 — *ClientDefinition* and *ServerDefinition*

So, to establish a communication between both servers is necessary to add the lines 37 to 42 to the model in Fig. 3.4. The first instruction (Line 27 to line 39) defines a *CommunicationDefinition* with the name "*EPSE_Server_01_d2_EPSE_Server_02*" and represents the communication from *server_02* to *server_01* through the use of the endpoints. The second instruction defines a *CommunicationDefinition* with the name "*EPSE_Server_02_d2_EPSE_Server_01*" and represents the communication from *server_01* to *server_02* through the use of the endpoints.

To make sure that the model does not have errors we can compile it. In order to compile we need to have installed the SDM Command Line Compiler (SdmC.exe), which is responsible for validating the correctness of a *.sdm* file according to the SDM Schema. The SDM Schema and SdmC.exe are installed with *Microsoft Visual Studio 2005 Team Edition for Architects*. The SDM compiler can be run from the command line on an *.sdm* file created. The *.sdm* file name to compile is the only required argument. Fig. 3.7 presents a successfully compilation of the ITI model.

System Definition Model: Successfully compilation of the SDM document in a command prompt

```
1   C:\> SDMC ITIinfrastructure.sdm
2
3   Microsoft (R)   SDM Compiler version 1.0.50818.0
4   Copyright (C)   Microsoft Corporation. All rights reserved.
5
6   Compiling file: C:\ ITIinfrastructure.sdm
7
8   Compilation succeeded.
9
10  C:\>_
```

Fig. 3.7 — Compilation of SDM document

4

Evaluation Approach

Contents

This chapter describes the application of the M2DM approach and presents all the components of the purposed ITI evaluation approach in a step-by-step fashion. Some ITIs' well-formedness rules and the SDM library for ITIs (ITILib) will be also presented.

4.1 Bootstrapping the application of M2DM

As described in section 3.2 to perform ITI evaluation using the M2DM approach, we need a metamodel in UML format to express the concepts and the relations of the domain to measure (in our case ITIs). According to the modeling language selection process performed in sections 3.4 and 3.5 we decided to use the SDM metamodel to accomplish our goals.

Since the SDM metamodel is provided in XML format and the M2DM approach require a metamodel expressed in UML class diagram, we decided to convert the original SDM metamodel in XML to a UML class diagram, that will be described in the following section. With the metamodel in the required format we will then be able to formal express semantics enforcement and metrics for ITIs using the OCL language. Finally the metamodel is loaded and ITIs data are instantiated into a UML tool.

Among the several existing UML tools, that can be used to achieve our goals, we decided to work with a tool called USE (UML based Specification Environment) [Richters, 2001]. This decision was based upon the reasons that will be presented in section 4.2.3. The USE tool was developed by Mark Richters at the University of Bremen with the purpose of creating information systems specifications. A specification in USE consists of textual descriptions of the modeling elements in an UML model and additional integrity constraints specified in the *Object Constraint Language* [Gogolla, et al., 2007].

4.1.1 SDM metamodel conversion

To be able to use the SDM metamodel available in product *Microsoft Visual Studio 2005 Team Edition for Architects* in the M2DM approach, we performed some conversions to the original metamodel as presented in Fig. 4.1.

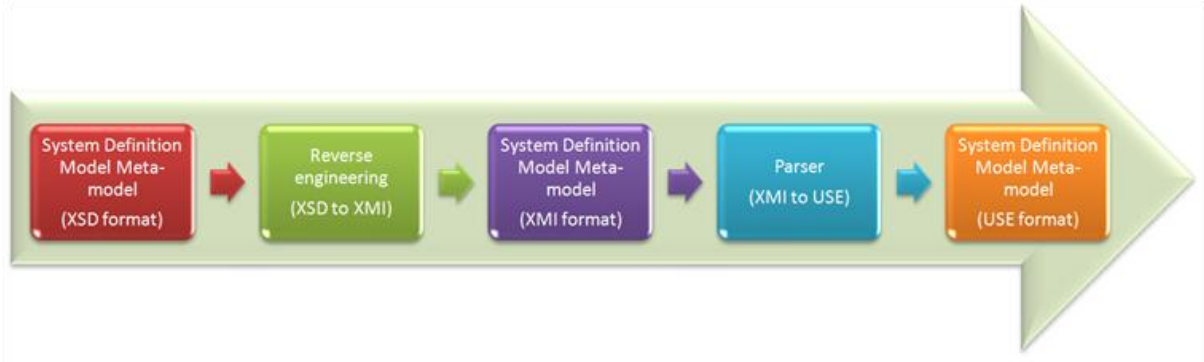


Fig. 4.1 — The SDM metamodel conversion

The SDM metamodel was provided in W3C XML Schema format (XSD), so the first step consisted in reverse engineering the SDM schema to XMI format (XML Metadata Interchange) because most of UML modeling tools support the XMI format. The XMI format is a standard that was defined and maintained by the OMG to support the exchange of metadata between modeling tools based on the UML. XMI exists in several earlier versions (1.0, 1.1 and 1.2) with 2.1 being the most recent [OMG, 2007c].

To perform the reverse engineering (XSD to XMI) conversion we evaluated several commercial tools such as the *Enterprise Architect* [Systems, 2008b], *Rational Rose* [IBM, 2008], XMLspy [Altova, 2008], *Objecteering* [Objecteering, 2008] and some open source tools such as *ArgoUML* [Tigris, 2008] and also some academic tools such as "A case tool for developing XML schemas" [Novotný, 2004]. Based mainly upon the simplicity and the quality of the results achieved with all these tools, we decided to perform the reverse engineering of the SDM metamodel with a trial version of the *Enterprise Architect, version 5.1*. After importing the SDM metamodel schema and reverse engineering it, we were able to export it to XMI 1.1 format [systems, 2008a].

With the SDM metamodel in XMI 1.1 format, the next step was to transform the metamodel in the USE format. To be able to perform this we decided to use some of the work developed in the *QUASAR research group* and we used a parser that transform *Rational Rose* files into the USE format [QUASAR, 2008]. So we imported the SDM XMI file into *Rational Rose*, we saved as rose format and we used the parser to convert the SDM metamodel to the USE format.

These conversions were also very important to the understandability of the SDM metamodel, since they allowed us to create an UML class diagram (available in appendix B). Fig. 4.2 shows a simplified extract of the SDM metamodel including the relevant model objects and relationships for the scope of this dissertation.

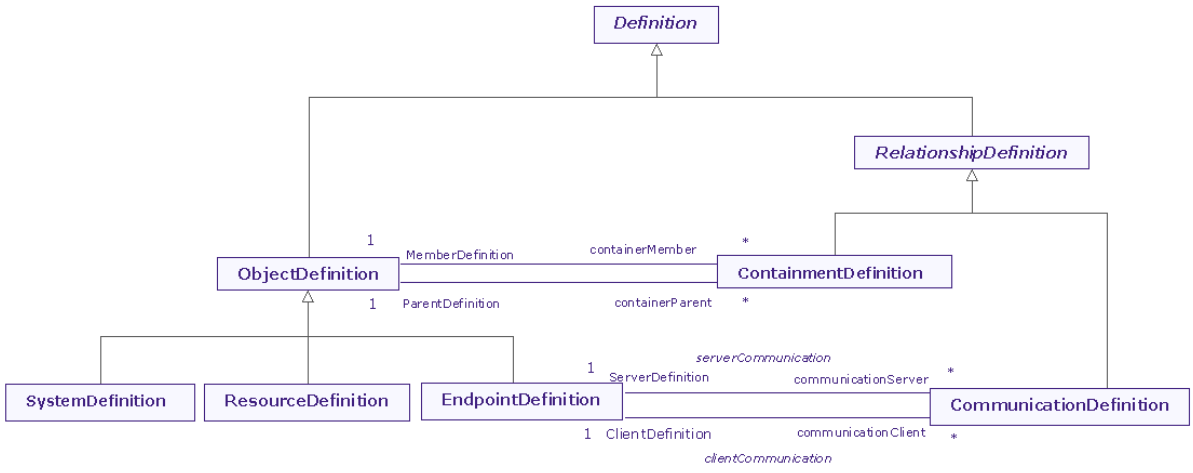


Fig. 4.2 — SDM metamodel to model for ITIs

In the definitions of Fig. 4.2 we can observe the core SDM types (*systems*, *resources* and *endpoints*) and two kinds of relationships (*containment* and *communication*).

4.1.2 Metamodel semantics enforcement

To ensure the consistency of our ITI metamodel, we enforce some semantics in the metamodel trough the definition of Well-Formedness Rules, shortly referred to as WFR, which are expressed as OCL invariants. The OCL invariants are OCL expressions that must be true for all instances of that type at any time. This approach is similar to the one used in the UML metamodel itself, to check its consistency [Chiorean, et al., 2004]. The number and type of WFRs to create depends from the domain.

In the domain of ITIs a member cannot be multiple contained (e.g. a server such as the *server_01* from our examples, cannot belong simultaneously to the site *Lisbon* and to the site *Paris*.). The expression *isUnique* specifies whether the return parameter is unique or not. The OCL expression to enforce this semantic is as follows:

Well-Formedness Rule: Member cannot be multiple contained

```
1   context ContainmentDefinition
2
3   inv noMultipleContainment:
4       ContainmentDefinition.allInstances->isUnique(MemberDefinition)
```

Fig. 4.3 — WFR for multiple contained objects

Another example is the semantic enforcement regarding the membership of objects. In ITIs servers must be contained by a site (e.g. the *server_01* must belong to site *Lisbon* or to site *Paris*.) The OCL expression to represent this WFR is as follows:

Well-Formedness Rule: A server must be contained by a site

```
1   context SystemDefinition
2
3   inv ServerContainedBySite:
4       IsServer() implies Container().IsSite()
```

Fig. 4.4 — WFR for definition of the membership of servers

A subnet must be contained by a site. The subnet is a property of a site and we want to ensure that all subnets are allocated to sites.

Well-Formedness Rule: A subnet must be contained by a site

```
1   context ResourceDefinition
2
3   inv SubnetContainedBySite:
4       IsSubnet() implies Container().IsSite()
```

Fig. 4.5 — WFR for definition of the membership of subnets

Sites and servers cannot be linked to itself. We want to ensure that there are no communications where the source and destination are the same.

Well-Formedness Rule: Site and servers cannot be linked to itself

```
1   context SystemDefinition
2
3   inv NotMutualConnection:
4       not CommunicationDefinition.allInstances->exists(Client()=self and Server()=self)
```

Fig. 4.6 — WFR for definition the membership of servers and sites

In a communication we want to ensure that this communication takes part between two servers and not between one server and one site or between one subnet and one server.

Well-Formedness Rule: Members allowed in communications among servers

```
1   context CommunicationDefinition
2
3   inv ConnectionBetweenServers:
4       IsNTDSConnection() implies Server().IsServer() and Client().IsServer()
```

Fig. 4.7 — WFR for definition of the types of members allowed in a server communication

From a site perspective, we want to ensure that the source and destination are objects of the type site, to avoid having sites communicating with servers and vice versa.

Well-Formedness Rule: Members allowed in communications among sites

```
1  context CommunicationDefinition
2
3  inv ConnectionBetweenSites:
4      IsSiteLink() implies Server().IsSite() and Client().IsSite()
```

Fig. 4.8 — WFR for definition of the types of members allowed in a site communication

All endpoints must have a container. We want to ensure that all endpoints belong to a server or to a site.

Well-Formedness Rule: Endpoints must have a container

```
1      context EndpointDefinition
2
3      inv noNullContainer:
4          not(ContainmentDef().isUndefined())
```

Fig. 4.9 — WFR for definition of the membership of endpoints

4.1.3 The SDM library for ITIs (ITILib)

In this section we give a general idea of how we have created an SDM library for ITIs, called *ITILib* trough the extension of the SDM metamodel. This library is a set of operations that support the quantitative assessments on ITIs.

A model of an ITI, expressed as a SDM model, is an instance of the SDM metamodel. This instance can be seen as a directed graph of meta-objects (sites) representing the modeling elements used in the SDM model and the appropriate meta-links (endpoints) among them. By traversing this graph, we can collect information on the ITI we want to analyze. This library is based on OCL expressions to collect the relevant information from the meta-data (meta-objects and meta-links).

Fig. 4.10 shows the SDM meta-model with a set of operations to perform quantitative assessment of ITIs. The Fig. 4.10 only presents a subset of attributes and operations defined in each class.

More details regarding each of these attributes and operations can be seen in Table B.2 and Table B.2 of Appendix B.

We decided to include also more details regarding each of the definitions and the relationships presented in Fig. 4.10 in a class diagram also presented in Appendixes (Fig. C.1, Fig. C.2, Fig. C.3, Fig. C.4 of Appendix C).

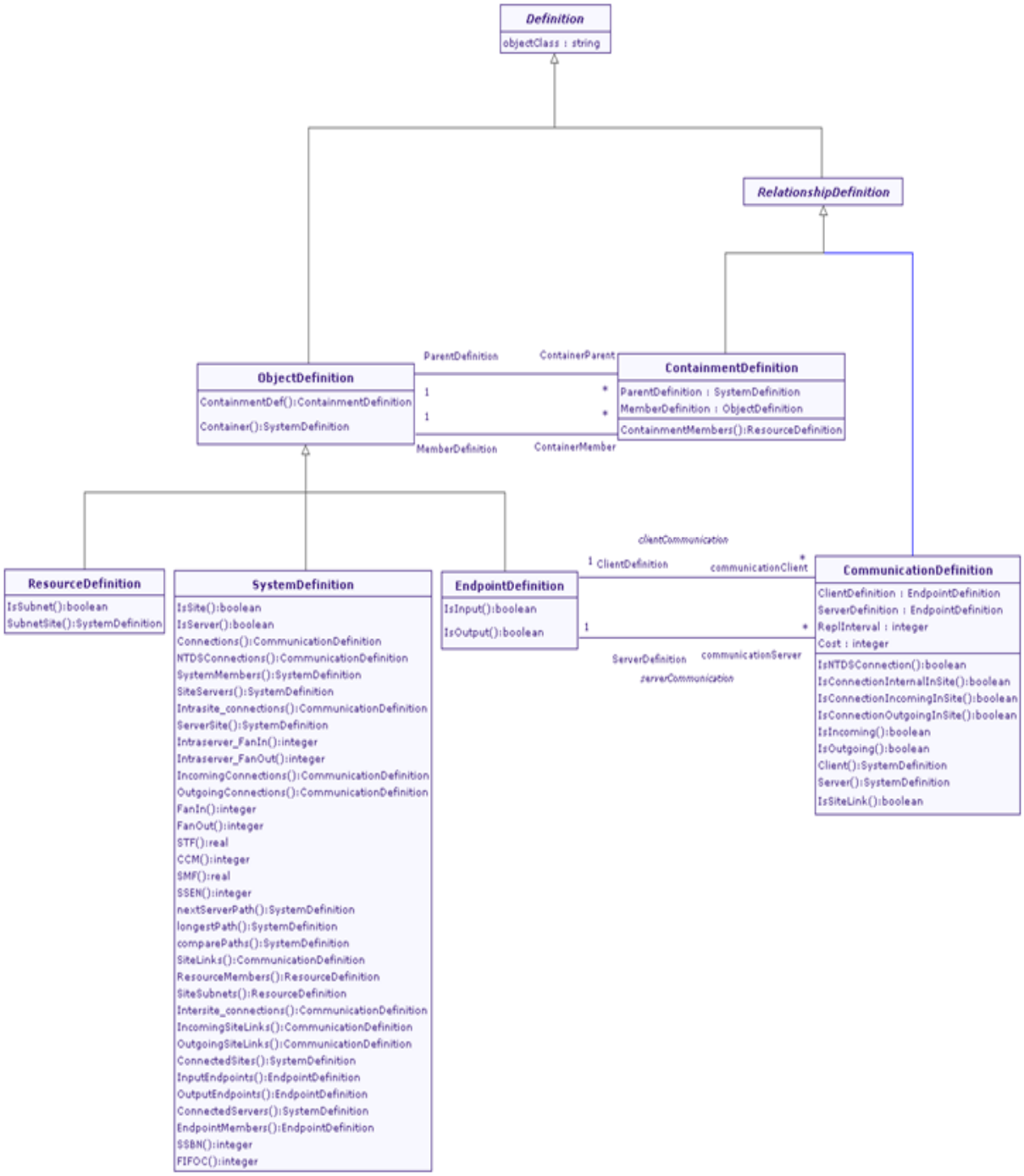


Fig. 4.10 — SDM metamodel with ITILib operations

4.2 The approach step-by-step

The methodology consists in an organized and documented set of procedures and guidelines to perform ITI evaluation. To perform ITI evaluation we defined and created a set of components that will be detailed later in this chapter and we defined a set of steps in Fig. 4.11, which must be followed in order to perform ITI evaluations.

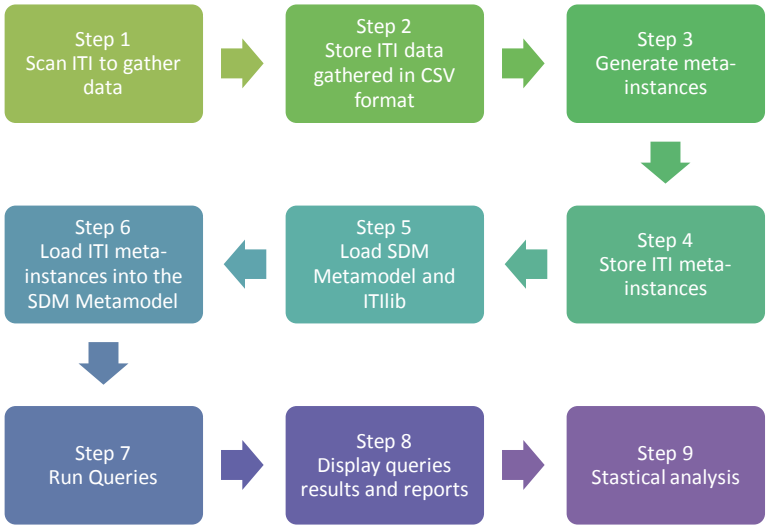


Fig. 4.11 — Steps to perform ITI evaluations

Each of these steps is performed by a component of the methodology and each has specific responsibilities as follows:

- **Scan ITI to gather data (step 1)** – the first step consists in gather data from infrastructure. This step is performed by a component that we called *ITI data gatherer* that is responsible for gathering data from an organization ITI through queries to directory services repositories;
- **Store ITI data gathered (step 2)** – This step is also performed by *ITI data gatherer* component and consists in saving the data gathered in the component *IT data store.* The *IT data store* is a repository with data stored in CSV format;
- **Generate meta-instances (step 3)** – the generation of meta-instances consists in loading the ITI data stored in the repository in CSV format, categorizing, transforming and generating meta-instances in ITI evaluator format. This step is perform by a component called *Meta-instances generator*;
- **Store ITI meta-instances (step 4)** – The component *ITI meta-instances generator* is also responsible for storing the ITI meta-instances generated in the component *ITI Meta-instances store*. The *ITI meta-instances store* is a repository that holds the meta-instances ready to be used by the component *ITI evaluator*;
- **Load SDM metamodel (step 5)** – this step consists in loading the *SDM metamodel* component into the *ITI evaluator* component. The process of loading the *SDM metamodel* component is performed by *ITI evaluator* component;
- **Load ITI meta-instances (step 6)** – after loading the *SDM metamodel* component into the *ITI evaluator* component, we can load ITI meta-instances generated in step 3. This process is also performed by *ITI evaluator* component and consists in loading data from *ITI meta-*

instances store component and instantiate this data into the *SDM metamodel* component loaded in step 5;

- **Run queries (step 7)** – With all the data instantiated in the *ITI evaluator* component, ITI stakeholders are able to run queries in the ITI evaluator component to obtain quantitative results, assess complexity or check constraint violations among other aspects;
- **Display query results and reports (step 8)** – this step is also performed by *ITI evaluator* component and consists in evaluating the queries performed in step 7 and presenting the results;
- **Statistical Analysis (step 9)** – This step consists in a deeper analysis of the results provided by the step 8. This type of analyzes is important for example to predict future grow, to compare ITIs of different organization among other aspects.

Fig. 4.12 illustrates the whole process to perform ITI evaluation using the proposed evaluation approach.

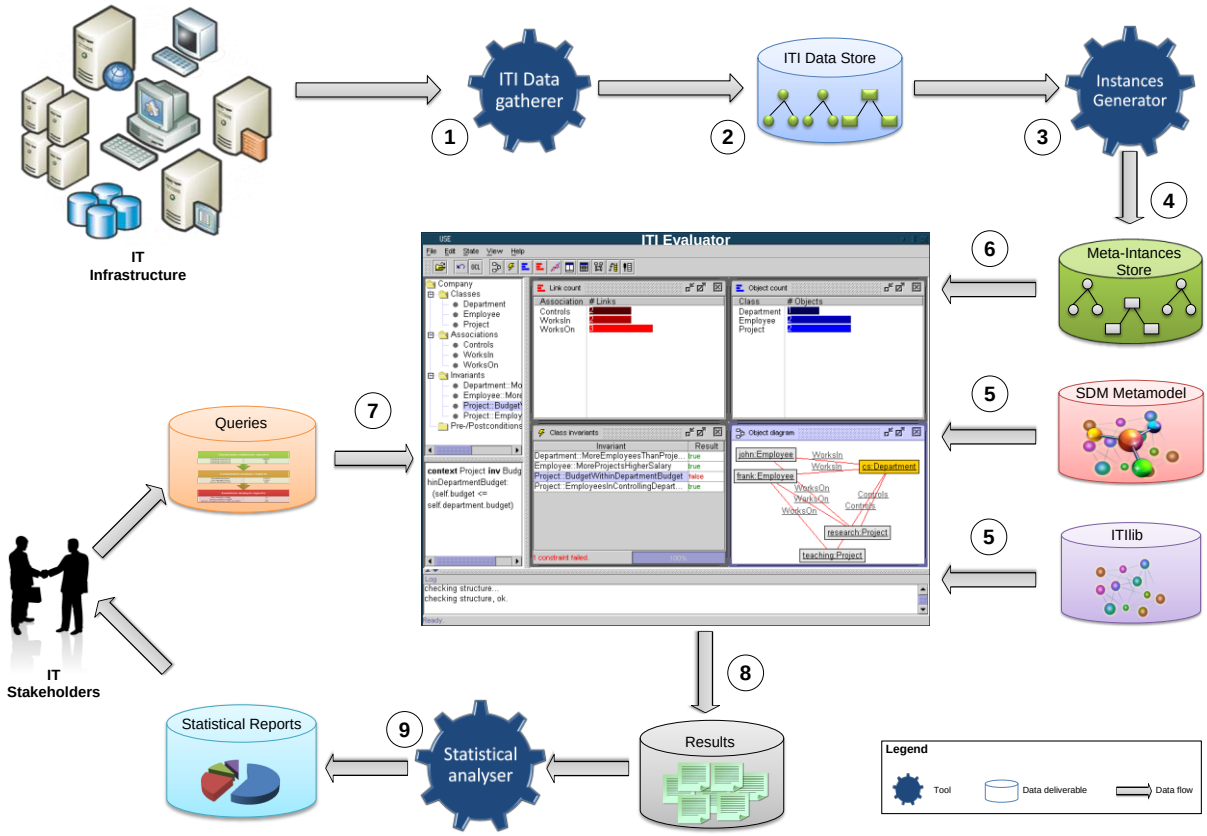


Fig. 4.12 — Evaluation approach illustration

The following sections present more details of the ITI evaluation methodology regarding each of the tools presented in Fig. 4.12 (ITI data gather, Instances generator, ITI evaluator and statistical analyser) and examples of the data deliverable commonly referred as output.

4.2.1 ITI data gatherer

The *ITI data gatherer* is a tool (represented in Fig. 4.12 as the step 1) that performs queries to an LDAP compatible directory server that stores the X.500 entities (The IT infrastructure) in an underlying database. To better understand this tool we will briefly explain the concepts of directory services, X.500 and other related concepts such as LDAP.

The directory services were an *Open Systems Interconnection (OSI)* initiative to get everyone in the industry to agree to common network standards to provide multi-vendor interoperability. These standards provide an information structure model, protocols for communicating directory information between systems, procedures that allow the directory information to be distributed among several independent systems.

The X.500 is a series of computer networks standards for directory services, developed by the *International Telecommunication Union Telecommunication Standardization (ITU-T)* and the *International Organization for Standardization (ISO)* and was developed for storing information about objects relevant to telecommunications, such as organizations, persons, distribution lists, sites, servers, subnets, etc.

The LDAP, currently in version 3, is an Internet protocol for accessing distributed directory services that act in accordance with X.500 data and service models and was specified in a series of *Internet Engineering Task Force (IETF) Standard Track Requests for Comments (RFCs)* [Zeilenga, 2006]. There are several implementations of LDAP/X.500 directory services from different organizations, such as:

- **eDirectory** – The eDirectory which was previously known as Novell Directory Services (NDS) is the Novell implementation of directory services that natively support LDAPv3 and can be used in different platforms such as Windows, Linux, Unix and Netware [Novell, 2008];
- **OpenLDAP** – The OpenLDAP is a free open source implementation that support LDAPv3 and are available for different platforms such as Unix, AIX, Linux, Windows, Solaries, z/OS, among others [OpenLDAP, 2008];
- **Fedora Directory Server** – This directory server also supports LDAPv3 and is available to some Linux distributions, Solaris 2.8 and later and HP/UX 11 [Fedora, 2008].
- **Active directory** – This directory server is compliant with LDAPv3 [MSFT, 2003] and is based on X.500 concepts. The data in Active Directory can be accessed by any LDAPv3 compliant application. Active Directory was created by Microsoft and is included in server operating systems such as Windows 2000, Windows Server 2003 and Windows Server 2008;

- **Open Directory** – The Open Directory is the directory service from Apple's MAC OS X which is based on OpenLDAP [ODP, 2008];
- **Apache Directory Server** – The Apache Directory Server was completely written in Java and is an open source project of Apache Software Foundation [ASF, 2008].
- **Oracle Internet Directory** – The Oracle Internet Directory (OID) is the Oracle implementation of directory service, which is compatible with LDAPv3 [Stullich, 2006];
- **Sun Java System Directory Server** – This is the Sun Microsystems' directory service implementation, which also supports LDAPv3 [Sun, 2008];

These are just a few examples of the directory services currently available because there are much more. In the context of this dissertation and in this step in particular (gatherer ITI data) we decided to work with *Active Directory*, mainly because to prove the feasibility of our approach we rely on organization ITI data and the most wide, complex and interesting ITIs data, that we had access, were *Active Directory* implementations.

Having chosen *Active Directory* to obtain ITI data, the next choice was to select a tool that was able to connect to *Active Directory* and bulk export the ITI data. As introduced earlier we used the *CSVDE* which is a command-line tool available in *Microsoft Windows Server* operating systems, created with the purpose of bulk exporting and importing data from *Active Directory* in the *Comma-Separated Value (CSV)* format.

The ITI data in CSV format has normally thousands of lines (depending on the size of the organization ITI). Example in Fig. 4.13 shows the header of the file (line 1) and the representation of a server with the name *Lisbon01* (line 2).

Evaluation Approach: Example of contents of ITI data store data deliverable (step 2 of Fig. 4.12)

1 DN,objectClass,cn,distinguishedName,instanceType,whenCreated,whenChanged,uSNCreated,uSNChanged,showInAdvancedViewOnly,name,objectGUID,systemFlags,objectCategory,siteObjectBL,serverReference,dNSHostName,hasMasterNCs,dMDLocation,invocationId,options,serverReferenceBL,msDS-Behavior-Version, msDS-HasInstantiatedNCs,msDS-HasDomainNCs,msDS-hasMasterNCs, enabledConnection, fromServer, schedule,mS-DS-ReplicatesNCReason,transportType,interSite TopologyGenerator, siteServer,siteObject ,transportAddress Attribute,cost,siteList,replInterval,dSCorePropagationData

2 "CN=lisbon01,CN=Servers,CN=Lisbon,CN=Sites,CN=Configuration,DC=unl,DC=net",server,lisbon01,"CN=lisbon01,CN=Servers,CN=Lisbon,CN=Sites,CN=Configuration,DC=unl,DC=net",4,20070423155239.0Z,20070423163657.0Z,7226,12692,TRUE,lisbon01,X'3d824644093071458105508f2ce224be',1375731712,"CN=Server,CN=Schema,CN=Configuration,DC=unl,DC=net",,"CN=lisbon01,OU=Domain Controllers, DC=unl,DC=net", lisbon01.unl.net, 20070423163657.0Z;2007 0423163657.0Z;20070423163657.0Z;160457845686151056.0Z

Fig. 4.13 — ITI data store contents (Infrastructure in CSV format)

4.2.2 ITI Meta-instances generator

The *Meta-instances generator* (represented in Fig. 4.12 as the step 3) was the name given to the tool that transforms the content of *ITI Data Store* (Fig. 4.13), into meta-instances. This tool parses the CSV files and generates instances in a format that can easily be imported into an *UML-based Specification Environment* (known as *ITI Evaluator* tool or component and described in the next section).

Because we worked with large amounts of data in a CSV format, we decided to build the *ITI meta-instances generator* using the capacities of *Microsoft Office Excel*. The *ITI meta-instances generator* presented in Fig. 4.14 is responsible for:

- Importing large text files in CSV format;
- Categorizing different types of data (e.g. servers, sites, subnets, etc.);
- Parsing each type of data and generating meta-instances expressions accordingly;
- Saving all ITI meta-instances into a format that can be loaded by the *ITI evaluator* component.

In Fig. 4.14 we represent the commands generated by the *ITI meta-instances generator*, which is ready to be imported into the *ITI evaluator* component. The following set of commands, allows the creation of six objects of type *SystemDefinition* (line 1 to 6) to represent *sites* and set a value with the name (line 7 to 12).

Evaluation Approach: Example of contents of meta-instances store data deliverable (step 4 of Fig. 4.12)

```
1  ! create Lisbon : SystemDefinition
2  ! create Madrid : SystemDefinition
3  ! create Paris : SystemDefinition
4  ! create Berlin : SystemDefinition
5  ! create London : SystemDefinition
6  ! create Dublin : SystemDefinition
7  ! set Lisbon.Name:= 'Lisbon'
8  ! set Madrid.Name:= 'Madrid'
9  ! set Paris.Name:= 'Paris'
10 ! set Berlin.Name:= 'Berlin'
11 ! set London.Name:= 'London'
12 ! set Dublin.Name:= 'Dublin'
```

Fig. 4.14 — Meta-instances store contents

The diagram of Fig. 4.15 shows a meta-object diagram that represent the *Lisbon* site (presented initially in section 3.6) and several relationships with subnets and servers. The information in the meta-object diagram was generated with meta-instances generator.

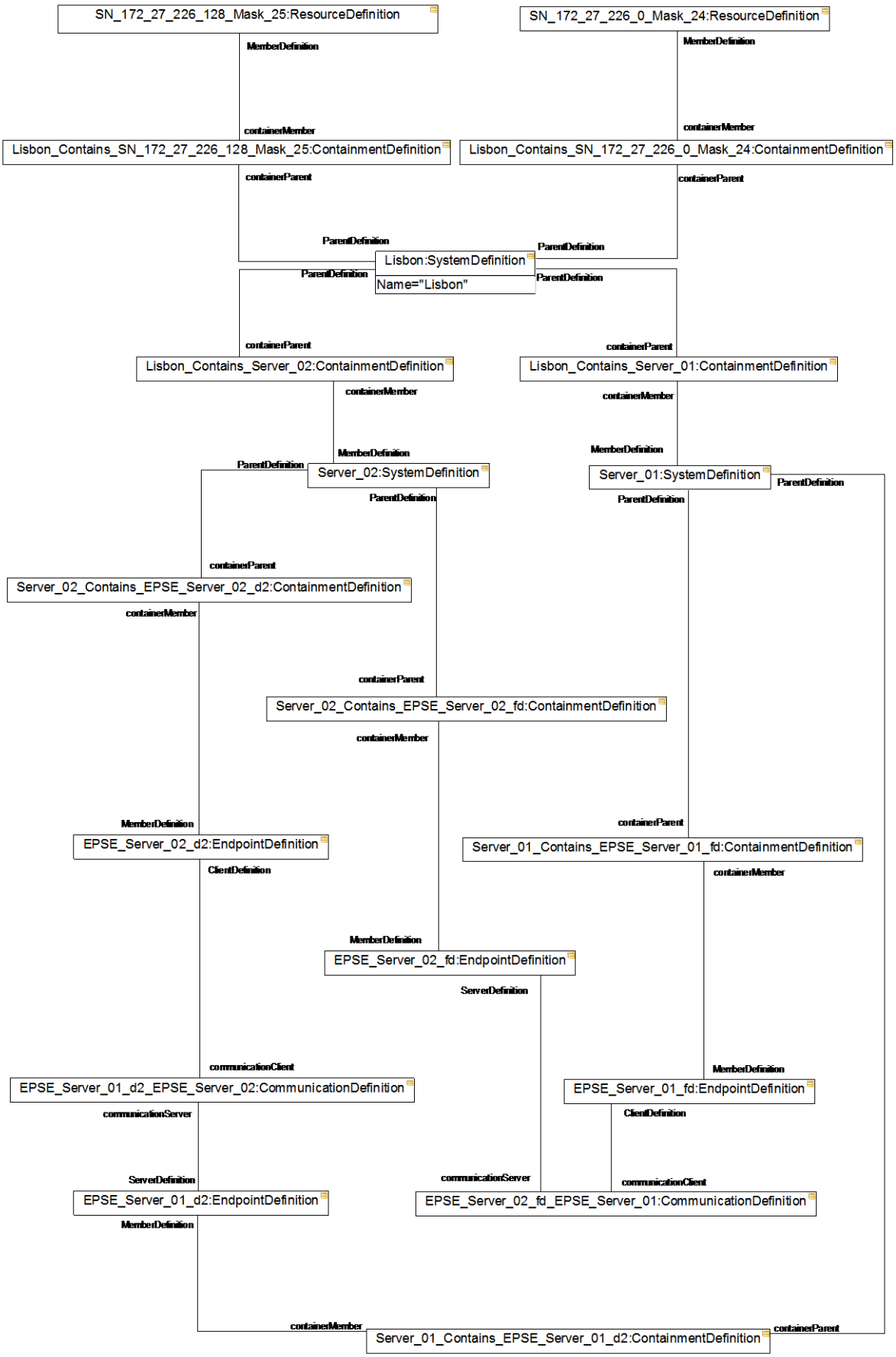


Fig. 4.15 — Meta-object diagram for the *Lisbon* site

4.2.3 ITI evaluator

The *ITI evaluator* (represented in the center of Fig. 4.12) was the name given to the tool that works with ITI data and makes the ITI evaluation possible. It does so by evaluating OCL expressions and constraints upon the SDM metamodel. OCL expressions can be used in for several purposes such as the specification of the initial value of an attribute or association, the specification of the body of an operation, indication of a guard condition and, most of all, to specify the following types of constraints on the SDM metamodel:

- **Invariants** – An invariant is a constraint that states a condition that must always be met by all instances of the class, type, or interface. An invariant is described using an expression that evaluates to true if the invariant is met. Invariants must be true all the times;
- **Preconditions** – A precondition to an operation is a restriction that must be true before the operation is called. Fulfilling a precondition is an obligation for the operation caller;
- **Postconditions** – A postcondition to an operation is a restriction that must be true when the operation ends its execution. Fulfilling a postcondition is a right for the operation caller.

Currently there are several tools available from both commercial companies and universities that support OCL. Some examples are *ModelRun* from *Boldsoft*, *OCL compiler* from University of Dresden and *OCL compiler* from Cybernetic Intelligence GMBH, *Octopus* from Klasse Objecten, USE from University of Bremen and many others. Among those tools we chose the *USE (UML-based Specification Environment)* tool from Bremen university [Gogolla, et al., 2005], since it fulfills the requirements for evaluating ITIs and we already had knowledge and good experiences in using it in other research projects. Notice that in the context of this dissertation sometimes the *ITI evaluator* is called the *USE* tool.

With USE we were able to load the SDM metamodel (represented in step 5 of Fig. 4.12) and ITILib (referred in section 4.1.3 and also represented as step 5 of Fig. 4.12) which contains meta-classes, meta-associations, meta-attributes, meta-operations and constraints). Once this metamodel has been loaded, we can add the meta-objects generated with *ITI meta-instances generator* tool and initialize their attributes as represented in Fig. 4.12 as step 6.

Each time a change in the system's state occurs, an automatic checking of the invariants is carried out. For example, when a new object is introduced, it is checked that it fulfills the specification of the SDM model and all the constraints defined. The "USE" tool can also validate the pre and post conditions.

With all the ITI data available in the ITI evaluator tool, ITI stakeholders can perform queries (represented in Fig. 4.12 as the step 7) as we will detail in the chapter ahead.

4.2.4 Statistical analyser

The *statistical analyser* (represented in Fig. 4.12 as step 9) was the name given to the tool that performs statistics using the result of ITI stakeholder's queries (represented in Fig. 4.12 as step 8). The statistics is a mathematical science pertaining to the collection, analysis, interpretation or explanation, and presentation of data.

To deal with a large amount of ITI data, we decided to use statistical analysis, which serves the purpose of description and inference. Descriptive statistics can be used to summarize the ITI data in a numeric or graphically format. Inferential statistics is used to model patterns in the ITI data what can take the form, for instance of hypothesis testing (yes/no questions), correlation (description of associations) or regression (modeling of relationships).

There are several statistical tools available that can be used to perform statistical analysis. These tools differ in the type of software license, cost, types of provided interfaces, supported operating systems, types of statistical tests, regression methods, statistical charts and diagrams provided, among other aspects. For the purpose of our work we decided to use one of the most well-known statistical tools called *SPSS (originally, Statistical Package for the Social Sciences)*, since it provides all the capabilities that we need.

4.3 Categorization of the evaluation approach

Using the taxonomy presented in section 2.1, we categorize our evaluation methodology using the same criteria:

- Complexity evaluation;
- Evolution analysis;
- Best practices assessment;
- ITI modeling;
- ITI characterization;
- Data collection;
- Sample;
- Results validation.

The results of the categorization of our evaluation approach are in the first row of Table 4.1. For comparative reasons we decided to repeat the results of the evaluations performed in the chapter 2.

Table 4.1 — Categorization of our evaluation approach

Survey	Complexity evaluation	Evolution analysis	Best practices assessment	ITI modeling	ITI characterization	Data collection	Sample	Results validation
Our evaluation approach	○	⊙	●	●	●	●	●	⊙
[Juurakko, 2004]	—	⊙	—	—	○	—	●	⊙
[DiDio, 2004b, DiDio, 2004a]	—	⊙	—	—	○	○	○	⊙
[Cybersource, et al., 2004]	—	⊙	—	—	○	○	○	⊙
[Wang, et al., 2005]	●	●	●	—	○	○	●	⊙
[CIOview, 2005]	⊙	●	○	—	○	⊙	⊙	⊙
[Wipro, et al., 2007]	○	⊙	●	—	○	○	○	○
[Jutras, 2007]	—	○	—	—	○	—	○	⊙
[Troni, et al., 2007]	○	●	○	—	○	—	○	○

Legend: ● Strong ⊙ Moderate ○ Weak — None

In terms of complexity evaluation we classify our evaluation approach with **weak**, since we only evaluate complexity of a few components in our approach. From an evolution analysis, we classify our evaluation approach with **moderate**, since our approach cover the complete ITI lifecycle but does not the present individual contributions of each phase. According to best practices assessment these criteria, we classify our evaluation approach with **strong**, since we formally defined best practices.

According to ITI modeling, we classify our evaluation approach with **strong**, since our approach performed the assessment with a formalized metamodel. Regarding ITI characterization, we classify our evaluation approach with **strong**, since we use a formal description language with no ambiguity.

According to data collection, we classify our evaluation approach with **strong**, since our process to capture data is largely automated. We classify the sample of our evaluation approach with **strong**, since our evaluation approach allows the load of multiple ITIs throughout time in the same metamodel. Lastly we classify our evaluation approach regarding results validation with **moderate**, since we are able to identify threats to validity of our conclusions.

5

ITI Assessment

Contents

This chapter presents several perspectives for evaluating ITIs using the approach presented in chapter 4. There are several case studies to illustrate the different perspective of ITI evaluation.

5.1 Introduction

In this chapter we will perform ITI evaluations using a complexity perspective a sizing perspective (which can also be seen as part of complexity) and using best practices. The sizing perspective evaluation is based upon real data from an ITI with hundreds of *sites*. To demonstrate the complexity evaluation we will create five ITIs with different network topologies but with the same number of *servers* and *sites* to foster the comparability process. To perform the best practices analysis we will change the complexity case studies to simulate specific problems in ITIs and we will formalize some rules for best practices compliance verification with the OCL constraint language and show how the violations can be detected. We will also define a set of metrics for both sizing and complexity evaluations and we will demonstrate how they can be applied using our approach.

There are several metrics that will be presented in this chapter. It is important to mention that in the development of these metrics we tried to create them with the following characteristics [Wendy, et al., 1994, Wendy, et al., 1995]:

- **Simple** – definition and use of the metric is simple;
- **Objective** – different people will obtain identical values from the same entities being evaluated, allows for consistency and prevents individual bias;
- **Easily collected** – the cost and effort to obtain the metric is reasonable;
- **Robust** – the metric is insensitive to irrelevant changes; allows for useful comparison;
- **Valid** – the metric measures what it is supposed to; this promotes trustworthiness of the measure.

Also as important as the Wendy characteristics are the Abreu's criteria for the development of metrics [Abreu, et al., 1994]:

- metrics determination should be formally defined;
- non-size metrics should be system size independent;
- metrics should be dimensionless or expressed in some consistent unit system;
- metrics should be obtainable early in the life cycle;
- metrics should be down scaleable;
- metrics should be easily computable;
- metrics should be language independent.

5.2 Sizing analysis

To better demonstrate how a sizing or a quantitative analysis can be performed, we will use an ITI with hundreds of sites as the one provided in Fig. 5.1. The diagram is presented in a very small size to

guarantee the confidentiality of the data origin. With an ITI like this, the identification of the total number of servers, sites or subnets may take some time without an automated process. Using the data from Fig. 5.1 instantiated in the SDM metamodel we are able to do a sizing analysis and provide almost all details in terms of size.

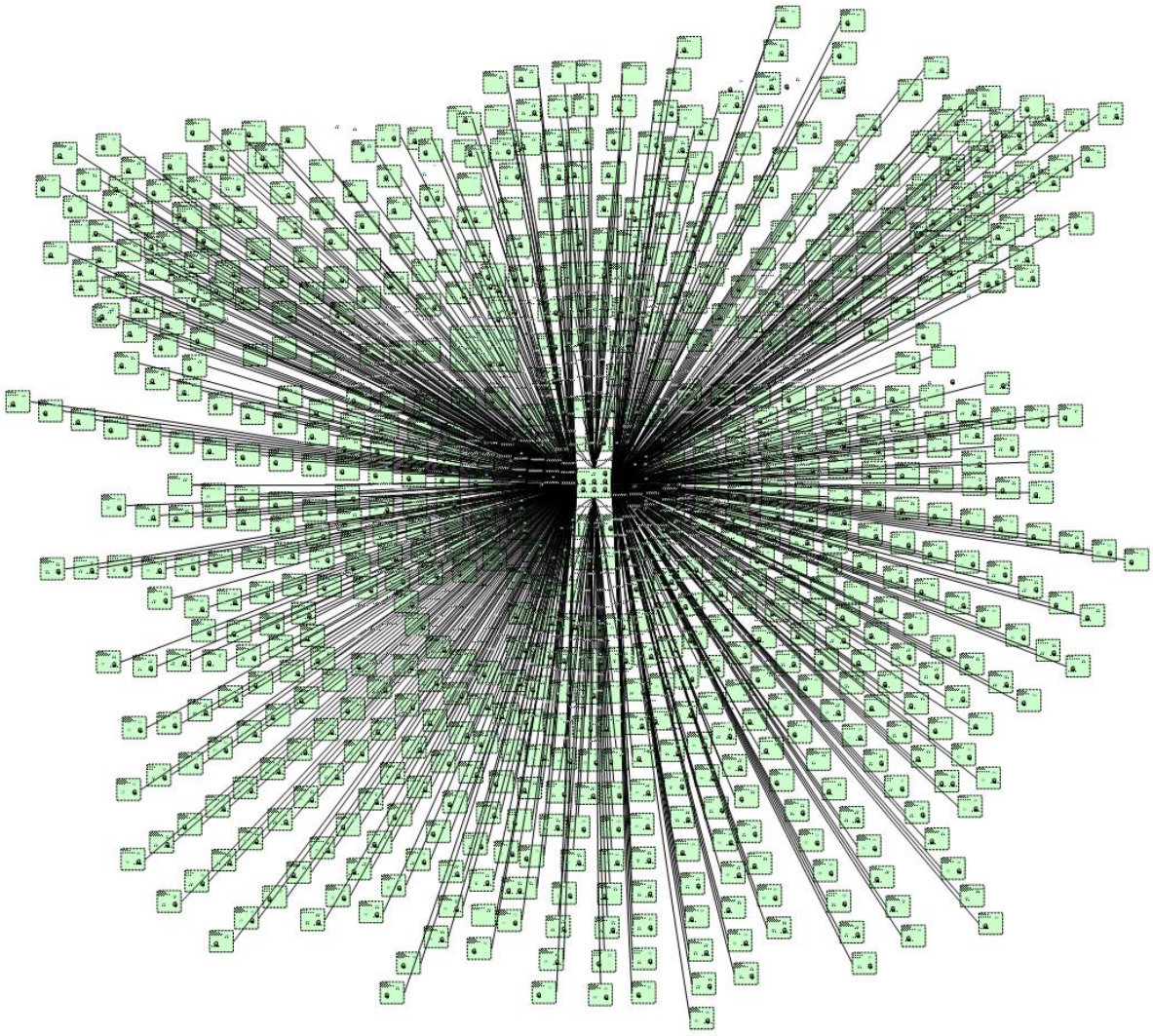


Fig. 5.1 — ITI with a large number of sites

Notice that the lines represent connections among *sites* and that each *site* has objects such as *servers* and *subnets* inside. The topology of this ITI is *centralized*, what means that every *site* is connected to a central *site*. Later in this chapter we will discuss the various ITI network topologies.

We already have the meta-instances store corresponding to the ITI in Fig. 5.1. This means that we already performed the steps 1 to 4 outlined in our evaluation approach. The next steps (step 5 and 6) are to load the SDM metamodel into *ITI evaluator* (*USE* tool) and then load the meta-instances corresponding to this ITI.

To load the *SDM Metamodel* we open the application *USE* tool and we press "*Control+o*" to open the window *Open Specification* to be able to select our "*SDM Metamodel.use"* as illustrated in Fig.

5.2. Notice in the left pane of use the *empty model,* meaning that no model is currently loaded in *USE.*

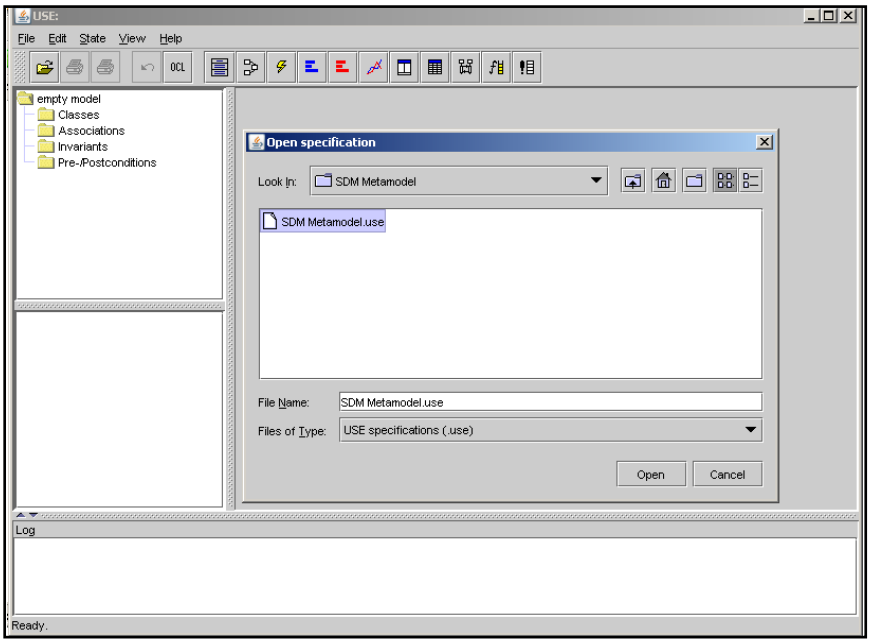


Fig. 5.2 — Open USE specification

This step will only be succeeded if our *SDM Metamodel.use* file has no errors. After loading the specification the *USE* automatically compiles the file and displays in the log pane the result of the compilation process and the number of classes, associations, invariants pre-/postconditions and operations as illustrated in Fig. 5.3. Notice that our *SDM Metamodel.use* contains 104 operations created in the context of this dissertation and corresponding to the ITILib presented earlier.

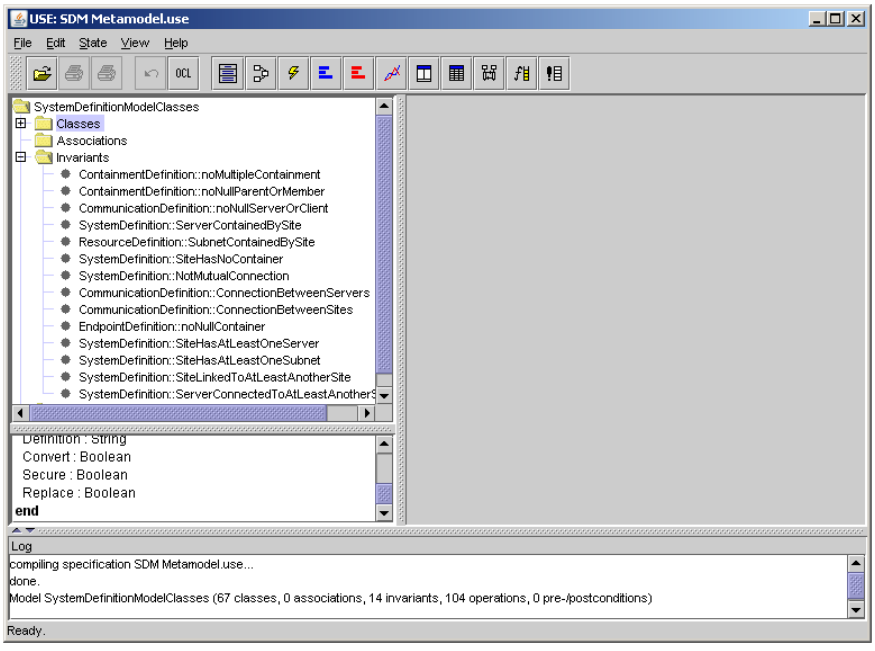


Fig. 5.3 — Load SDM metamodel into *USE*

With the five first steps of our evaluation approach already performed, the next step (step 6) consists in loading the meta-instances corresponding to the ITI of Fig. 5.1. Since we already have the meta-instances generated and stored in a file (with the name *ITI4SizingAnalysis.cmd*) we will use the command "readq FILE" in File input section of Fig. 5.4 to load the ITI data into *USE*.

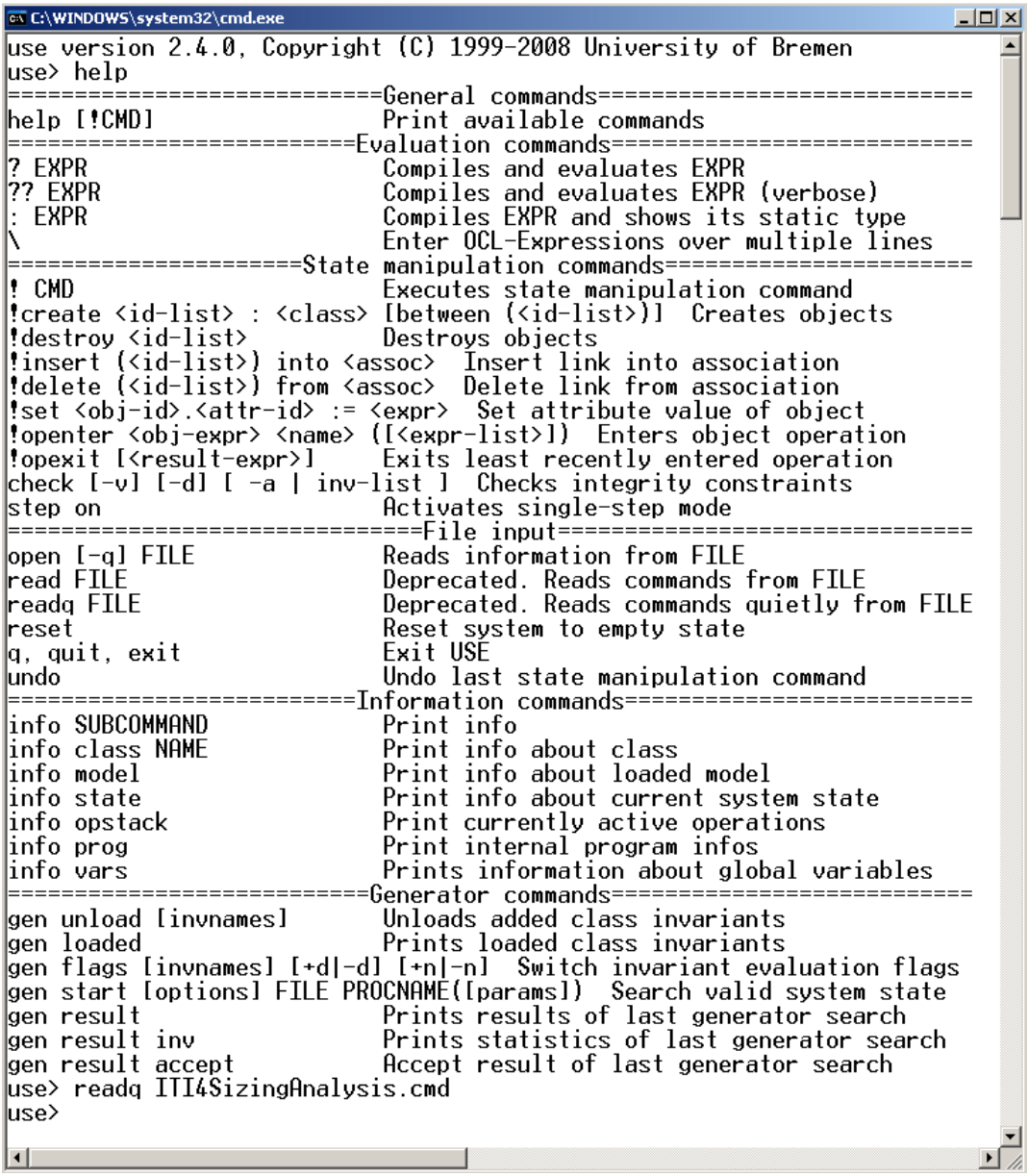


Fig. 5.4 — Command lines in *USE*

The *USE* tool provides a set of commands that can only be performed in a command line as illustrated by the output of help command in Fig. 5.4. The last command in Fig. 5.4 (*readq ITI4SizingAnalysis*) was successfully and finalizes the step 6 of our approach. With all ITI data loaded ITI stakeholders can perform queries and analyze results (step 7 to 9). Before demonstrating the use

"sizing queries", for understandability reasons we will first describe some of the sizing operations such as:

- **Total number of sites** – this metric was defined in ITILib as *TotalSites()* and returns the total number of *sites* in a particular ITI;
- **Total number of servers** – this metric was defined in ITILib as *TotalServers()* and returns the total number of *servers* in a particular ITI;
- **Total number of subnets** – this metric was defined in ITILib as *TotalSubnets()* and returns the total number of *subnets* in a particular ITI;
- **Total number of connections** – this metric was defined in ITILib as *TotalConnections()* and returns the total number of connections among servers or *nTDSconnections* in a particular ITI;
- **Total number of sitelinks** – this metric was defined in ITILib as *TotalSiteLinks()* and returns the total number of connections among sites or *sitelinks* in a particular ITI;
- **The average of servers by site** – this metric was defined as *AverageServersPerSite()* and returns a real number corresponding to the average of servers per site;
- **The average of subnets per site** – this metric was defined as *AverageServersPerSite()* and returns a real number corresponding to the average of subnets per site;
- **The average of connections per server** – this metric was defined as *AverageConnectionsPerServer()* and returns a real number corresponding to the average of *server* connections per server;
- **The maximum number of servers in a single site** – this metric was defined as *MaxServersPerSite()* and returns the maximum number of servers in a single site. This metric discovers which site has the highest number of servers and returns that maximum.

We created the class *ITIoperations()* to define all these counting or sizing metrics. Most of the operations that return the total number of objects were created with the prefix "*Total*" for understandability reasons. Fig. 5.5 has all these metrics that will be further detailed in ITILib in appendix B.

Sizing metrics defined in ITILib

```
1   model SystemDefinitionModelClasses
2   class ITIoperations
3     Sites(): Set(SystemDefinition) =
4               SystemDefinition.allInstances->select(IsSite())
5
6     Servers(): Set(SystemDefinition) =
7                 SystemDefinition.allInstances->select(IsServer())
8
9     Subnets(): Set(ResourceDefinition) =
10                ResourceDefinition.allInstances->select(IsSubnet())
11
12    Sitelinks(): Set(CommunicationDefinition) =
13                 CommunicationDefinition.allInstances->select(IsSiteLink())
14
15    Connections(): Set(CommunicationDefinition) =
16                     CommunicationDefinition.allInstances->select(IsNTDSConnection())
17
18
20     TotalSites(): Integer = Sites()->size
21     TotalServers(): Integer = Servers()->size
22     TotalSubnets(): Integer = Subnets()->size
23     TotalSitelinks(): Integer = Sitelinks()->size
24     TotalConnections(): Integer = Connections()->size
25
26
27     AverageServersPerSite(): Real =
28                                    TotalServers() / TotalSites()
29
30     AverageSubnetsPerSite(): Real =
31                                     TotalSubnets() / TotalSites()
32
33     AverageConnectionsPerServer(): Real =
34                                              TotalConnections() / TotalServers()
35
36
37    MaxServersPerSite(): Integer =
38                            Sites()->collect(SystemMembers()->size)->
39                            iterate(elem: Integer; acc: Integer = 0 | if elem > acc then
40                                                                        elem
41                                                                     else
42                                                                        acc
43                                                                     endif)
44  (...)
```

Fig. 5.5 — Sizing metrics defined in ITILib

Now that the sizing metrics are defined we can apply them to obtain sizing information regarding the ITI presented in Fig. 5.1. In order to do that we will continue using the command line provided by

the USE tool. The commands use to evaluate expressions in USE start with a question mark (?). Notice that the available commands in USE were presented in Fig. 5.6.

Performing queries in the USE tool

```
1   use> ! create op:ITIoperations
2   use> ? op.TotalSites()
3   -> 1167 : Integer
4   use> ? op.TotalServers()
5   -> 1205 : Integer
6   use> ? op.TotalSubnets()
7   -> 4264 : Integer
8   use> ? op.TotalConnections()
9   -> 1928 : Integer
10  use> ? op.TotalSitelinks()
11  -> 2184 : Integer
12  use>
13  use> ? op. AverageServersPerSite()
14  -> 1.,0325621251071122: Real
15  use>
16  use> ? op.AverageSubnetsPerSite()
17  -> 3.6538131962296486: Real
18  use>
19  use> ? op.AverageConnectionsPerServer()
20  -> 1.6 : Real
21  use>
22  use> ? op.MaxServersPerSite()
23  -> 7 : Integer
```

Fig. 5.6 — Queries to ITI using sizing ITILib operations

The output presented in Fig. 5.6 is the result of the application of each sizing metric in the ITI presented before. There are several variations to this sizing metrics in ITILib such as to provide the name of servers instead of the number or the name of the site with the maximum number of servers, instead the maximum number of servers in a site. These results complete the step 8 of our approach. The last step (step 9) regarding statistically analysis will be detailed in the following chapters.

5.3 Complexity analysis

The term complexity is very frequent in scientific literature and, depending on the field, it has different meanings what makes the term difficult to define. Complexity originated from the Latin word *complexus*, which means “embrace”, "entwined", or "twisted together". The Merriam-Webster dictionary, defines complexity as “the state or quality of having many interrelated parts or aspects.” [Merriam-Webster]. These expressions may be interpreted as two or more parts or aspects that are joined in such a way that is difficult to separate them.

It is easier to access complexity in relative terms than in absolute ones. Nevertheless we can say that a system is complex if it consists of several interacting elements [Herbert, 1996] what makes the behavior of the system difficult to understand from the behavior of its parts. [Edmonds, 1995] provides a review of different system complexities and parts of his conclusions were that there is no one appropriate measure of complexity, but at the very least we should distinguish concepts like size, order and variety from complexity.

In Computer Science there are a number of approaches to characterize complexity. As an example, IEEE standard 610 defines complexity as the degree to which a system or component has a design or implementation that is difficult to understand and verify [Anne, 1990]. To allow measuring the complexity of these systems we require complexity metrics. Different complexity measures have also been proposed for different contexts, such as computational, social, economic among others [Edmonds, 2000]. In the next sections we will describe five ITI network topologies (backbone, unidirectional ring, bidirectional ring, centralized and fully meshed) with the same number of servers and the same number of sites. The only difference among these topologies is the topology type and the respective number of connections. To understand if the type of the topology has impact on the level of complexity we will later apply different complexity measures to each of the topologies and analyze the results.

5.3.1 ITI network topologies

With the purpose of demonstrate the use of complexity metrics in ITIs using our evaluation approach and assess the impact of network topologies on complexity we have created the following stereotypical topologies for ITIs:

- Backbone;
- Unidirectional ring;
- Bidirectional ring;
- Centralized;
- Fully meshed.

We provide an overview and a diagram of each topology. To foster comparability, all network topologies have the same number of sites and servers.

5.3.1.1 Backbone

In this type of network topology all sites of the network are connected to a common transmission medium commonly referred as backbone or bus, which has exactly two endpoints. All data that is transmitted between sites in the network is transmitted over this common transmission medium.

In this network topology example there are six sites (*Lisbon, Madrid, Paris, Berlin, London, Dublin*) which are connected trough *sitelinks* (*Lisbon-Madrid, Madrid-Paris, Paris-Berlin, Berlin-London, London-Dublin*). Because the connections between sites are bidirectional the number of *sitelinks* are ten. The number of servers is also ten, since with the exception of site Lisbon that has fours servers and Madrid that has two, all other sites have just one server. This is required to illustrate some complexity metrics in section 5.3.2. In this topology the total number of connections between servers in different *sites* (represented in blue in Fig. 5.7) is ten and the total number of connections between servers (represented in blue and green in Fig. 5.7) are eighteen.

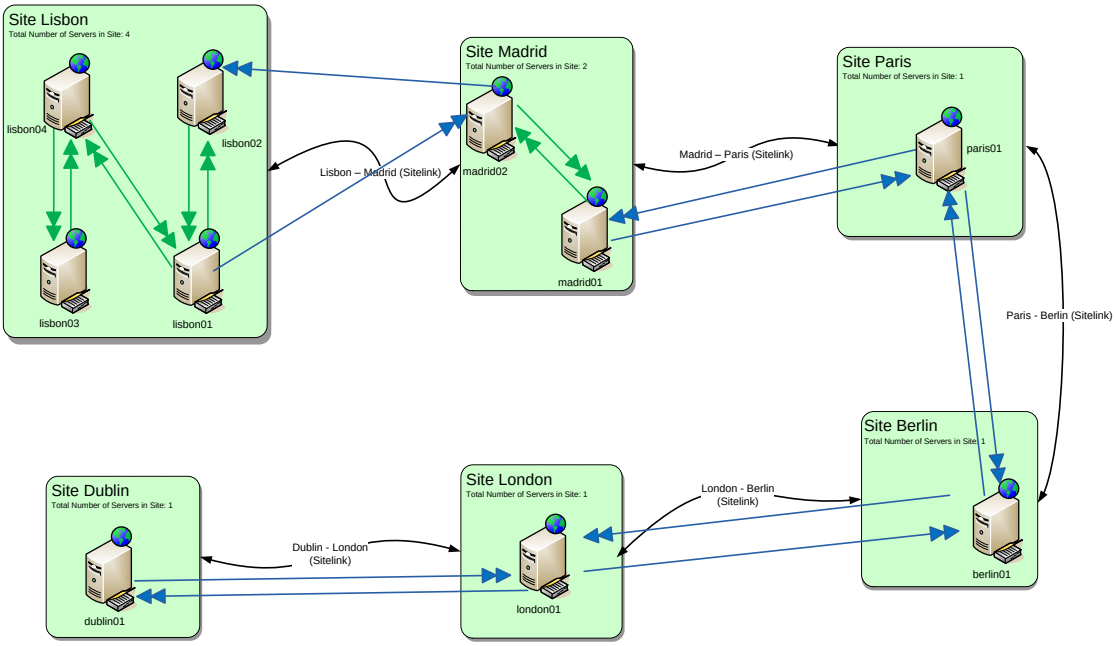


Fig. 5.7 — Backbone network topology

Notice that the Lisbon and Dublin sites are not directly connected and, as stated before, each represent an endpoint which means that, in a communication from Dublin to Lisbon data must travel across all the other sites to reach the destination.

5.3.1.2 Unidirectional ring

In this type of network topology, each site of the network is connected to another site forming a ring. All data that is transmitted between sites in the network, travels from one site to the next in a circular manner with the data flowing in a single direction only.

The main difference between this network topology (unidirectional ring) and the previous (backbone), is that sites Dublin and Lisbon are connected and instead of having two connections between each server, we have just one and in a single direction only. This means that data from site Dublin to Lisbon is sent directly and the opposite means that data must travel through all the other

sites to reach Dublin. In this topology type the number of *sitelinks* are twelve. The total number of connections between servers in different sites (represented in blue in Fig. 5.8), in this network topology is six and the total number of connections between servers (represented in blue and green in Fig. 5.8) are ten.

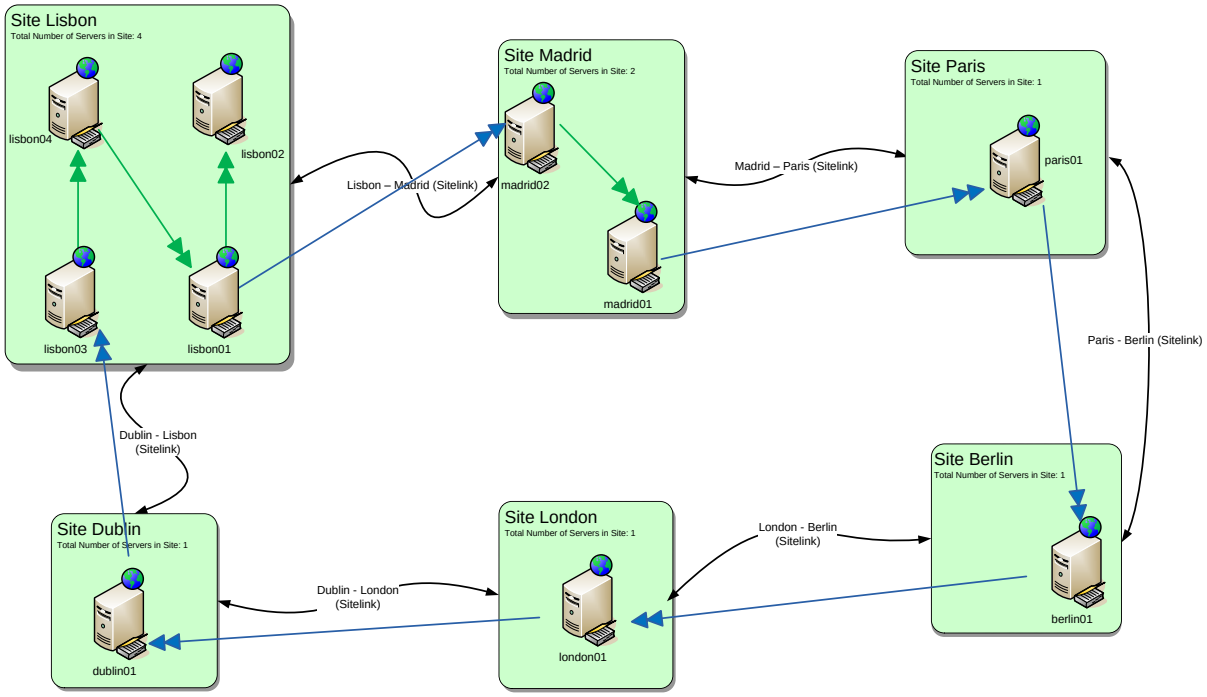


Fig. 5.8 — Unidirectional ring network topology

The number of servers and the number of sites are the same as the backbone topology, which are ten and six respectively.

5.3.1.3 Bidirectional ring

In this type of network topology all the sites are also connected, forming a ring. This network topology differs from the unidirectional ring because servers in adjacent sites are mutually connected and so data flows in both directions. The total number of connections among servers (represented in blue in Fig. 5.9) in different sites is twelve. The total number of connections among servers (represented in blue and green in Fig. 5.9) are twenty.

In this topology type the number of *sitelinks* is also twelve since they are bidirectional (*Lisbon-Madrid, Madrid-Paris, Paris-Berlin, Berlin-London, London-Dublin, Dublin-Lisbon*).

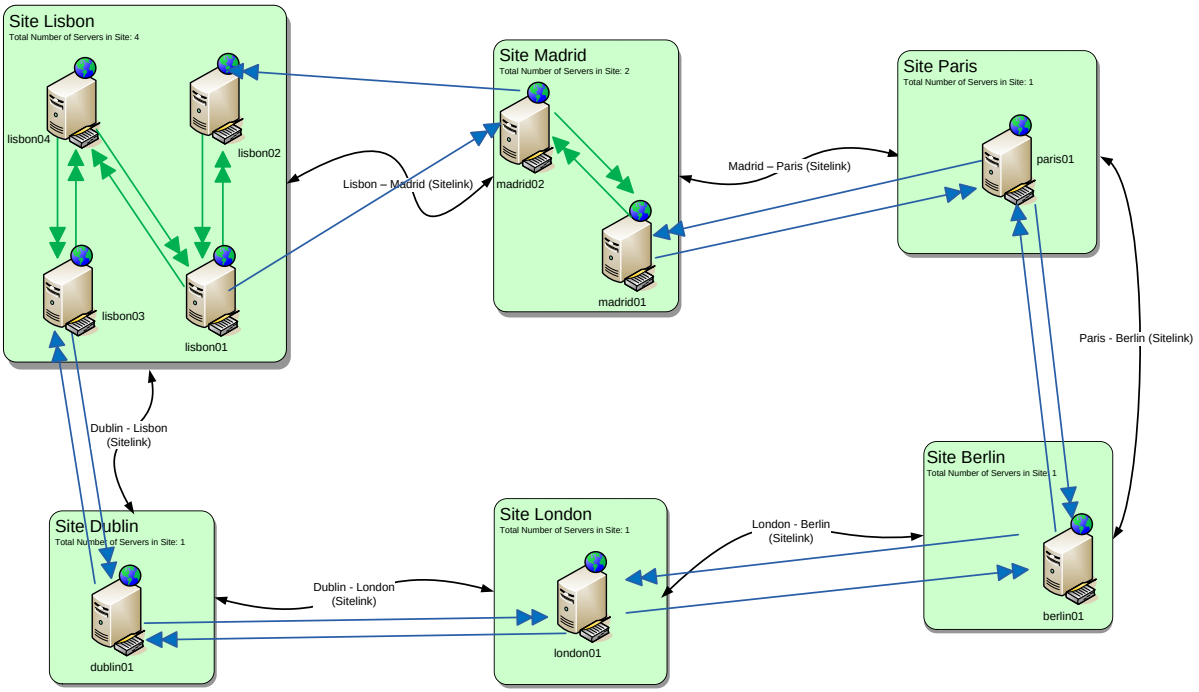


Fig. 5.9 — Bidirectional ring network topology

The number of servers and the number of sites are the same as the previous topologies, which are ten and six respectively.

5.3.1.4 Centralized

In this type of network topology each of the sites of the network is connected to a central site with a point-to-point link in a 'hub' and 'spoke' fashion, the central site being the 'hub' and the other sites that are attached to the central site being the 'spokes'. All data that is transmitted between sites in the network is transmitted to this central site.

The site Lisbon in the following example is the central site and is connected to all the others. The number of total connections between servers in different sites (represented in blue in Fig. 5.10) is ten. In the centralized topology the total number of connections among servers (represented in blue and green in Fig. 5.10) are eighteen.

The number of servers and the number of sites are the same as the previous topologies, which are ten and six respectively.

In the centralized topology type the number of *sitelinks* is ten since they are bidirectional and all to or from the site Lisbon (*Lisbon-Madrid, Lisbon-Paris, Lisbon-Berlin, Lisbon-London, Lisbon-Dublin*).

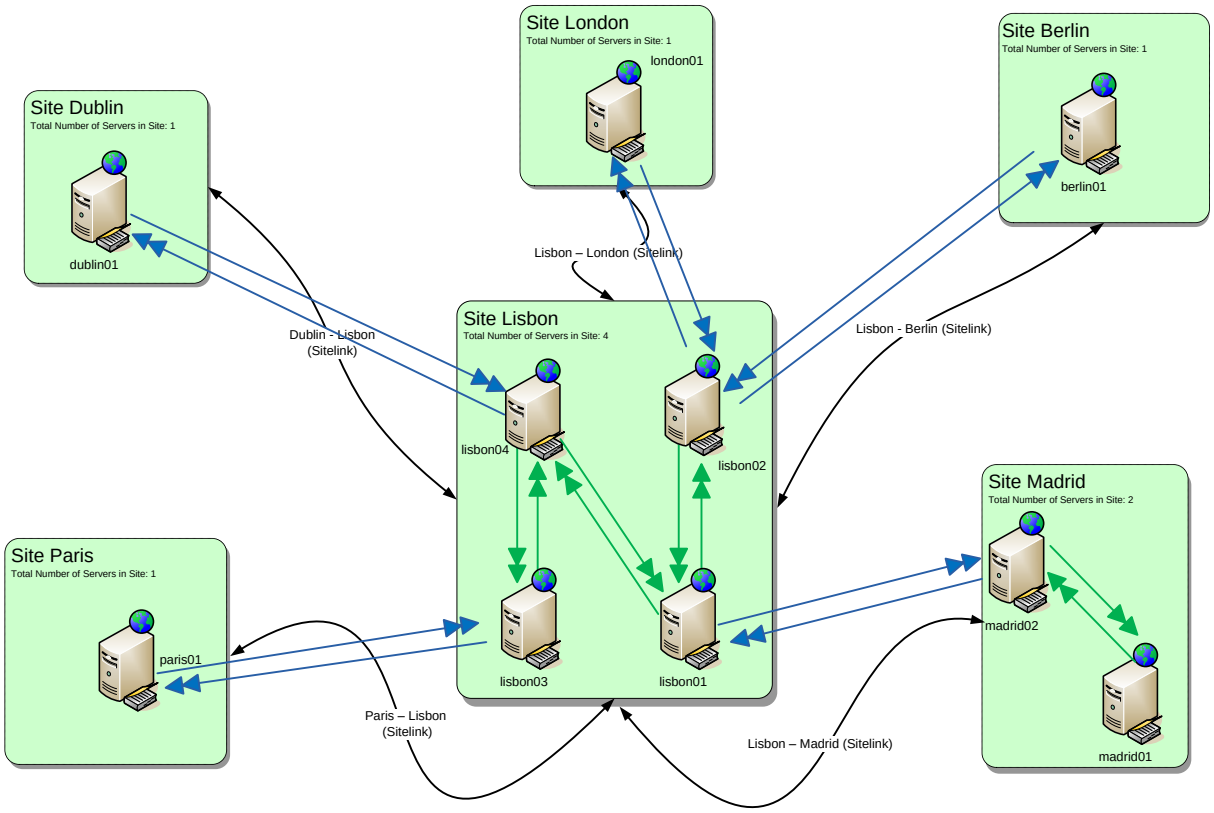


Fig. 5.10 — Centralized network topology

5.3.1.5 Fully meshed

In the full meshed network topology all servers in each site are connected to all the others, what makes a fully meshed network topology. The main difference of this network topology is that all sites and all servers are connected. The total number of connection among servers in different sites (represented in blue in Fig. 5.11) is thirty.

Since each site is connected to all the others the number of *sitelinks* in the fully meshed topology is thirty since they are bidirectional (*Lisbon-Madrid, Lisbon-Paris, Lisbon-Berlin, Lisbon-London, Lisbon-Dublin*, *Madrid-Paris, Madrid-Berlin, Madrid-London, Madrid-Dublin, Paris-Berlin, Paris-London, Paris-Dublin*, *Berlin-London, Berlin -Dublin*, *London -Dublin*).

The number of servers and the number of sites are the same as the previous topologies, which are ten and six respectively.

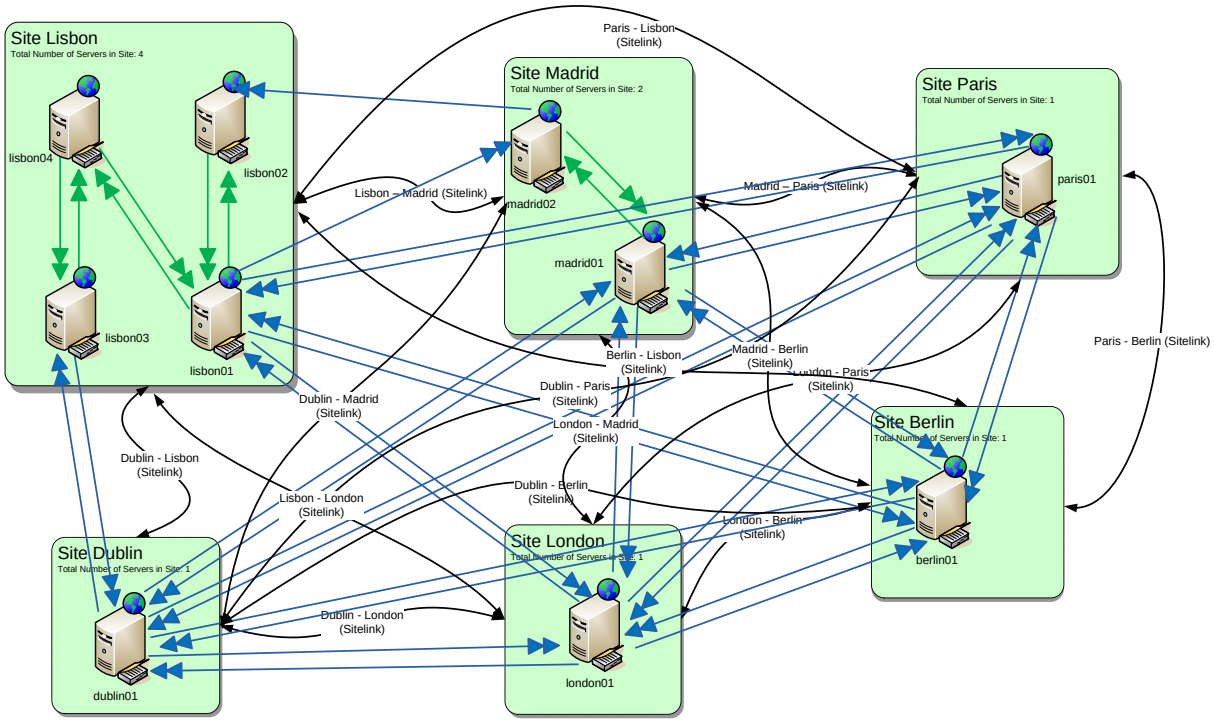


Fig. 5.11 — Fully meshed network topology

5.3.2 Complexity metrics

In this section we will use the prototypical topologies presented in section to evaluate the impact of the network topology on ITI complexity. To evaluate the ITI complexity based on network topology we decided to use three well-known metrics, which have been used in many other experiments: Coefficient of Network Complexity (CNC) [Pascoe, 1966], Cyclomatic Complexity Metric (CCM) [McCabe, 1976] and Henry and Kafura Metric (HKM) [Henry, et al., 1981]. To evaluate specific aspects of ITI, we also decided to create a few new complexity metrics based on some of the existing.

For each of the selected complexity metrics, we give a general overview, we present the original definition and how we have implemented in our SDM library and then we evaluate each of the network topologies presented in section 5.3.1 before summarizing the results.

5.3.2.1 Coefficient of network complexity

In the field of network analysis the Coefficient of Network Complexity referred in this thesis as CNC is a widely used metric for evaluating network complexity [Pascoe, 1966]. The CNC provides a rather simple metric for the complexity of a graph. It can easily be calculated as the number of arcs divided by the number of nodes. Its original definition is:

$$CNC = \frac{Number\ of\ arcs}{Number\ of\ nodes} \quad \textbf{(5.1)}$$

It was noted that two networks with equal number of arcs and nodes, but with different topologies (and therefore different levels of complexity) cannot be differentiated by simply using this metric [Elmaghraby, et al., 1980]. Despite that some variations of this metric were proposed [Davies, 1974, Kaimann, 1974, Kaimann, 1975], it is still often used in the literature in its original version [Vanhoucke, et al., 2008].

In the context of ITIs, the number of arcs is represented as the total number of *connections* or *sitelinks* and the number of nodes is represented as the total number of servers or sites, depending on if we are applying this metric to servers or sites. We defined both as follows:

$$CNC\_Servers = \frac{TotalConnections}{TotalServers} \quad \textbf{(5.2)}$$

$$CNC\_Sites = \frac{TotalSitelinks}{TotalSites} \quad \textbf{(5.3)}$$

We define the metric *CNC_Servers* (Coefficient of network complexity for servers) and the metric *CNC_Sites* (Coefficient of network complexity for sites) as follows using the M2DM approach upon the SDM metamodel:

Formal specification: Coefficient of network complexity metric

```
1   CNC_Servers(): Real =
2           TotalConnections() / TotalServers()
3
4   CNC_Sites(): Real =
5           TotalSitelinks() / TotalSites()
```

Fig. 5.12 — Coefficient of network complexity ITILib operations

To illustrate the use of coefficient of network complexity applied to the infrastructure, we applied these two operations to the network topologies defined in the previous section. Notice that all the defined network topologies have the same number of sites and servers.

Table 5.1 has the coefficient of network complexity for servers (*CNC_Servers*) and for sites (*CNC_Sites*).

Table 5.1 — Coefficient of network complexity for ITI

Network Topology	Total Sites	Total Servers	TotalSiteLinks	TotalConnections	CNC_Servers	CNC_Sites
Backbone	6	10	10	18	1,8	1,6
Unidirectional ring	6	10	12	10	1,0	2,0
Bidirectional ring	6	10	12	20	2,0	2,0
Centralized	6	10	10	18	1,8	1,6
Fully Meshed	6	10	30	40	4,0	5,0

According to the expectations the topology with higher complexity is fully meshed. From a servers perspective the less complex topology is unidirectional ring since it has the lower number of connections. Regarding sites the topology centralized and backbone both have the same level of complexity since both have the same number of *Sitelinks*.

5.3.2.2 Cyclomatic complexity

In Computer Science one of the first known applications of measuring graph complexity was proposed by Tom McCabe to evaluate the complexity of flowcharts (known as control flow charts) representing the implementation of software modules [McCabe, 1976]. His most well-known metric, the Cyclomatic Complexity Metric (CCM), which represents the number of linearly independent paths through source code and the original defined as follows:

$$CCM = number\ of\ arcs - number\ of\ nodes + number\ of\ entry\ or\ exit\ points \quad \textbf{(5.4)}$$

In the context of ITIs this metric may represent linearly independent paths (unidirectional connection channels) through the infrastructure. The number of arcs will be mapped to the total number of *connections* or the total number of *sitelinks*, the number of nodes will be the total number of *servers* or *sites* and the number of entry or exit points will be 2 assuming that there is at least one entry and one exit point. Notice that for cases where a site is isolated (no connections), the number of entry/exit points is zero. We defined three operations in ITIlib to calculate cyclomatic complexity. The cyclomatic complexity can be applied to all the servers of the infrastructure (CCM_Servers) to all the sites of the infrastructure (CCM_Sites) or to a specifc site in the infrastructure (CCM).

$$CCM\_Servers = TotalConnections - TotalServers + 2 \quad \textbf{(5.5)}$$

$$CCM\_Sites = TotalSitelinks - TotalSites + 2 \quad \textbf{(5.6)}$$

$$CCM = Intrasite\_Connections - SiteServers + Incoming + Outgoing \quad \textbf{(5.7)}$$

The formal definition of all these metrics are the following, again using the M2DM approach for definition:

Formal specification: Cyclomatic complexity metric

```
1   CCM_Servers(): Integer =
2               TotalConnections() - TotalServers() + 2
3
4   CCM_Sites(): Integer =
5               TotalSitelinks() - TotalSites() + 2
6
7   CCM(): Integer =
8       if (IsSite()) then
9           Intrasite_connections()->size - SiteServers()->size
10          + IncomingConnections()->size + OutgoingConnections()->size
11      else
12          0
13      Endif
```

Fig. 5.13 — Cyclomatic complexity ITILib operations

The *CCM()* operation can be used to calculate the complexity of a specific *site*. This operation rely on *Intrasite_connections()* to identify the number of *connections* among *servers* in that specific *site* (*number of arcs*), *SiteServers()* to identify the total number of *servers* in that specific *site* (*number of nodes*) and *IncomingConnections()* and *OutgoingConnections()* to identify the exact number of entry and exit point in that specific *site*.

To illustrate the use of *cyclomatic complexity* metrics applied to the infrastructure, we applied all these operations to the network topologies defined in section 5.3.1. Notice that all the defined network topologies have the same number of sites and servers. Table 5.2 presents the results of the application of the cyclomatic complexity metrics to servers (CCM_Servers) and to sites (CCM_Sites).

Table 5.2 — Cyclomatic complexity for ITI

Network Topology	Total Sites	Total Servers	TotalSiteLinks	TotalConnections	CCM_Servers	CCM_Sites
Backbone	6	10	10	18	10	6
Unidirectional ring	6	10	12	10	2	8
Bidirectional ring	6	10	12	20	12	8
Centralized	6	10	10	18	10	6
Fully Meshed	6	10	30	40	32	26

According to these results we can confirm that the fully meshed topology presents the most higher level of complexity. Regarding servers the unidirectional ring appears to be the less complex and regarding sites the centralized topology and backbone have the lower values of complexity.

To illustrate also the application of the *CCM()* to a specific *site* all the network topologies defined in section 5.3.1 have the same *site* names but different configurations in terms of the number of *servers* and incoming and outgoing *connections.* The Table 5.3 summarizes the count of *intrasite_connections()*, *IncomingConnections()*, *OutgoingConnections()* represented as columns ***IntC***, ***IC*** and ***OC*** respectively. These values are required to calculate the cyclomatic complexity metric for each of the sites and for all the topologies. All these values are based upon the topologies of 5.3.1. The last column **siteservers** represent the total number of servers in each site.

Table 5.3 — Required values for cyclomatic complexity calculation

Topology	Backbone			Unidirectional			Bidirectional			Centralized			Fully Meshed			
Sites	**IntC**	**IC**	**OC**	**IntC**	**IC**	**OC**	**IntC**	**IC**	**OC**	**IntC**	**IC**	**OC**	**IntC**	**IC**	**OC**	**SiteServers**
Site Lisbon	6	1	1	3	2	2	6	2	2	6	5	5	6	5	5	4
Site Madrid	2	2	2	1	2	2	2	2	2	2	1	1	2	5	5	2
Site Paris	0	2	2	0	2	2	0	2	2	0	1	1	0	5	5	1
Site Berlin	0	2	2	0	2	2	0	2	2	0	1	1	0	5	5	1
Site London	0	2	2	0	2	2	0	2	2	0	1	1	0	5	5	1
Site Dublin	0	1	1	0	2	2	0	2	2	0	1	1	0	5	5	1

Table 5.4 used the auxiliary values from Table 5.3 to apply the equation (5.7) to calculate the cyclomatic complexy for each site using the five different network topologies.

Table 5.4 — Cyclomatic complexity for all network topologies

Topology	Backbone	Unidirectional	Bidirectional	Centralized	Fully Meshed
Site Lisbon	4	1	6	12	12
Site Madrid	4	1	4	2	12
Site Paris	3	1	3	1	11
Site Berlin	3	1	3	1	9
Site London	3	1	3	1	9
Site Dublin	1	1	3	1	9

According to the results of Table 5.4 we can conclude that the sites (Lisbon, Madrid and Paris) are the sites with higher complexity and that sites (Berlin, London and Dublin) are the sites with lower level of complexity.

5.3.2.3 Henry and Kafura metric

The well-known Henry and Kafura Metric (HKM) [Henry, et al., 1981] has been used to evaluate the complexity of components (nodes) of the so-called "call graph" representing the calls among all software components (procedures or functions, at the time of the proposal) in the considered system. Its value, for each component, is defined as:

$$HKM = size \times (FanIn \times FanOut)^2 \quad \textbf{(5.8)}$$

Several ways have been proposed in the literature for calculating the *FanIn* of a component (e.g. total number of received calls, total number of input parameters or the number of global data structures read) as well as for the *FanOut* (e.g. number of sent calls, total number of output parameters or the number of global data structures modified). Also, the measure for size can be chosen among several alternatives such as lines of code, function points or the CCM of the component. Henry and Kafura validated their metric using the UNIX system and suggested that it allowed to identify potentially faulty components, since they found that higher values of HKM were often obtained for components where an higher number of problems had been reported. We also expect that ITI's nodes with higher values of HKM will be more problematic.

In the domain of infrastructures, we also have applied HKM, based on CCM size. The complexity metric is defined as:

$$HKM = CCM \times (IncomingConnections \times OutgoingConnections)^2 \quad \textbf{(5.9)}$$

The *FanIn* is represented as *IncomingConnections()* operations and *FanOut* is represented as *OutgoingConnections()* operation. The formal definition of the HKM metric in OCL upon the SDM metamodel is then the following:

Formal specification: Henry and Kafura complexity metric

```
1   HKM(): Integer =
2       if (IsSite()) then
3           CCM() * ((IncomingConnections()->size * OutgoingConnections()->size)
4           * (IncomingConnections()->size * OutgoingConnections()->size))
5       else
6           0
7       endif
```

Fig. 5.14 — Henry and Kafura complexity ITILib operation

The following tables (to) illustrate the application of HKM() defined in Fig. 5.14, to all network topologies of section 5.3.1 and uses the results of *CCM(), Incoming_Connections* and *Outgoing_Connections()* operations calculated earlier as input.

Table 5.5 present the *CCM()* results calculated earlier and required in this metric and summarizes the count of *IncomingConnections()*, *OutgoingConnections()* represented in Table 5.5 as columns ***IC*** and ***OC*** respectively. These values represent the required input to calculate the HKM for each of the sites and for all the topologies. All these values are based upon the topologies of 5.3.1.

Table 5.5 — Required values for HKM calculation

Topology	Backbone			Unidirectional			Bidirectional			Centralized			Fully Meshed		
Sites	**CCM**	**IC**	**OC**	**CCM**	**IC**	**OC**	**CCM**	**IC**	**OC**	**CCM**	**IC**	**OC**	**CCM**	**IC**	**OC**
Site Lisbon	4	1	1	1	2	2	6	2	2	12	5	5	12	5	5
Site Madrid	4	2	2	1	2	2	4	2	2	2	1	1	12	5	5
Site Paris	3	2	2	1	2	2	3	2	2	1	1	1	11	5	5
Site Berlin	3	2	2	1	2	2	3	2	2	1	1	1	9	5	5
Site London	3	2	2	1	2	2	3	2	2	1	1	1	9	5	5
Site Dublin	1	1	1	1	2	2	3	2	2	1	1	1	9	5	5

Table 5.6 — HKM for all network topologies

Topology	Backbone	Unidirectional	Bidirectional	Centralized	Fully Meshed
Site Lisbon	4	16	96	7500	7500
Site Madrid	64	16	64	2	7500
Site Paris	48	16	48	1	6875
Site Berlin	48	16	48	1	5625
Site London	48	16	48	1	5625
Site Dublin	1	16	48	1	5625

According to the results of Table 5.6 the site Lisbon appear to be the most complex in all the topologies with exception of Backbone topology. The reason for this is due to the fact that, there is only one incoming and only one outgoing connection since the site Lisbon represents an endpoint. The same is applicable to the site Dublin.

5.3.2.4 Infrastructure topology factor

The infrastructure topology factor (ITF) is a new metric created in the context of this dissertation with the purpose of evaluating the ITIs complexity based on topology. This metric is suited for infrastructures of any size and evaluates the ITIs topology based on centrality. This means that an

infrastructure where one site is connected to all the others, has an ITF of 100%. Part of this metric consists in an adaptation of the Henry and Kafura metric defined in section 5.3.2.3. This complexity metric is defined as:

$$ITF\_Sites = \frac{\frac{Max(FanIn + FanOut)}{2}}{TotalSites - 1} \quad \textbf{(5.10)}$$

This complexity metric search for the ITI site with the maximum number of c*onnections*. In this context the maximum number of *connections* is the sum of all incoming connections (*FanIn*) with all outgoing connections (*FanOut*) among *sites*.

The numerator represents the average connectivity of the most connected *site* in the ITI, while the denominator represents the total number of *sites* in the infrastructure. The same rationale can be applied to servers. The complexity metric is defined as:

$$ITF\_Servers = \frac{\frac{Max(FanIn + FanOut)}{2}}{TotalServers - 1} \quad \textbf{(5.11)}$$

This complexity metric search for the ITI server with the maximum number of c*onnections*. In this context the maximum number of *connections* is the sum of all incoming connections (*FanIn*) with all outgoing connections (*FanOut*) among *servers*. The *FanIn()* and *FanOut()* can be used to identify the most connected *server* or *site*.

The numerator represents the average connectivity of the most connected *server* in the ITI, while the denominator represents the total number of *servers* in the infrastructure. Their formal definitions for each of the metrics are the following:

Formal specification: Infrastructure topology factor complexity metric

```
1   ITF_Sites(): Real =
2     if (TotalSites()=1) then
3       0.0
4     else
5       Sites()->collect(FanIn() + FanOut())->iterate(elem: Integer; acc: Integer = 0 |
6       if elem > acc then
7         elem
8       else
9         acc
10      endif) / 2  / (TotalSites() - 1)
11    endif
12
13  ITF_Servers(): Real =
14    if (TotalSites()=1) then
15      0.0
16    else
17      Servers()->collect(FanIn() + FanOut())->      iterate(elem: Integer; acc: Integer = 0 |
18        if elem > acc then
19          elem
20        else
21          acc
22        endif) / 2  / (TotalServers() - 1)
23    endif
```

Fig. 5.15 — Infrastructure topology ITILib operations

To illustrate the application of the infrastructure topology metric to servers and sites, we created Table 5.7 and

Table 5.8 with the number of incoming connections (*FanIn*) and outgoing connections (*FanOut*) relatively to each site and each server in the ITI. Notice that we have calculated this for all network topologies.

Table 5.7 — *FanIn* and *FanOut* for each site using all network topologies

Topology	Backbone		Unidirectional		Bidirectional		Centralized		Fully Meshed	
Sites	**FanIn**	**FanOut**	**FanIn**	**FanOut**	**FanIn**	**FanOut**	**FanIn**	**FanOut**	**FanIn**	**FanOut**
Site Lisbon	1	1	**2**	**2**	**2**	**2**	**5**	**5**	**5**	**5**
Site Madrid	**2**	**2**	**2**	**2**	**2**	**2**	1	1	**5**	**5**
Site Paris	**2**	**2**	**2**	**2**	**2**	**2**	1	1	**5**	**5**
Site Berlin	**2**	**2**	**2**	**2**	**2**	**2**	1	1	**5**	**5**
Site London	**2**	**2**	**2**	**2**	**2**	**2**	1	1	**5**	**5**
Site Dublin	1	1	**2**	**2**	**2**	**2**	1	1	**5**	**5**

Table 5.8 — *FanIn* and *FanOut* for each server using all network topologies

	Backbone		Unidirectional		Bidirectional		Centralized		Fully Meshed	
Servers	**FanIn**	**FanOut**	**FanIn**	**FanOut**	**FanIn**	**FanOut**	**FanIn**	**FanOut**	**FanIn**	**FanOut**
lisbon01	**3**	**3**	**1**	**2**	**3**	**3**	**3**	**3**	**6**	**6**
lisbon02	1	1	1	0	1	1	**3**	**3**	1	1
lisbon03	1	1	1	1	2	2	2	2	2	2
lisbon04	2	2	1	1	2	2	**3**	**3**	2	2
madrid01	2	2	1	1	2	2	1	1	**6**	**6**
madrid02	2	2	1	1	2	2	2	2	2	2
paris01	2	2	1	1	2	2	1	1	**6**	**6**
berlin01	2	2	1	1	2	2	1	1	5	5
london01	2	2	1	1	2	2	1	1	5	5
dublin01	1	1	1	1	2	2	1	1	5	5

For both (*sites* and *servers*) we highlighted the maximum numbers of *FanIn* and *FanOut* for each network topology that will be used in the ITF calculations. Table 5.9 has the result of infrastructure complexity for servers and sites. Please remember that the total number of servers is ten and the total number of sites is six for all network topologies.

Table 5.9 — Infrastructure topology factor complexity

Network Topology	ITF_Servers	ITF_Sites
Backbone	33%	40%
Unidirectional ring	16%	40%
Bidirectional ring	33%	40%
Centralized	33%	100%
Fully Meshed	66%	100%

According to the results of Table 5.9 from a site perspective the network topology with higher complexity is Fully Meshed and centralized network topology. The results are similar for servers, however the unidirectional ring is the less complex.

5.3.2.5 Site topology factor

The site topology factor (STF), is a new metric created in the context of this dissertation, similar to ITF presented above, with the purpose of evaluating a site complexity based on topology. This metric is suited for sites of any size and evaluates site topology based on centrality.

Contrary to the ITF which measures infrastructure complexity, the STF only measures the complexity of a specified site and the definition is as follows:

$$STF = \frac{\frac{Intraserver\_FanIn + Intraserver\_FanOut}{2}}{SiteServers - 1} \quad \textbf{(5.12)}$$

This metric relies on *Intraserver_FanIn()* and *Intraserver_FanOut()* operations which are very similar to *FanIn()* and *FanOut()* of ITF and they consist also in an adaptation of the Henry and Kafura metric defined in section 5.3.2.3.

In the context of a site, *Intraserver_FanIn* represents the number of incoming connections for a specific *site* where *Intraserver_FanOut* represents the number of outgoing connections for a specific *site*. *SiteServers* corresponds to the total number of *servers* in a specific *site*. To be able to measure the *STF* for any given site, we formally define this complexity metrics as follows, using the M2DM approach:

Formal specification: Site Topology Factor complexity metric

```
1   STF(): Real =
2       if (IsSite()) then
3         if (SiteServers()->size = 1) then
4           0.0
5         else
6           SiteServers()->collect(Intraserver_FanIn() + Intraserver_FanOut())
7       ->iterate(elem: Integer; acc: Integer = 0 | if elem > acc then elem else acc endif) / 2
8       / (SiteServers()->size - 1)
9         endif
10      else
11          0.0
12      endif
```

Fig. 5.16 —Site topology ITILib operations

We defined that this metric can only be applied to *sites* with more than one *servers*. According to our case studies of section 5.3.1 this complexity metric can only be applied to *Site_Lisbon* and *Site_Madrid* since all the other have only one *server*.

To simplify the application of site topology factor complexity metric to *Site_Lisbon* and *Site_Madrid* we created the Table 5.10 with *Intraserver_FanIn()* (*IFI*) and *Intraserver_FanOut()* (*IFO*) for each network topology.

Table 5.10 — *Intraserver_FanIn* and *Intraserver_FanOut* for each site using all network topologies

Topology	Backbone		Unidirectional		Bidirectional		Centralized		Fully Meshed		Total
Sites	IFI	IFO	IFI	IFO	IFI	IFO	IFI	IFO	IFI	IFO	Servers
Site Lisbon	**2**	**2**	**1**	**1**	**2**	**2**	**2**	**2**	**2**	**2**	**4**
Site Madrid	**1**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**2**
Site Paris	0	0	0	0	0	0	0	0	0	0	1
Site Berlin	0	0	0	0	0	0	0	0	0	0	1
Site London	0	0	0	0	0	0	0	0	0	0	1
Site Dublin	0	0	0	0	0	0	0	0	0	0	1

Table 5.11 has the presents the site topology complexity values for both sites for all network topologies. Notice that this metric only makes sense for sites with more than one server such as the *Lisbon* and *Madrid* sites.

Table 5.11 — Site topology factor for each site using all network topologies

Topology	Backbone	Unidirectional	Bidirectional	Centralized	Fully Meshed
Site Lisbon	**60%**	**30%**	**60%**	**50%**	**60%**
Site Madrid	**100%**	**50%**	**100%**	**100%**	**100%**
Site Paris	0	0	0	0	0
Site Berlin	0	0	0	0	0
Site London	0	0	0	0	0
Site Dublin	0	0	0	0	0

Taking as an example the Lisbon *site* from the case study in section 5.3.1, we can observe that it has a connection from *server madrid01* and it has *connection* to *madrid01*, what makes *Intraserver_FanIn()* and *Intraserver_FanOut()* equal to 2. So the application of *STF* will indicate that the complexity is 1.

5.3.2.6 Infrastructure meshing factor

The infrastructure meshing factor (IMF) is a new metric created in the context of this dissertation, with the purpose of evaluating a infrastructure complexity based in its connectivity. This metric is suited for infrastructures of any size and is defined as:

$$IMF = \frac{Actual\ ITI\ Connections}{Maximum\ ITI\ Connections} \quad \textbf{(5.13)}$$

This complexity metric can then be generalized and be applied to servers and sites. The application of this complexity to *servers* relies on the *TotalConnections* which represents the number of connections among servers and *TotalServers* which represent the total number of servers in the infrastructure.

$$IMF\_Servers = \frac{TotalConnections}{TotalServers^2 - TotalServers} \quad \textbf{(5.14)}$$

In a infrastructure with two servers (one in each site) where both are connected to each other, the infrastructure meshing factor corresponds to 100% because the infrastructure is completely connected. If just one server is connected, the infrastructure meshing factor is 50%.

A similar rationale can be applied to sites instead of servers. The resulting definition would then be:

$$IMF\_Sites = \frac{TotalSitelinks}{TotalSites^2 - TotalSites} \quad \textbf{(5.15)}$$

Notice that both complexity metrics can only be applied in infrastructures with more than one server and one site. We formally define these complexity metrics using the M2DM approach as follows:

Formal specification: Infrastructure meshing factor complexity metric

```
1   IMF_Servers(): Real =
2           if (TotalServers()=1) then
3              0.0
4           else
5            TotalConnections() / ( TotalServers() * TotalServers() - TotalServers() )
6           endif
7
8   IMF_Sites(): Real =
9           if (TotalSites()=1) then
10             0.0
11          else
12             TotalSitelinks() / ( TotalSites() * TotalSites() - TotalSites() )
13          endif
```

Fig. 5.17 — Infrastructure meshing ITILib operations

Table 5.12 — Infrastructure meshing factor for different network topologies

Network Topology	Total Sites	Total Servers	TotalSiteLinks	TotalConnections	IMF_Servers	IMF_Sites
Backbone	6	10	10	18	20%	33%
Unidirectional ring	6	10	12	10	10%	40%
Bidirectional ring	6	10	12	20	20%	40%
Centralized	6	10	10	18	20%	33%
Fully Meshed	6	10	30	40	44%	100%

According to this metric and from a site perspective the most complex topologies are fully meshed followed by unidirectional and bidirectional ring. From a server perspective the result is similar.

5.3.2.7 Site meshing factor

The site meshing factor (IMF), is a new metric created in the context of this dissertation, with the purpose of evaluating sites complexity based in its connectivity.

$$SMF = \frac{Actual\ Intrasite\ Connections}{Maximum\ Intrasite\ Connections} \quad \textbf{(5.16)}$$

The connections among *servers* are unidirectional and can connect *servers* in the same *site* or in different *sites*. This metric is suited for sites of any size and is defined as:

$$SMF = \frac{Intrasite\_connections}{SiteServers^2 - SiteServers} \quad \textbf{(5.17)}$$

This metric relies on the operation *Intrasite_connections*, which represents the total number of connections from servers within the same site and in the operation *SiteServers*, which represents the number of servers in a specific site. For example, in a site with three servers and each server is connected to the other two, the site meshing factor corresponds to 100%. If no connections exist between servers the site meshing factor will be 0%. We have defined the *SMF* metric to be applied to sites as follows.

Formal specification: Site Meshing Factor complexity metric

```
1   SMF(): Real =
2     if (IsSite()) then
3       if (SiteServers()->size = 1) then
4         0.0
5       else
6         Intrasite_connections()->size/( SiteServers()->size * SiteServers()->size - SiteServers()->size )
7       endif
8     else
9       oclUndefined(SystemDefinition)
10  endif
```

Fig. 5.18 — Site meshing ITILib operation

Taking as example the site Madrid from the case study in section 5.3.1 we can observe that it has two servers (madrid01 and madrid02) that are fully connected. The application of the operation *Intrasite_connections* in this site results in the value two (one connection from madrid01 to madrid02 and other connection from madrid02 to madrid01). The value for *SiteServers* is also two

because the total number of servers in the Madrid site is two. So the application of the SMF will indicate that the complexity is 100%. According to the formal definition this formula will not be applied for sites with just one server. Only sites *Lisbon* and *Madrid* have values since all the others have just one server.

Table 5.13 — *Intrasite_connections* for each site using all network topologies

Topology	Backbone	Unidirectional	Bidirectional	Centralized	Fully Meshed	Site Servers
Site Lisbon	**6**	**3**	**6**	**6**	**6**	**4**
Site Madrid	**2**	**1**	**2**	**2**	**2**	**2**
Site Paris	0	0	0	0	0	1
Site Berlin	0	0	0	0	0	1
Site London	0	0	0	0	0	1
Site Dublin	0	0	0	0	0	1

Table 5.14 presents the site meshing factor complexity values for both sites for all network topologies. Notice that this metric only makes sense for sites with more than one server such as the *Lisbon* and *Madrid* sites.

Table 5.14 — Site meshing factor for each site using all network topologies

Topology	Backbone	Unidirectional	Bidirectional	Centralized	Fully Meshed
Site Lisbon	**0,50%**	**25%**	**50%**	**50%**	**50%**
Site Madrid	**100%**	**50%**	**100%**	**100%**	**100%**
Site Paris	0	0	0	0	0
Site Berlin	0	0	0	0	0
Site London	0	0	0	0	0
Site Dublin	0	0	0	0	0

Apparently the site Lisbon appears to be the most complex since it has higher number of servers. However because Site Madrid has two servers and are fully connected (each server in Madrid is connected to all the others servers in Madrid) the level of complexity is higher than in site Lisbon that only half of the servers are connected. Taking as an example the server *lisbon03* is only connected to server *lisbon04* in the site Lisbon.

5.4 Best practices analysis

There are several benefits that can derive from the application of best practices to ITIs. Their adoption implies process improvements, what normally leads to an increase on productivity, while reducing ITI costs [MSFT, 2007]. The value of an ITI is seen by [Gillen, Perry, Dowling, et al., 2007] as an equation encompassing IT labor cost, service levels and business agility where the adoption rate

of best practices determines the maturity level of ITIs. The number and type of best practices that can be applied to ITIs may differ from organization to organization and from technology to technology. In the following chapters we show how best practices can be applied to the SDM metamodel and how we can detect violations of best practices.

5.4.1 Best practices description

To express best practices for ITIs we extended the SDM metamodel by adding constraints. In this section the best practices are first given in natural language and will later be expressed more formally in OCL. We have defined the following best practices for ITIs:

- **A site in an ITI have at least one server** – Sometimes, due to reorganizations, consolidation, virtualization or other efforts, sites may become empty of servers, what represents a waste of resources and makes the infrastructure larger and probably more complex without any reason. In an organization with just a few sites, empty sites may be easier to detect and delete. However, in organizations with hundreds of sites and servers this situation is often undetected. Fig. 5.19 shows an example of an ITI where the Paris site do not have servers, probably due to a consolidation.

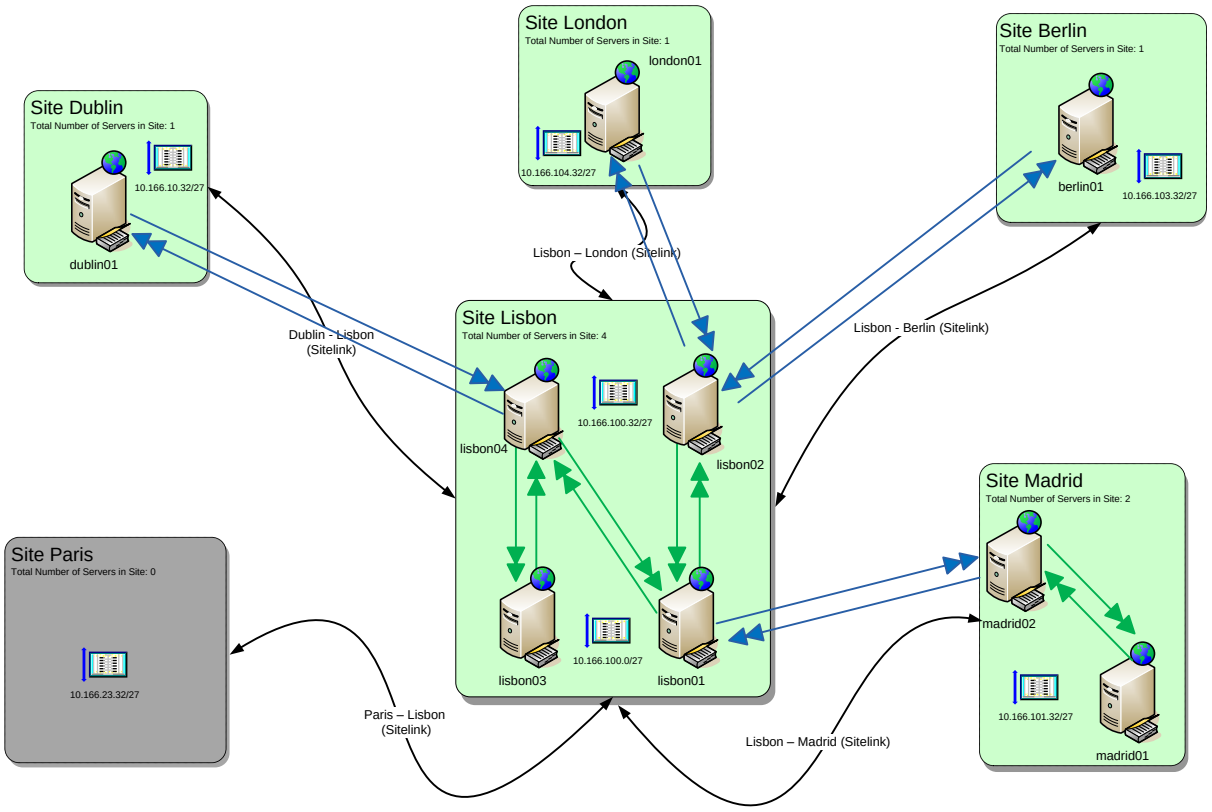


Fig. 5.19 — ITI site without servers

- **A site in an ITI should have at least one subnet defined** – Since servers rely on IP addresses and subnets to work and communicate, having sites without subnets defined represents probably a mistake in the configuration, leading to other problems such as replication failures, authentication failures, communication problems, among others. Fig. 5.20 shows the example of Paris site with one server but without any subnets defined.

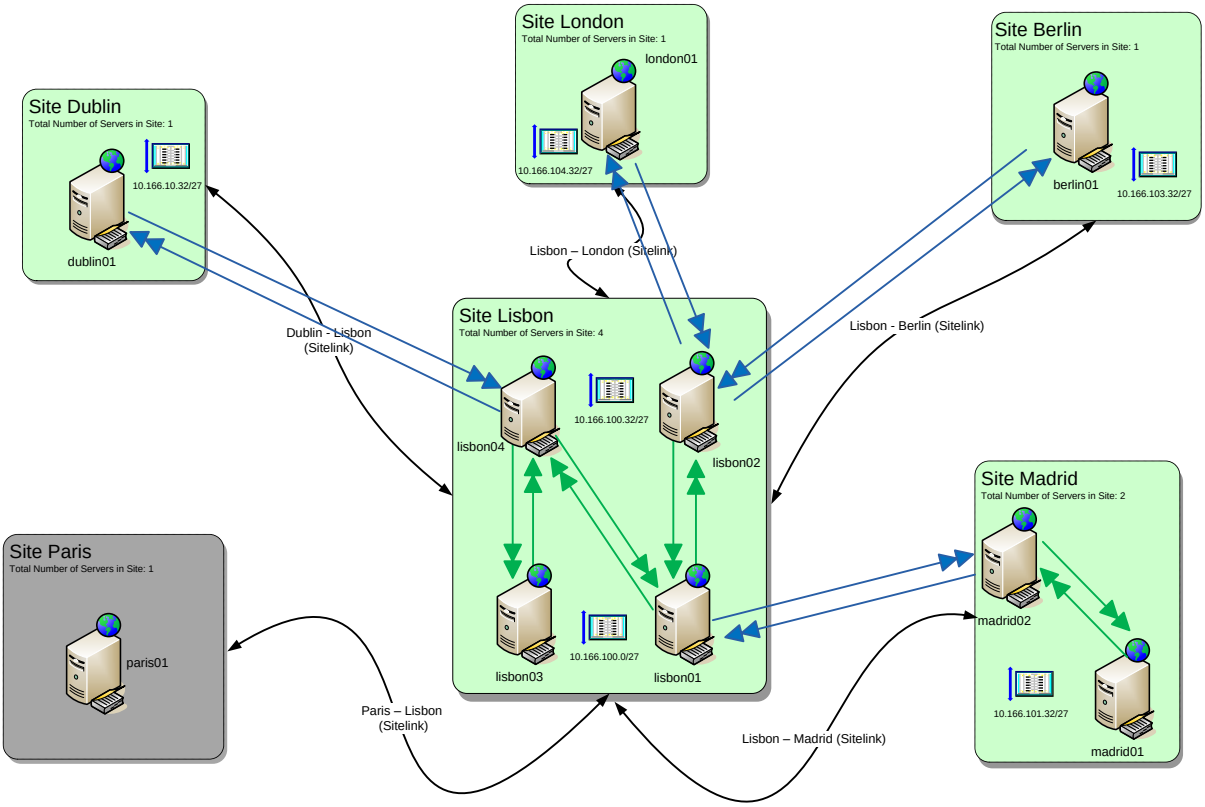


Fig. 5.20 — Site without subnet defined

- **When an organization has more than one site, they should be interconnected** – To allow the communication among servers in different sites, the latter must be connected to other sites. Sometimes we have problems because sites do not have a connection to a least another site which represents an isolated "island" without connectivity with the rest of the ITI. This occurs more often in ITIs with hundreds of sites. Fig. 5.21 shows an example of an ITI where the Dublin Site is isolated from the rest of the infrastructure. Consequently, the server Dublin01 in Dublin site has no communications with the rest of the ITI.

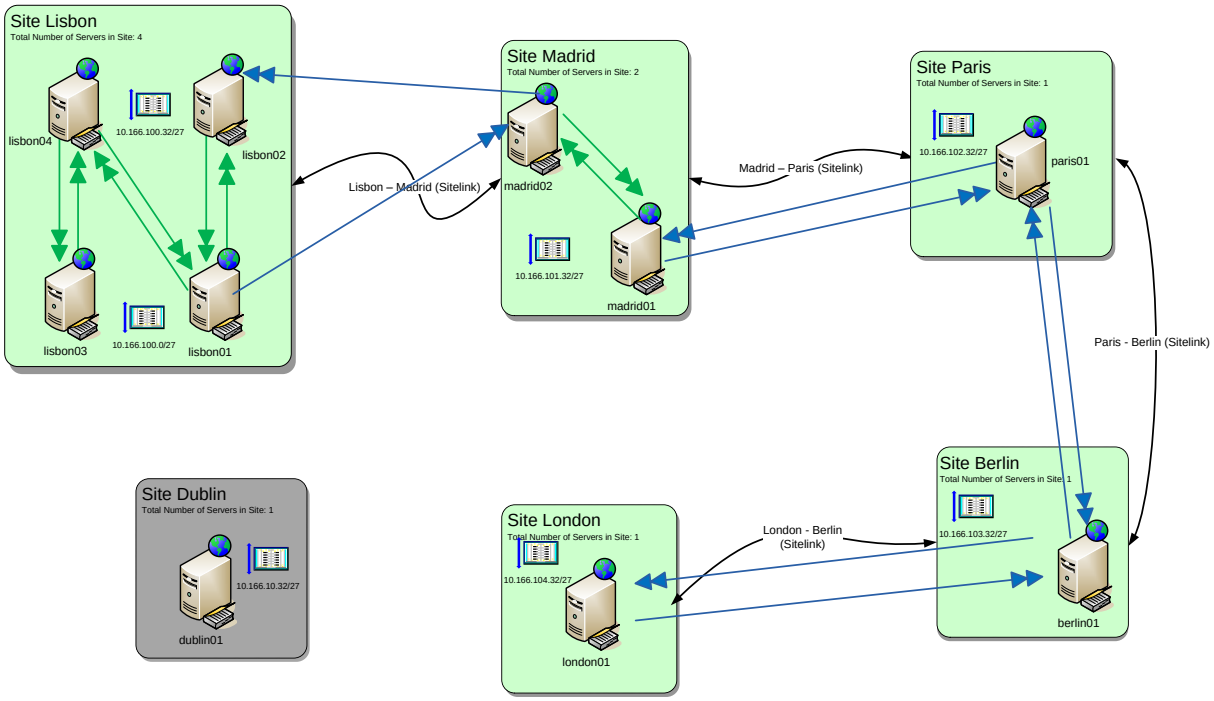


Fig. 5.21 — Isolated ITI site

- **<u>To allow information interchange, servers should be interconnected</u>** – When a server is disconnected from other servers, thus not being able to exchange information, this normally represents a mistake of the ITI. Fig. 5.22 shows an example of an ITI where the server *"london01"* in *"Site London"* is not connected to at least another server.

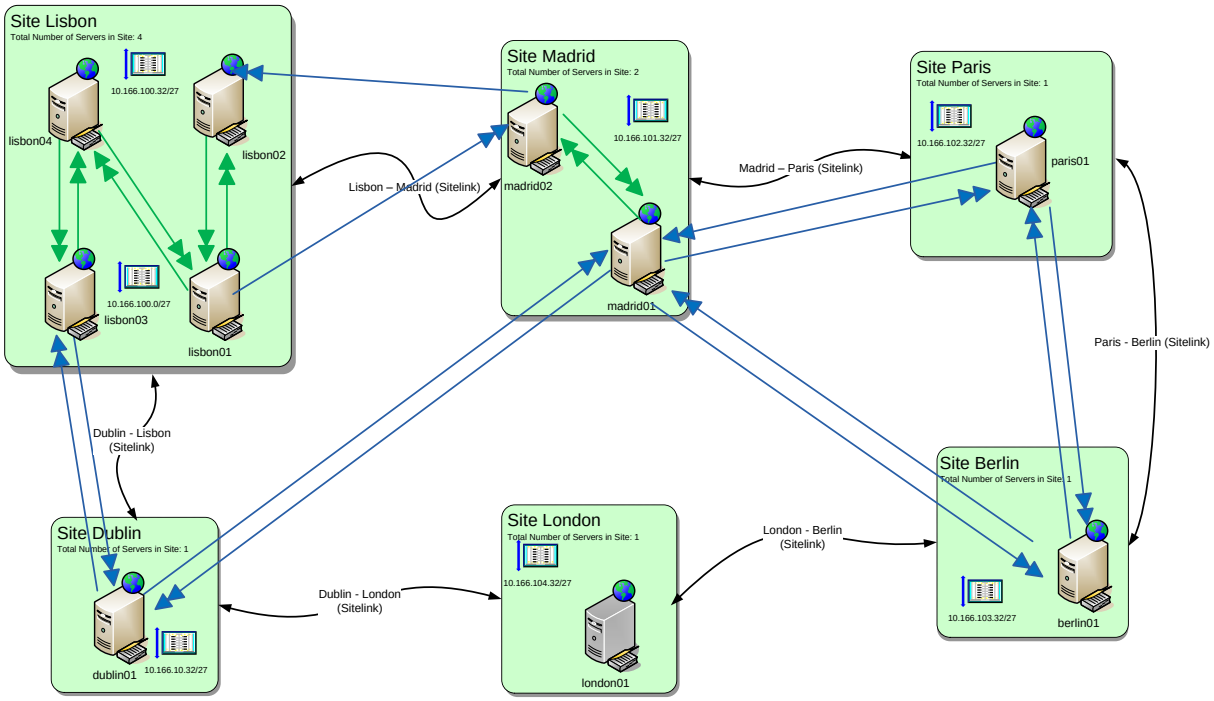


Fig. 5.22 — Isolated ITI server

5.4.2 Formal specification of best practices

In this section we will take each of the best practices defined above and we will formally define them using OCL. Each best practice will be defined as an invariant in the context of the SDM class. We have defined the following names for those invariants:

- *SiteHasAtLeastOneServer*;
- *SiteHasAtLeastOneSubnet;*
- *SiteLinkedToAtLeastAnotherSite;*
- *ServerConnectedToAtLeastAnotherServer.*

"A site in an ITI should have at least one server". The invariant*SiteHasAtLeastOneServer* says that if a site exists it should have at least a member of the type server.

Invariant definition: SiteHasAtLeastOneServer

```
1  context SystemDefinition
2  inv SiteHasAtLeastOneServer:
3     IsSite() implies ContainmentDefinition.allInstances
4       ->select(MemberDefinition.oclIsTypeOf(SystemDefinition))
        ->exists(ParentDefinition=self and MemberDefinition.oclAsType(SystemDefinition).IsServer())
```

Fig. 5.23 — *SiteHasAtLeastOneServer* invariant definition

"A site in an ITI should have at least one subnet defined". The invariant *SiteHasAtLeastOneSubnet* says that if a site exists it should have at least a member of the type subnet.

Invariant definition: SiteHasAtLeastOneSubnet

```
1  inv SiteHasAtLeastOneSubnet:
2     IsSite() implies ContainmentDefinition.allInstances
3        ->select(MemberDefinition.oclIsTypeOf(ResourceDefinition))
4        ->exists(ParentDefinition=self and
5          MemberDefinition.oclAsType(ResourceDefinition).IsSubnet())
```

Fig. 5.24 — *SiteHasAtLeastOneSubnet* invariant definition

"When an organization has more than one site, they should be interconnected". The invariant *SiteLinkedToAtLeastAnotherSite* says that if more than one site exists they should be connected.

Invariant definition: SiteLinkedToAtLeastAnotherSite

```
1   context SystemDefinition
2     inv SiteLinkedToAtLeastAnotherSite:
3       IsSite() implies CommunicationDefinition.allInstances
4       ->exists(Client()=self and Server().IsSite())
```

Fig. 5.25 — *SiteLinkedToAtLeastAnotherSite* invariant definition

"To allow information interchange, servers should be interconnected". The invariant *ServerConnectedToAtLeastAnotherServer* says that when more than one site exists the servers have to be connected to other servers.

Invariant definition: ServerConnectedToAtLeastAnotherServer

```
1   context SystemDefinition
2   inv ServerConnectedToAtLeastAnotherServer:
3         IsServer() implies CommunicationDefinition.allInstances
4         ->exists(Client()=self and Server().IsServer()) and
5          CommunicationDefinition.allInstances->exists(Server()=self and Client().IsServer())
```

Fig. 5.26 — *ServerConnectedToAtLeastAnotherServer* invariant definition

In the following section we will apply each one of these invariants to a real example to check if there are best practices violations. An invariant can be evaluated to true, false or can be not applicable (n/a). One has not to worry about a true invariant. A false invariant indicates an invalid system state which can be inspected by double-clicking the invariant name, and this opens the evaluation browser explained further down.

5.4.3 Detecting best practices violations

In this section we present a case study of an ITI and we will use the "USE" tool, to detect if there are best practices violations. The case study of Fig. 5.27, represents an ITI organization with one site on the right that is not connected to the rest of the ITI. This disconnected site has the name *Site_Lisbon*. The diagram is presented in a very small size to guarantee the confidentiality of the data origin.

There are several reasons that can lead to problems like this. The most common are anomalies or human errors.

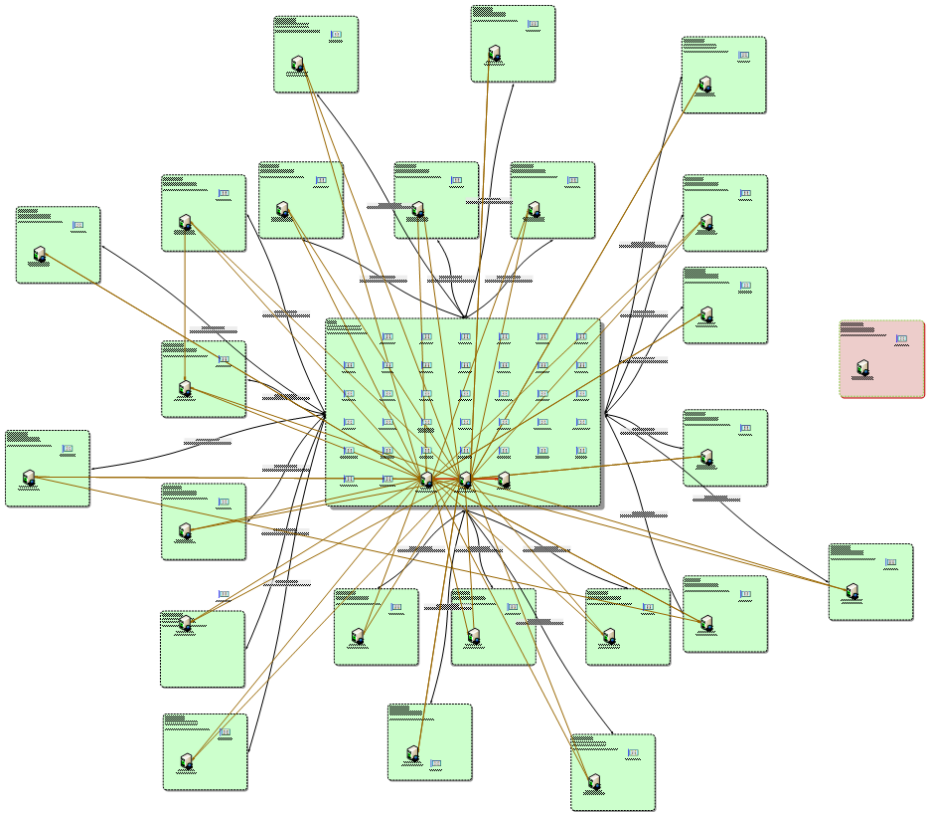


Fig. 5.27 — ITI for best practices analysis

The result of checking the application of the best practices against the previous infrastructure gives the following results.

USE: Checking invariants on infrastructure

```
1   use> check
2   checking structure...
3   checking invariants (using 5 concurrent threads)...
4   checking invariant (1) `SystemDefinition::ServerConnectedToAtLeastAnotherServer': OK.
5   checking invariant (2) `SystemDefinition::SiteHasAtLeastOneServer': OK.
6   checking invariant (3) `SystemDefinition::SiteHasAtLeastOneSubnet': OK.
7   checking invariant (4) `SystemDefinition::SiteLinkedToAtLeastAnotherSite': FAILED.
8     -> false : Boolean
9   Instances of SystemDefinition violating the invariant:
10    -> Set(@Site_Lisbon) : Set(SystemDefinition)
11  checked 4 invariants in 0.080s, 1 failure.
12  use>
```

Fig. 5.28 — Check best practices violations in ITI1

With the exception of *invariant SiteLinkedToAtLeastAnotherSite* all are OK, meaning that most of the best practices are in place in this organization. The FAILED *invariant* (line 7) is due to the fact that there is an isolated site in the infrastructure. In this case the isolated *site* is presented in Fig. 5.27 (one the right with a different color).

6

ITI Topology Detection

Contents

This chapter is dedicated to the detection of network topologies based upon logistic regression techniques. Using a simulated sample we will calibrate an estimation model that then will be used to detect the topology of ten real ITIs collected using the approach defined in chapter 4.

6.1 Introduction

Understanding the relationships among the components (topology) of an ITI and classify the topology is a central question in several organizations because the topology is related with the ITI level of complexity. As we have seen in chapter 2 most organizations have the desire to reduce the complexity of their ITIs in order to decrease the corresponding TCO. For that purpose they first need to know what topology is currently in place. The goal of this chapter is to propose a model to automatically classify the topology of infrastructures based on the complexity metrics identified earlier We first create a sample with 100 "pure" infrastructure topologies and we calculate the site complexity metrics identified earlier for each of them. This simulated sample, for each case we know the independent variables (the complexity metrics) and the dependent one (The topology), is used to calibrate our topology detection model. The latter is based on multinomial regression analysis. Since we had many descriptors (candidate independent variables), we have to reduce their number to avoid over-specification of our estimation model.

The last section of this chapter is dedicated to the application of the created classification model to ten real ITIs with the purpose of demonstrating the feasibility of our approach.

6.2 Simulated sample

To calibrate[1] the model to be used to classify topologies we decided to generate an artificial sample with 100 cases (covering in a balanced way all of the identified ITI network topologies in section 5.3.1) with different number of sites and for each of them we applied some of the site complexity metrics identified in section 5.3.2 such as the *CCM_Sites* (defined in equation (5.6)), *ITF_Sites* (defined in equation (5.10)) and *IMF_Sites* (defined in equation (5.15)). For simplicity reasons we grouped the unidirectional ring and bidirectional ring into the "ring". Table 6.1 presents an extract of the sample data created. Notice that the column *TotalSitesLinks* represents the number of sitelinks required to match a specific topology (e.g. in an infrastructure with four sites we need to have twelve *sitelinks* to match a topology of the "fully meshed" type).

[1] Model calibration corresponds to the determination of parameter values that maximize the fit between estimates and observed values of the outcome variable in a training set.

Table 6.1 — Simulated sample

Topology	TotalSites	TotalSiteLinks	CCM_Sites	ITF_Sites	IMF_Sites
Backbone (3)	3	4	3	1,00	0,67
Ring (3)	3	6	5	1,00	1,00
Centralized (3)	3	4	3	1,00	0,67
Fully Meshed (3)	3	6	5	1,00	1,00
Backbone (4)	4	6	4	0,67	0,50
Ring (4)	4	8	6	0,67	0,67
Centralized (4)	4	6	4	1,00	0,50
Fully Meshed (4)	4	12	10	1,00	1,00
(...)	(...)	(...)	(...)	(...)	(...)
Backbone (99)	99	196	99	0,02	0,02
Ring (99)	99	198	101	0,02	0,02
Centralized (99)	99	196	99	1,00	0,02
Fully Meshed (99)	99	9702	9605	1,00	1,00
Backbone (100)	100	198	100	0,020	0,020
Ring (100)	100	200	102	0,020	0,020
Centralized (100)	100	198	100	1	0.020
Fully Meshed (100)	100	9900	9802	1	1

Notice that our sample identifies pure network types (e.g. 100% backbone or 100% centralized network). However, with real data infrastructures, there are often more than one network topology present in ITIs.

Table 6.2 summarizes the variables, their scale type and description that will be used in the analysis. To perform an analysis we will first identify the dependent (aka outcome) and independent variables (aka explanatory) of our sample. The dependent variables are those that are observed to change in response to the independent variables. The independent variables are those that are deliberately manipulated to cause a change in the dependent variables.

Table 6.2 — Variables used in this experiment, their scale types and description

Variable	Scale type	Description
Topology	Nominal	Type of topology (Centralized, Fully Meshed, Ring, Backbone, etc...)
TotalSites	Absolute	Total number of sites in the infrastructure
TotalSiteLinks	Absolute	Total number of sitelinks in the infrastructure
CCM_Sites	Absolute	Complexity associated with cyclomatic complexity
ITF_Sites	Ratio	Complexity associated with site topology
IMF_Sites	Ratio	Complexity associated with infrastructure meshing

In this sample the outcome variable is the topology and all the others are explanatory variables. Since we want to classify the topology, the problem that we want to solve is given a set of values of the explanatory variables, which are the percentages of fit for each of the topology categories, only

for a "pure" topology we will expect to get a 100% fit for one topology and 0% for all others. For that purpose we will use the multinomial logistic regression which is an extension of the logistic regression. The logistic regression can be used to predict values for a dependent variable based on independent variables. It is also used to predict the percent of variance in the dependent variable explained by the independents.

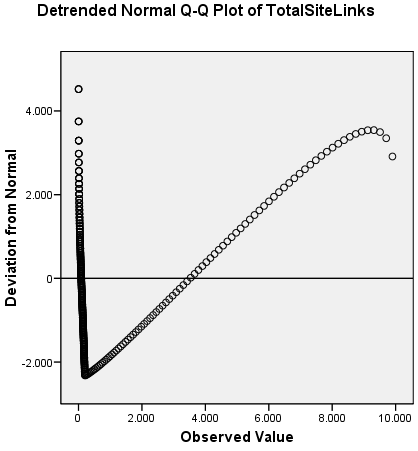
Before using the multinomial logistic regression we will first detect if we have an over-specified model. In regression models over-specification is a problem that arises whenever a large number of correlated explanatory variables are related with a single result. As we can see in the Table 6.2 we have five explanatory variables (*TotalSites*, *TotalSiteLinks, CCM_Sites, ITF_Sites, IMF_Sites*). Since we have five potential explanatory variables we will perform some variable reduction using correlations analyses, in order to avoid over specified models.

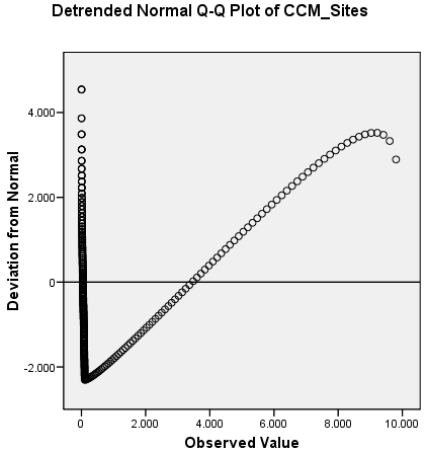
6.3 Variable reduction

In order to check if we can reduce the number of explanatory variables and simplify the model, we will use correlations analysis to compute correlation coefficients that describe the linear relationship between two variables while controlling for the effects of one or more additional variables.

To determine the most adequate correlation coefficient to use, we need to test the explanatory variables statistical distribution. If they are normally distributed we can use a parametric correlation coefficient. Otherwise we should use a nonparametric one.

In figure Fig. 6.1 we reproduce the detrended normal Q-Q plots to represent the standardized deviation of the observed values from a Normal distribution. To be Normal, a given variable should have its points near the horizontal line corresponding to a null deviation. None of the metrics being analyzed exhibits such a behavior, so most probably they do not have a normal distribution.





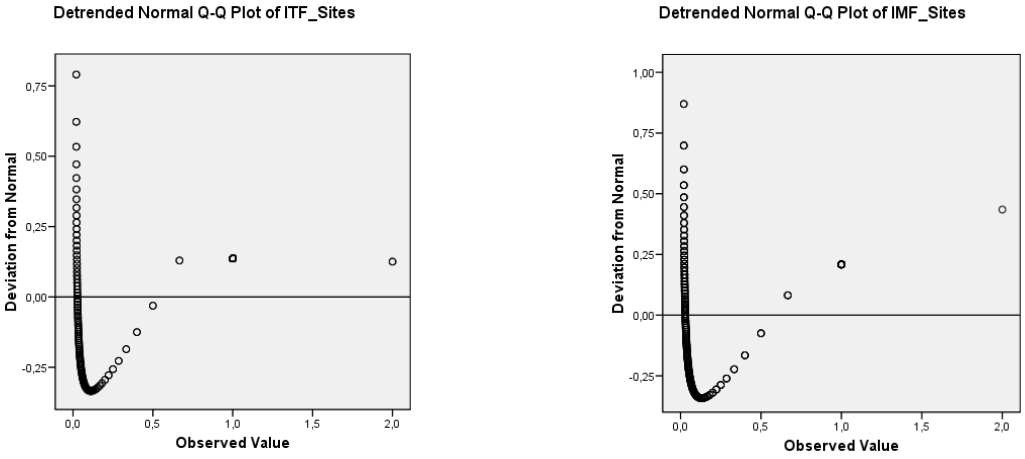


Fig. 6.1 — QQ Plots for complexity metrics

Notice that the Q-Q Plot of *TotalSiteLinks* and QQ Plot of *CCM_Sites* are very similar since both are dimension measures, as we will see in the sections ahead.

To test the hypothesis of normality we have applied the One-Sample Kolmogorov-Smirnov Test, which is based on the maximum difference between the sample cumulative distribution and the hypothesized cumulative distribution. The underlying hypotheses for this test are the following:

$$H_0: \mathrm{X} \sim \mathrm{N}(\mu; \sigma) \qquad \text{Vs.} \qquad H_1: \neg \mathrm{X} \sim \mathrm{N}(\mu; \sigma) \tag{6.1}$$

Table 6.3 — Testing Normal distribution with the Kolmogorov-Smirnov test

		TotalSiteLinks	CCM_Sites	ITF_Sites	IMF_Sites
N		396	396	396	396
Normal Parameters [a,b]	Mean	917,17	868,17	,55230	,31845
	Std. Deviation	2056,502	2046,024	,478094	,422357
Most Extreme Differences	Absolute	,420	,421	,336	,318
	Positive	,420	,421	,239	,318
	Negative	-,328	-,336	-,336	-,240
Kolmogorov-Smirnov Z		8,356	8,382	6,678	6,336
Asymp. Sig. (2-tailed)		,000	,000	,000	,000

a Test distribution is Normal.
b Calculated from data.

Considering a confidence level of 95%, which implies a test significance $\alpha = 0.05$ (probability of type I error of 5%). We can conclude from Table 6.3 that we must reject the null hypothesis for all variables, since we get a significance $p < \alpha$, which means that we have significant Z statistics for all variables being analyzed. In other words, we cannot sustain that the considered variables of our sample come from a Normal population. Therefore we can only use a non parametric correlation coefficient. We have chosen the spearman correlation coefficient [Fagin, et al., 2003, Kendall, 1962] since it is the most widely used one.

The following table shows the Spearman's correlation coefficients for the five explanatory variables.

Table 6.4 — Correlations among five explanatory variables

			Total Sites	TotalSiteLinks	CCM_Sites	ITF_Sites	IMF_Sites
Spearman's rho	Total Sites	Correlation Coefficient	1,000	,733**	,705**	-,292**	-,577**
		Sig. (2-tailed)	.	,000	,000	,000	,000
		N	396	396	396	396	396
	TotalSiteLinks	Correlation Coefficient	,733**	1,000	,994**	,091	,013
		Sig. (2-tailed)	,000	.	,000	,069	,790
		N	396	396	396	396	396
	CCM_Sites	Correlation Coefficient	,705**	,994**	1,000	,108*	,044
		Sig. (2-tailed)	,000	,000	.	,032	,378
		N	396	396	396	396	396
	ITF_Sites	Correlation Coefficient	-,292**	,091	,108*	1,000	,613**
		Sig. (2-tailed)	,000	,069	,032	.	,000
		N	396	396	396	396	396
	IMF_Sites	Correlation Coefficient	-,577**	,013	,044	,613**	1,000
		Sig. (2-tailed)	,000	,790	,378	,000	.
		N	396	396	396	396	396

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

From Table 6.4 we can observe that there are some relatively high[2] correlations among the variables TotalSites, TotalSiteLinks and CCM_Sites. This is expected since all three variables somehow measure the ITI size. So we decided to eliminate the first two variables and keep only the CCM_Sites variable, along with ITI_Sites and IMF_Sites. In the next section we will give more information regarding the use of the multinomial regression method and we will apply this method using these three variables. The goal is to estimate the topology type (dependent or outcome variable) based upon the complexity metrics (independent or explanatory variables).

6.4 Multinomial logistic regression

The multinomial logistic regression is useful for situations in which we want to be able to classify subjects based on values of a set of predictor variables. This type of regression is similar to binary logistic regression, but is more general because the dependent variable is not restricted to two categories.

[2] There is no consensus in the literature on what should be considerable "High" correlation. We have taken the 70% threshold as a reference in our approach.

This statistical regression technique aggregates cases to form subpopulations with identical covariate patterns for the predictors, producing predictions, residuals, and goodness-of-fit tests based on these subpopulations.

Unlike other regression methods, logistic regression does not assume linearity of relationship between the independent variables and the dependent one and does not require normally distributed variables. The predictive success of the logistic regression can be assessed by looking at the classification table, showing correct and incorrect classifications of the variable. Goodness-of-fit tests, such as the likelihood ratio test, are available as indicators of model appropriateness, as is the Wald statistic to test the significance of individual independent variables.

6.4.1 Definitions

For a dependent variable with K categories, consider the existence of K unobserved continuous variables $Z_1 \ldots Z_k$, each of which can be thought of as the "*propensity toward*" a category. Mathematically, the relationship between the $Z's$ and the probability of an outcome is described in formula **(6.2)** [Rekkas, 2008].

$$\pi_{ik} = \frac{e^{z_{ik}}}{e^{z_{i1}} + e^{z_{i2}} + \ldots + e^{z_{iK}}} \quad \textbf{(6.2)}$$

where:

π_{ik} is the probability the i^{th} case falls in category k

z_{ik} is the value of the k^{th} unobserved continuous variable for the i^{th} case

Z_k is also assumed to be linearly related to the predictors, as described in the formula **(6.3)**.

$$Z_{ik} = b_{k0} + b_{k1}x_{i1} + b_{k2}x_{i2} + \cdots + b_{kJ}x_{iJ} \quad \textbf{(6.3)}$$

where:

x_{ij} is the j^{th} predictor for the i^{th} case

b_{kJ} is the j^{th} coefficient for the k^{th} unobserved variable

J is the number of predictors

If Z_k were observable, we could fit a linear regression to each Z_k. However if Z_k is unobserved, we must relate the predictors to the probability of interest by substituting for Z_k, thus obtaining formula **(6.4)**.

$$\pi_i = \frac{e^{b_{k0} + b_{k1} x_{i1} + \ldots + b_{kJ} x_{iJ}}}{e^{b_{i0} + b_{i1} x_{i1} + \cdots + b_{iJ} x_{iJ}} + \cdots + e^{b_{k0} + b_{k1} x_{k1} + \cdots + b_{kJ} x_{kJ}}} \quad \textbf{(6.4)}$$

As it stands, if we add a constant to each Z, then the outcome probability is unchanged. This is the problem of non-identifiability [Hsieh-Hua Yang, et al., 2008]. To solve this problem, Z_k is (arbitrarily) set to 0. The K_{kth} category is called the reference category, because all parameters in the model are interpreted in reference to it. The reference category is the "standard" category to which others would naturally be compared.

Due to the exploratory nature of statistical analysis, we are going to perform four different regression analyses using, the identified variables *CCM_Sites, ITF_Sites* and *IMF_Sites.* We will then present the results achieved in terms of:

- **Model fitting Information** — A likelihood ratio test shows whether the model fits the data better than a null model. We can define the hypotheses:

  H_0 The *model does not have a statistically significant different outcome than another model that only considers the intercept parameter*.

  Vs. **(6.5)**

  H_1 T*he model does have a statistically significant different outcome than another model that only considers the intercept parameter.*

- **Pseudo-R-Square** — To analyze data with a logistic regression, an equivalent statistic to R-squared goodness of fit coefficient does not exist. A wide variety of pseudo-R-squares measures (e.g. *Cox and Snell's*, *Nagelkerke's*, and *McFadden's*) have been proposed to evaluate the goodness-of-fit of logistic models. The name "pseudo" is due to the fact that these coefficients look like R-squared in the sense that they are on a similar scale, ranging from 0 to 1 with higher values indicating better model fit. The *Cox and Snell's* coefficient is an attempt to imitate the interpretation of multiple R-Square based on the log likelihood of the final model vs. log likelihood for the baseline model, but its maximum can be (and usually is) less than 1.0, making it difficult to interpret. The *Nagelkerke's* coefficient is a modification of the *Cox and Snell* one to assure that it can vary from 0 to 1. That is, *Nagelkerke's R2* divides *Cox and Snell's* by its maximum in order to achieve a measure that ranges from 0 to 1. Therefore, *Nagelkerke's R2* will normally be higher than the *Cox and Snell* measure. Lastly, the *McFadden's* coefficient is a less common pseudo-R2 variant, based on log-likelihood kernels for the full, versus the intercept-only, models;
- **Likelihood ratio tests** — *The likelihood ratio* is a function of *log likelihood* used in significance testing in multinomial logistic regression. A "*likelihood*" is a probability, specifically the

probability that the observed values of the dependent variable may be predicted from the observed values of the independent variables. Like any probability, the *likelihood* varies from 0 to 1. The log likelihood (LL) is its log, this varying from 0 to minus infinity. LL is calculated through iteration, using maximum likelihood estimation. Because -2LL has approximately a chi-square distribution, it can be used for assessing the significance of logistic regression. The likelihood ratio is not used directly in significance testing, but it is the basis for the likelihood ratio test, which is the test of the difference between two likelihood ratios. The chi-square statistic is the difference in -2 log-likelihoods between the final model and a reduced model. The reduced model is formed by omitting an effect from the final model. The null hypothesis is that all parameters of that effect are 0.

- **Classifications** — A classification table shows the number of cases classified correctly and incorrectly for each category of the dependent variable. The classification table shows both the observed versus predicted responses. The columns are the predicted values of the dependent variable, while the rows are its observed (actual) values. In a perfect model the main diagonal will be fitted with 100% value and all other cells will obviously be 0%.

6.4.2 Regression using three variables

In our first attempt to perform the multinomial regression we used the three explanatory variables (*CCM_Sites, IMF_Sites, ITF_Sites*). We used the centralized network topology as reference category since from our experience centralized is one of the most common infrastructures.

Table 6.5 — Model fitting for *CCM_Sites*, *ITF_Sites* and *IMF_Sites* variables

	Model Fitting Criteria	Likelihood Ratio Tests		
Model	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	1093,786			
Final	60,559	1033,227	9	,000

Taking a confidence level of 95%, which implies a test significance $\alpha = 5\%$ and upon the information of Table 6.5 we can reject the null hypothesis and accept the alternate one that a model is better than a null model.

Table 6.6 — Likelihood ratio tests for *CCM_Sites*, *ITF_Sites* and *IMF_Sites* variables

Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	235,790[a]	175,230	3	,000
ITF_Sites	675,292	614,733	3	,000
IMF_Sites	418,123	357,564	3	,000
CCM_Sites	82,415[a]	21,856	3	,000

Table 6.7 — Pseudo-R Square for *CCM_Sites*, *ITF_Sites* and *IMF_Sites* variables

Cox and Snell	,926
Nagelkerke	,988
McFadden	,941

Based upon the Table 6.5, Table 6.6 and Table 6.7 we can conclude that using three variables the model fit is very high, what is expected since we manually generated each of the ITI network topologies.

Table 6.8 — Topology classification table using *CCM_Sites*, *ITF_Sites* and *IMF_Sites* variables

Observed	Predicted				
	Centralized	Backbone	Fully Meshed	Ring	Percent Correct
Centralized	98	0	1	0	99,0%
Backbone	2	97	0	0	98,0%
Fully Meshed	0	0	99	0	100,0%
Ring	0	0	2	97	98,0%
Overall Percentage	25,3%	24,5%	25,8%	24,5%	98,7%

Based upon the results of the Table 6.8 our model can predict the network topology with a precision of **98,7%.** Notice that in the case of fully meshed network topology the precision of our model is **100%**, what means that this model can successfully identify all the fully meshed cases.

6.4.3 Regression using two variables

In our second attempt to perform the multinomial regression we decided to remove the existing dimension variable from the equation to analyze the impact on the dependent variable and we used only (*IMF_Sites, ITF_Sites*). Again we used the centralized network topology as the reference category.

Table 6.9 — Model fitting for *ITF_Sites* and *IMF_Sites* variables

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	1078,118			
Final	66,747	1011,371	6	,000

Taking a confidence level of 95%, which implies a test significance $\alpha = 5\%$ and upon the information of Table 6.9 we can reject the null hypothesis and accept the alternate one that a model is better than a null model.

Table 6.10 — Likelihood ratio tests for *ITF_Sites* and *IMF_Sites* variables

Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	380,561[a]	313,813	3	,000
ITF_Sites	690,879	624,132	3	,000
IMF_Sites	613,685	546,938	3	,000

Table 6.11 — Pseudo-R Square for *ITF_Sites* and *IMF_Sites* variables

Cox and Snell	,922
Nagelkerke	,984
McFadden	,921

Based upon the Table 6.9, Table 6.10, Table 6.11, we can conclude that even removing the dimension variable *CCM_Sites*, the model fit is very high with very similar results.

Table 6.12 — Classification table for *ITF_Sites* and *IMF_Sites* variables

Observed	Predicted				
	Centralized	Backbone	Fully Meshed	Ring	Percent Correct
Centralized	98	0	1	0	99,0%
Backbone	2	97	0	0	98,0%
Fully Meshed	0	0	99	0	100,0%
Ring	0	0	2	97	98,0%
Overall Percentage	25,3%	24,5%	25,8%	24,5%	98,7%

From Table 6.12 we can conclude that even excluding the dimension variable *CCM_Sites* we still can predict the network topology with an overall precision of **98,7%.**

6.4.4 Regression using one variable (ITF_Sites)

In our third attempt to perform the multinomial regression we decided to use only one variable, to understand how affected is our model if we removed two variables. We will use just the *ITF_Sites* variable.

Table 6.13 — Model fitting for *ITF_Sites* variable

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	672,161			
Final	207,728	464,434	3	,000

Taking a confidence level of 95%, which implies a test significance $\alpha = 5\%$ and upon the information of Table 6.13 we can reject the null hypothesis and accept the alternate one that a model is better than a null model.

Table 6.14 — Likelihood Ratio Tests for *ITF_Sites* variable

Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	495,070	287,342	3	,000
ITF_Sites	672,161	464,434	3	,000

Table 6.15 — Pseudo-R Square for *ITF_Sites* variable

Cox and Snell	,691
Nagelkerke	,737
McFadden	,423

Based upon the Table 6.13, Table 6.14, Table 6.15, we can conclude that using just the variable *ITF_Sites* the model fit decreases substantially.

Table 6.16 — Classification table for *ITF_Sites* variable

Observed	Predicted				
	Centralized	Backbone	Fully Meshed	Ring	Percent Correct
Centralized	99	0	0	0	100,0%
Backbone	2	96	1	0	97,0%
Fully Meshed	99	0	0	0	,0%
Ring	2	96	1	0	,0%
Overall Percentage	51,0%	48,5%	,5%	,0%	49,2%

Based upon the results of Table 6.16 using just the variable *ITF_Sites* we observed a significant precision reduction. There is a decrease in the overall predicted percentage from **98,7%** with two variables to **49,2**% with just one. In the first row of Table 6.16 we can observe that the model has a precision of **100%** in the detection of network topologies of type "centralized". This is due to the fact that proposed metric *ITF_Sites* quantifies the centrality of a network topology. Also notice that with just ITF_Sites we are unable to predict fully meshed and ring topologies.

6.4.5 Regression using one variable (IMF_Sites)

The fourth attempt is very similar to the third since we will perform the multinomial regression with only one variable. This time we will use only the *IMF_Sites* variable.

Table 6.17 — Model fitting for *IMF_Sites* variable

Model	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	721,267			
Final	334,028	387,239	3	,000

Taking a confidence level of 95%, which implies a test significance $\alpha = 5\%$ and upon the information of Table 6.17 we can reject the null hypothesis and accept the alternate one that a model is better than a null model.

Table 6.18 — Likelihood Ratio Tests for *IMF_Sites* variable

Effect	Model Fitting Criteria	Likelihood Ratio Tests		
	-2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	535,722	201,694	3	,000
IMF_Sites	721,267	387,239	3	,000

Table 6.19 — Pseudo-R Square for *IMF_Sites* variable

Cox and Snell	,624
Nagelkerke	,665
McFadden	,353

Table 6.17, Table 6.18, Table 6.19 confirm that using just the variable *IMF_Sites* the model fit decreases substantially.

Table 6.20 — Classification table for *IMF_Sites* variable

Observed	Predicted				
	Centralized	Backbone	Fully Meshed	Ring	Percent Correct
Centralized	18	61	2	18	18,2%
Backbone	18	61	2	18	61,6%
Fully Meshed	0	0	99	0	100,0%
Ring	18	60	3	18	18,2%
Overall Percentage	13,6%	46,0%	26,8%	13,6%	49,5%

The results are very similar to the Table 6.16. Based upon the results of the Table 6.20 on using just the variable *IMF_Sites*, we observed a significant precision reduction of our model. The overall precision decreases from **98,7%** with two variables to **49,5**% with just one. Notice that the model has a precision of **100%** in the detection of network topologies of type fully meshed. This is due to the fact that the proposed complexity metric *IMF_Sites* quantifies the meshing of a network topology.

6.5 Experiments

In this section we will use the model coefficients resultant from our simulated sample and we will apply them to real ITIs with the purpose to detect the topology. Using the ITI data gatherer process defined in our evaluation approach (see section 4.2.1) we had access to ITIs from ten different organizations whose data we slightly changed, in order to guarantee origin anonymity. Table 6.21 has the parameters used in the previous multinomial logistic regression tests. Notice that we treated the centralized topology as the reference category and we estimated a model for the other types of topologies.

Table 6.21 — Parameter estimates

TopologyRecode[a]		B	Std. Error	Wald	df	Sig.	Exp(B)	95% Confidence Interval for Exp(B)	
								Lower Bound	Upper Bound
Backbone	Intercept	4,733	1,087	18,947	1	,000			
	ITF_Sites	-9,914	1,547	41,091	1	,000	4,95E-005	2,39E-006	,001
	IMF_Sites	7,689	2,511	9,376	1	,002	2183,495	15,915	299578,020
Fully Meshed	Intercept	2,959	1,475	4,026	1	,045			
	ITF_Sites	-7391,574	2,565	8306533	1	,000	,000	,000	,000
	IMF_Sites	7395,863	,000	.	1	.	.[b]	.	.
Ring	Intercept	9,690	1,373	49,849	1	,000			
	ITF_Sites	-36139,2	2,576	2E+008	1	,000	,000	,000	,000
	IMF_Sites	36133,452	,000	.	1	.	.[b]	.	.

a The reference category is: Centralized.
b Floating point overflow occurred while computing this statistic. Its value is therefore set to system missing.

We will use the B values that represent the coefficients of the multinomial logistic regression model to our real ITI data.

As described earlier, Table 6.22 presents ten infrastructures collected from real organizations. In order to obtain all this data we used the ITI data gatherer component of our approach. To better illustrate the application of our classification model we will demonstrate the application of the equations defined in section 6.4.1 using the values from Table 6.21 and the values of the first infrastructure (ITI 1) in Table 6.22.

Table 6.22 — ITI assessment to real cases

	Total Sites	Total Servers	Total Subnets	Total Sitelinks	Total Connections	ITF_Sites	IMF_Sites
ITI 1	212	161	6852	486	547	0,011	0,322
ITI 2	44	65	148	102	200	0,053	0,325
ITI 3	39	76	648	104	225	0,070	0,421
ITI 4	29	52	1116	60	135	0,073	0,571
ITI 5	11	14	56	24	60	0,272	0,218
ITI 6	6	7	9	0	12	0	0
ITI 7	7	14	1657	12	48	0,285	1
ITI 8	8	16	531	16	45	0,285	1
ITI 9	2	2	159	2	2	1	1
ITI 10	26	28	117	48	56	0,073	0,96

In the following formulas we will not consider infrastructure six (ITI 6) since we found that the number of *sitelinks*, is zero probably due a problem in the collection of data, and infrastructure nine (ITI 9) due to reduced number of sites.

The following equations ((6.6) to (6.13)) uses the data from the first infrastructure in Table 6.22 (ITI1) to detect the topology.

$$Z_{ITI1\ backbone} = 4{,}733 + (-9{,}914 \times 0{,}322) + (7{,}689 \times 0{,}011)$$
$$Z_{ITI1\ backbone} = 1{,}621 \quad \textbf{(6.6)}$$

Equation (6.6) is an illustration of equation (6.3) for the backbone category. The "B"$_{kj}$ coefficients are taken from the backbone row, column B of Table 6.21. The x_{ij} predictors are taken from the corresponding columns of the first row of Table 6.22 (The one of ITI1).

$$Z_{ITI1\ FullyMes\ hed} = 2{,}959 + (-7391{,}574 \times 0{,}322) + (7395{,}863 \times 0{,}011)$$
$$Z_{ITI1\ FullyMes\ hed} = \text{-}2298{,}805 \quad \textbf{(6.7)}$$

Equation (6.7) is an illustration of equation (6.3) for the fully meshed category. The "B"$_{kj}$ coefficients are taken from the Fully Meshed row, column B of Table 6.21. The x_{ij} predictors are taken from the corresponding columns of the first row of Table 6.22 (The one of ITI1).

$$Z_{ITI1\ Ring} = 9{,}690 + (-36139{,}200 \times 0{,}322) + (36133{,}451 \times 0{,}011)$$
$$Z_{ITI1\ Ring} = \text{-}11244{,}486 \quad \textbf{(6.8)}$$

Equation (6.8) is an illustration of equation (6.3) for the ring category. The "B"$_{kj}$ coefficients are taken from the Ring row, column B of Table 6.21. The x_{ij} predictors are taken from the corresponding columns of the first row of Table 6.22 (The one of ITI1). Notice that centralized topology is our reference category:

$$Z_{ITI1\ Centralized} = 0 \quad \textbf{(6.9)}$$

Now that we have the *Z* values for each of the topologies of infrastructure 1, we can calculate the probability of ITI 1 being of type centralized, backbone, fully meshed or ring. The following formulas are instantiations of equation (6.2):

$$Probability_{\ ITI1\ Centralized} = \frac{0^1}{1 + e^{11244{,}486} + e^{-2298{,}805} + e^{1621}}$$
$$Probability_{\ ITI1\ Centralized} = 15{,}5\% \quad \textbf{(6.10)}$$

Based on the data of Table 6.22, there is a **15,5%** probability that ITI 1 having a topology of the Centralized type.

$$Probability_{\ ITI1\ Backbone} = \frac{e^{1{,}621}}{1 + e^{11244{,}486} + e^{-2298{,}805} + e^{1621}}$$
$$Probability_{\ ITI1\ Backbone} = 83{,}5\% \quad \textbf{(6.11)}$$

Based on the data of Table 6.22, there is a **83,5%** probability that ITI 1 having a topology of the Backbone type.

$$Probability_{\ ITI1\ FullyMes\ hed} = \frac{e^{2298{,}805}}{1 + e^{11244{,}486} + e^{-2298{,}805} + e^{1621}}$$
$$Probability_{\ ITI1\ FullyMes\ hed} = 0\% \quad \textbf{(6.12)}$$

Based on the data of Table 6.22, there is no probability (**0%**) of ITI 1 having a topology of the Fully Meshed type.

$$Probability_{\ ITI1\ Ring} = \frac{e^{11244,486}}{1 + e^{11244,486} + e^{-2298,805} + e^{1621}} \quad \textbf{(6.13)}$$

$$Probability_{\ ITI1\ Ring} = 0\%$$

Based on the data of Table 6.22, there is no probability (**0%**) of ITI 1 having a topology of the Ring type.

We applied these equations to each of the ITIs and we summarize the results in Table 6.23. The last column *Topology* represents the topology with higher probability.

Table 6.23 — ITIs Classification

ITI	Probability of being Centralized	Probability of being Backbone	Probability of being Fully Meshed	Probability of being Ring	Topology
ITI 1	16,5%	83,5%	0,0%	0,0%	Backbone
ITI 2	12,8%	87,2%	0,0%	0,0%	Backbone
ITI 3	25,0%	75,0%	0,0%	0,0%	Backbone
ITI 4	59,0%	41,0%	0,0%	0,0%	Centralized
ITI 5	2,4%	97,6%	0,0%	0,0%	Backbone
ITI 6	N/A	N/A	N/A	N/A	N/A
ITI 7	95,2%	4,8%	0,0%	0,0%	Centralized
ITI 8	95,2%	4,8%	0,0%	0,0%	Centralized
ITI 9	N/A	N/A	N/A	N/A	N/A
ITI 10	98,5%	1,5%	0,0%	0,0%	Centralized

Based upon the Table 6.23 we concluded that most topologies are of type centralized and backbone, which is in accordance with our expectations. Notice that ITI4 is an interesting case because his type is centralized (**59%**) but there is a relatively high probability of being of type Backbone **41%**. From the knowledge we have about this organization, one of the reasons that can explain this numbers is the fact that this organization was involved in acquisitions and merger processes.

[This page has been intentionally left blank]

7

Conclusions and Future Work

Contents

As a conclusion of this dissertation, the major contributions are reviewed and summarized. Several limitations of the research work presented in this dissertation are identified and discussed. Finally, directions for future work are outlined. Some of those directions are intended to mitigate the identified limitations.

7.1 Review of contributions

The main contribution of this dissertation was to present an open framework for performing metamodel-based quantitative studies upon ITIs based upon the M2DM technique. The M2DM approach proved to be capable to support evaluation of infrastructures of different sizes in an efficient and reliable way. The M2DM uses (i) a domain metamodel, expressed as a UML2 class diagram, to provide the context and (ii) the OCL constraint language to guarantee metamodels well-formedness and to formalize required quantifiers (e.g. complexity or sizing metrics) or qualifiers (e.g. best practices verifiers). We also described the SDM metamodel and proved the feasibility of the M2DM approach with ten case studies collected from real organizations, although slightly modified to guarantee confidentiality.

We started our work by identifying some of the possible applications of ITI evaluation and the corresponding stakeholders. Part of this work was the proposal, in the related work chapter, of a taxonomy to support a survey of several evaluation studies conducted by different organizations and indicate how the ITI structural evaluation can positively contribute for the TCO calculation.

We also provide a comparison of three ITI modeling languages in terms of their expressiveness, relevance and model availability and we presented the reasons that lead us to choose the System Definition Model language as a basis for the application of our methodological approach to evaluating ITIs (the M2DM).

Before using the System Definition Model language in our approach, we analyzed the SDM metamodel in terms of his structure and we developed an example to demonstrate how to model with SDM.

We also provided the details of the automated process that has allowed scaling-up the evaluation to arbitrarily large real-world ITIs. We detailed each component of the evaluation methodology and we presented how it integrates with the others.

Other important contribution was the SDM library for ITIs known in this dissertation as ITILib, comprehends a set of different metrics, developed in the context of this dissertation with the purpose of evaluating ITIs. The metrics available in the SDM library can be used for several different purposes, such as to support synchronic and diachronic analysis, among other aspects.

We used synchronic analysis approach to look at ITIs at a particular point in time, rather than over time. We have developed several metrics which are available in the SDM library to make this approach feasible. This approach allowed us to compare ITIs in a quantitative perspective. This synchronic analysis allowed us to evaluate ITIs complexity and to perform comparisons among infrastructures from other organizations. Besides the synchronic analysis we also used a diachronic analysis approach to look at ITIs in a period of time, rather than in a particular point in time. This type

of analysis gave us the opportunity to understand the evolution of ITIs on a chronological perspective. This analysis may be applied to different purposes such as the prediction of future growth, TCO evolution forecast or to provide evidence of the occurrence of important actions, among other things. We have extended the SDM metamodel to include a set of best practices that can be used for several purposes such as to detect anomalies in ITIs.

Other important contribution was the detection of topologies. We used the multinomial logistic regression analysis and we were able to create a model that determines the network topology of ITIs. We have successfully applied this model to ten real ITIs whose data we collected during the course of this dissertation.

7.2 Limitations

This section presents some of the limitations found during the execution of our work. We call limitations to the issues, problems or difficulties that we faced that could somehow have influenced the achieved results.

We faced many problems, during the execution of this dissertation. We were able to fully solve some of them and partially solve others, but there are still a significant number of problems to work on. Some of the problems that we identified, with more impact in our research work are:

- **Number of ITIs evaluated** – We spent a considerable amount of effort and time to collect real ITIs to use, with the objective of proving the feasibility of our evaluation approach. Even with that effort, we were able to collect only a limited number of real ITIs. The relatively small size of our sample does not allow us to generalize our conclusions;
- **Partial evaluation** – The reduced number of properties collected from ITIs allowed us to only partial evaluate them. There is a good probability that other non detected properties influence for example the level of complexity of a particular ITI, what could lead to wrong decisions. Some of the properties or aspects that may be interesting to evaluate in an ITI are the software inventory (to understand what is installed in each server), the hardware inventory (to identify all the hardware currently in production), the load of each component of the ITI, among other aspects;
- **The adoption of SDM** – During the execution of this work the SDM modeling language that we choose to work with, is being replaced by the SML language. The study of the SDM metamodel in the perspective of how it works, how classes are related to each other and where it can be applied, took us as a reasonable effort that we decided not to lose. Since there is a supported path to migrate from SDM to SML, we hope to follow that path shortly.

- **Active Directory only data** – All the work performed in this dissertation was based on data collected from Active Directory only. Since most of ITIs are built of systems from different vendors. Collecting ITI data from different vendors will allow us to better generalize our conclusions.

7.3 Future work

We now present a set of future research directions, that we think deserve to be further explored:

- **The adoption of SML** – Future work might concentrate in the migration of this approach based on SDM to its successor, the SML Language. When we started our work, the SML specification was work in progress. Currently, the SML is publicly available at the W3C's web site, but is still in draft and, according to the schedule available in the same site, it will probably remain so until March 2009. Since SML is based on standards and was created to promote the interoperability among different ITI management systems, enable easier management of heterogeneous systems and allow the creation of models that can be used across management systems from different technology vendors, the potential of using SML to evaluate ITIs is enormous;
- **Collecting ITI data from different platforms** – In the IT industry there is a long history of tools and processes being developed for specific roles or tasks that did not integrate with each other, even though they all serve the same objective. The number of LDAP/X.500 implementations described in chapter 4 is one of these examples. Since most ITIs are built with components from different vendors, having a process or tool that can be used to collect data across all these platforms, allows the use of the same evaluation methodology across any kind of ITI;
- **Definition of baseline configuration** – The idea behind the baseline is to define a set of configurations that can be used across the ITI to identify its compliance with security policies, thus identifying security vulnerabilities. The work performed in ITI best practices is a valuable input to this area;
- **Distribution of ITI configurations –** Particularly in organizations with completely distributed ITIs, setting a specific configuration to a group of machines, such as change the replication time interval or configuring a specific service or changing local passwords of all servers may take days and sometimes weeks (depending on the size of the ITI). Extending the evaluation methodology presented in this dissertation to not only evaluate, but also effectively make changes, constitutes an interesting topic. One possible way to address this is to move from

proprietary-based network management systems to standardized model-based ITI management systems;

- **Design of new ITIs** – another interesting area of research is to improve design of new ITIs. This can be achieved through the extension of the evaluation methodology presented in this dissertation to not only to gather and analyze ITI data, but also to allow the users to provide requirements on the new ITI, such as the expected growth, the number of users or the available budget, among other factors. Having a methodological approach to infrastructure design can be very useful to increase or decrease the size of an ITI and adequate it to the business needs;
- **Estimation of the time required to distribute ITI software** – depending on the ITI size, the software distribution across an ITI is another interesting topic. The estimation of the required time to distribute a specific software package for a remote location based upon factors such as the physical network topology, available bandwidth, size of the package, number of destinations and other related aspects, is very important to guarantee the efficiency of the process and to minimize the impact on the network. Extending the evaluation methodology to perform this type of analysis, based on a specific ITI, is another interesting area of research;
- **Full automation of the evaluation approach** – there are several aspects of the proposed evaluation approach that are manual but that can be automated. One of these examples relates to the results provided by the ITI evaluator tool in step 8. Currently these results have to be loaded manual in the statistical analyzer tool.

[This page has been intentionally left blank]

Bibliography

[Abreu, et al., 1994] Abreu, and Carapuca, "Object-Oriented Software Engineering: Measuring and Controlling the Development Process," in In Proceedings of the 4th International Conference on Software Quality, 1994.

[Adams, 2002] Adams, "Management Update: Best Practices to Launch an IT Asset Management Program," 24 April, 2002.

[Altova, 2008] Altova: XMLSpy. http://www.altova.com/products/xmlspy/xml_editor.html, accessed on April, 2008

[Anne, 1990] Anne, IEEE Standard Computer Dictionary: A Compilation of IEEE Standard Computer Glossaries 610. New York: The Institute of Electrical and Electronics Engineers Inc., 1990.

[APC, 2003a] APC, "Determining Total Cost of Ownership for Data Center and Network Room Infrastructure," 2003a.

[APC, 2003b] APC, "Avoiding Costs From Oversizing Data Center and Network Room Infrastructure," 2003b.

[ASF, 2008] ASF: Apache Directory Server - (ApacheDS v1.5). http://directory.apache.org/apacheds/1.5/, accessed on August, 2008

[Axeda, 2007] Axeda, "Secure Remote Vendor Access to the Enterprise Data Center," Foxboro, MA 02035 USA 2007.

[Aziz, et al., 2003] Aziz, Nie, Yam, and Wei: TCO reduction. In: Proc. of APCC 2003. The 9th Asia-Pacificic Conference on Communications, Malaysia, pp. 1147-1151. IEEE (2003)

[Babey, 2006] Babey, "Costs of Enterprise Resource Planning System Implementation — and Then Some," Winter 2006.

[Baroni, et al., 2002] Baroni, and Abreu: Formalizing Object-Oriented Design Metrics upon the UML Meta-Model. In: Proc. of Brazilian Symposium on Software Engineering, Gramado - RS, Brazil (2002)

[Baroni, et al., 2003] Baroni, and Abreu, "A Formal Library for Aiding Metrics Extraction," in International Workshop on Object-Oriented Re-Engineering at ECOOP'2003, Darmstadt, Germany, 2003.

[Baroni, et al., 2004] Baroni, Calero, Ruiz, and Abreu: Formalizing Object-Relational Structural Metrics. In: Proc. of 5ª Conferência da APSI, Lisbon (2004)

[Bartels, 2008] Bartels, "The State Of Enterprise IT Budgets: 2008," March 27, 2008.

[Blowers, 2006a] Blowers, "Management Foundation based on Service-Driven Operations," November, 2006a.

[Blowers, 2006b] Blowers, "Data Center Consolidation - Management Foundation based on Service-Driven Operations," November, 2006b.

[Blum, 2004] Blum, "Network and Systems Management Total Cost of Ownership," September, 2004.

[Bon, 2004] Bon, Chief Editor,“IT Service Management, an introduction based on ITIL”, itSMF Library: Van Haren Publishing, 2004.

[Booch, 1994] Booch, Object Oriented Analysis and Design with Applications, 2nd ed. Redwood City, LA, USA: The Benjamin Cummings Publishing Company Inc, 1994.

[Bothma, 2005] Bothma, "Best practices in managing the Total Cost of Ownership," SAP INSIGHT, p. 10, 2005.

[Bothma, 2006] Bothma, "State of the art in TCO: Managing the Total Cost of Ownership," SAP INSIGHT, p. 10, January 2006.

[Boyle, 2007] Boyle, "Wireless Device Management: Controlling The Wireless Enterprise And Reducing Total Cost of Ownership," 2007.

[Brenner, et al., 2006] Brenner, Garschhammer, and Hegering, "When Infrastructure Management Just won’t do: The Trend towards Organizational IT Service Management," 2006.

[Brito e Abreu, et al., 1997] Brito e Abreu, Ochoa, and Goulão, "The GOODLY Design Language for MOOD Metrics Collection," INESC, Software Engineering Group, Technical Report R16/97, March, 1997.

[Brito e Abreu, 2001] Brito e Abreu, "Using OCL to Formalize Object-Oriented Design Metrics Definitions," Software Engineering Group, INESC, Technical Report ES007/2001, May, 2001.

[Brynjolfsson, et al., 2000] Brynjolfsson, and Hitt, "Computing Productivity: Firm-Level Evidence," MIT Sloan School of Management April, 2000.

[Builders, 2002] Builders, "Examining Total Cost of Ownership for Business Intelligence Solutions," 2002.

[Castellani, et al., 2005] Castellani, Grasso, O’Neill, and Tolmie: Total Cost of Ownership: Issues around Reducing Cost of Support in a Manufacturing Organization Case. In: Proc. of Proceedings of the 2005 Seventh IEEE International Conference on E-Commerce Technology Workshops, Munich - Germany. IEEE (2005)

[Cater-Steel, et al., 2006] Cater-Steel, Tan, and Toleman: Challenge of Adopting Multiple Process Improvement Frameworks. In: Proc. of Proceedings of the 14th European Conference on Information Systems, Göteborg, Sweden, pp. 12–14 (2006)

[Chiorean, et al., 2004] Chiorean, Pasca, Carcu, Botiza, and Moldovan, "Ensuring UML Models Consistency Using the OCL Environment," November, 2004.

[CIOview, 2005] CIOview, "The Business Value of Migrating from Oracle to SQL Server 2005," Acton June, 2005.

[Conley, et al., 2007] Conley, and Mootz: Lowering Cost of Ownership through Predictive Maintenance. In: Proc. of Advanced Semiconductor Manufacturing Conference, Stresa, Italy, pp. 313-319. IEEE (2007)

[Counsel, 2006] Counsel, "North American Enterprise IT Users – Security and Identity Access and Management Outlook," 2006.

[Cranefield, et al., 1999] Cranefield, and Purvis: UML as an Ontology Modelling Language. In: Proc. of Workshop on Intelligent Information Integration, 16th International Joint Conference on Artificial Intelligence (IJCAI-99) (1999)

[Cybersource, et al., 2004] Cybersource, and OSV, "Linux vs Windows - Total Cost of Ownership Comparison," Melbourne 2004.

[David, et al., 2002] David, Schuff, and Louis, "Managing your total IT cost of ownership," January, 2002.

[Davies, 1974] Davies, "An Experimental Investigation of Resource Allocation in Multiactivity Projects," 1974.

[DiDio, 2004a] DiDio, "Linux, Unix and Windows TCO Comparison, Part 2," Boston, MA: The Yankee Group, 2004a.

[DiDio, 2004b] DiDio, "Linux, Unix and Windows TCO Comparison, Part 1," Boston, MA: The Yankee Group, 2004b.

[DMTF, 2007] DMTF, "Common Information Model (CIM) Infrastructure," November, 2007.

[Dublish, et al., 2006] Dublish, Eckert, Ehnebuske, Golovinsky, Jerman, Kreger, Milenkovic, Murray, Prasek, Reeves, Saiyed, Sluiman, Tabbara, Tewari, Tollefsrud, Vambenepe, and Westerinen: Service Modeling Language Specification, Version 0.5. http://www.dell.com/downloads/global/corporate/standards/service_sml.pdf, accessed on August, 2008

[Dublish, et al., 2008a] Dublish, Eckert, Ehnebuske, Golovinsky, Jerman, Kreger, Milenkovic, Murray, Prasek, Reeves, Saiyed, Sluiman, Tabbara, Tewari, Tollefsrud, Vambenepe, and Westerinen: Service Modeling Language Interchange Format Version 1.1. http://www.w3.org/TR/sml-if/, accessed on May, 2008

[Dublish, et al., 2008b] Dublish, Eckert, Ehnebuske, Golovinsky, Jerman, Kreger, Milenkovic, Murray, Prasek, Reeves, Saiyed, Sluiman, Tabbara, Tewari, Tollefsrud, Vambenepe, and Westerinen: Service Modeling Language Specification, Version 1.1. http://www.w3.org/Submission/2007/SUBM-sml-20070321/, accessed on May, 2008

[Edmonds, 1995] Edmonds: What is Complexity? - The philosophy of complexity per se with application to some examples in evolution. In: Proc. of The Evolution of Complexity, Free University of Brussels, Belgium (1995)

[Edmonds, 2000] Edmonds, "Complexity and Scientific Modelling," Foundations of Science, vol. 5, pp. 379-390, 2000.

[Elmaghraby, et al., 1980] Elmaghraby, and Herroelen, "On the measurement of complexity in activity networks," European Journal of Operational Research, 1980.

[EMC, 2005] EMC, "CLARiiON Integration with VMware ESX Server," 8 September, 2005.

[Engels, 2006] Engels, "Reducing the Total Cost of Ownership," in Broadband Fixed Wireless Access: Springer, 2006, pp. 163-183.

[Ernest, et al., 2007] Ernest, and Nisavic, "Adding value to the IT organization with the Component Business Model," IBM Systems Journal, vol. 46, pp. 387-403, July 2007.

[Fagin, et al., 2003] Fagin, Kumar, and Sivakumar, "Comparing top k lists," Proceedings of the fourteenth annual ACM-SIAM symposium on …, 2003.

[Fallside, et al., 2004] Fallside, and Walmsley, "XML Schema Part 0: Primer Second Edition," 28 October, 2004.

[Fedora, 2008] Fedora: Fedora Directory Server Project. http://directory.fedoraproject.org/wiki/Architecture, accessed on August, 2008

[Ganek, et al., 2007] Ganek, and Kloeckner, "An overview of IBM Service Management," IBM SYSTEMS JOURNAL, vol. 46, pp. 375-385, 2007.

[Gartner, 1997] Gartner, "TCO Analyst - Next Generation Total Cost of Ownership Methodology," 1997.

[Gartner, 2003] Gartner, "Distributed Computing - Chart of Accounts," 16 June 2003, 2003.

[Gillen, et al., 2007] Gillen, Perry, Dowling, and Grieser, "The Relationship Between IT Labor Costs and Best Practices for Systems Management Server," 2007.

[Gillen, et al., 2007] Gillen, Perry, and Waldman, "Understanding the Business Benefits Associated with x86 64 -Bit Windows Server," September, 2007.

[Gogolla, et al., 2005] Gogolla, Bohling, and Richters, "Validating UML and OCL models in USE by automatic snapshot generation," Software and Systems Modeling, vol. 4, pp. 386-398, Wednesday, August 10, 2005 2005.

[Gogolla, et al., 2007] Gogolla, Buttner, and Richters, "USE: A UML-Based Specification Environment for validating UML and OCL," University of Bremen, Bremen 2007.

[Gomolski, 2004] Gomolski, "How to Use IT Cost Metrics Effectively," G00123098, 2004.

[Goulão, et al., 2004a] Goulão, and Abreu: Formalizing Metrics for COTS. In: Proc. of International Workshop on Models and Processess for the Evaluation of COTS Components (MPEC 2004) at ICSE 2004, Edimburgh, Scotland, pp. 37-40. IEE (2004a)

[Goulão, et al., 2004b] Goulão, and Abreu: Cross-Validation of a Component Metrics Suite. In: Proc. of IX Jornadas de Ingeniería del Software y Bases de Datos, Málaga, Spain (2004b)

[Goulão, et al., 2005a] Goulão, and Abreu: Formal Definition of Metrics upon the CORBA Component Model. In: Proc. of First International Conference on the Quality of Software Architectures, QoSA'2005, Erfurt, Germany. Springer (2005a)

[Goulão, et al., 2005b] Goulão, and Abreu: Composition Assessment Metrics for CBSE. In: Proc. of 31st Euromicro Conference - Component-Based Software Engineering Track, Porto, Portugal. IEEE Computer Society (2005b)

[Greschler, et al., 2002] Greschler, and Mangan, "Networking lessons in delivering 'Software as a Service'—Part I," International Journal of Network Management, vol. 12, pp. 317 – 321, 2002.

[Gunasekaran, et al., 2005] Gunasekaran, Williams, and McGaughey, "Performance measurement and costing system in new enterprise," 2005.

[Haes, et al., 2005] Haes, and Grembergen: IT Governance Structures, Processes and Relational Mechanisms: Achieving IT/Business Alignment in a Major Belgian Financial Group. In: Proc. of Proceedings of the 38th Annual Hawaii International Conference on System Sciences, Hawaii, pp. 10. IEEE (2005)

[Harris, 2005] Harris, "IT Complexity May Be the Reason You're Spending More and Gaining Less," 2005.

[Hassan, et al., 1999] Hassan, and Saeed: A framework for determining IT effectiveness: an empirical approach. In: Proc. of Proceedings of the 32nd Hawaii International Conference on System Sciences, Island of Maui, pp. 11. IEEE Computer Society (1999)

[Heine, 2003] Heine, "Management Update: Five Sure Ways to Reduce IT Asset Costs," Gartner, p. 4, 26 March 2003.

[Henry, et al., 1981] Henry, and Kafura, "Software Structure Metrics Based on Information Flow," Transactions on Software Engineering, vol. 7, pp. 510-518, September 1981.

[Herbert, 1996] Herbert, The sciences of the artificial (3rd ed.): MIT Press, 1996.

[Heschl, et al., 2006] Heschl, CISA, and CISM, Overview of International IT Guidance 2nd Edition ed. Rolling Meadows: IT Governance Institute, 2006.

[Ho, et al., 2007] Ho, and Inokuchi: SEM ADC (Auto Defect Classification): How it improves the Cost of Ownership without Risk of Yield Loss. In: Proc. of IEEE/SEMI Advanced Semiconductor Manufacturing Conference. IEEE (2007)

[HP, 2006a] HP, "Putting a price on document-based business processes," 2006a.

[HP, 2006b] HP, "The top five most common hidden imaging and printing infrastructure costs," 2006b.

[HP, 2007] HP: The HP Service Management Framework. http://activeanswers.compaq.com/ERC/downloads/4AA1-3338ENW.pdf, accessed on April, 2008

[Hsieh-Hua Yang, et al., 2008] Hsieh-Hua Yang, Hung-Jen Yang, Jui-Chen Yu, and Hu, "Multinomial Regression Model for In-service Training," International Journal of Mathematical Models and Methods in Applied Sciences, vol. 2, p. 6, 2008.

[Hurkens, et al., 2006] Hurkens, Valk, and Wynstra, "Total Cost of Ownership in the Services Sector A Case Study," The Journal of Supply Chain Management, pp. 27-37, Winter 2006 2006.

[Iansiti, et al., 2006] Iansiti, Sarnoff, and Favaloro, "Enterprise IT Capabilities and Business Performance," March 16, 2006.

[IBM, 2007] IBM: The IBM Process Reference Model for IT (PRM-IT). http://www-306.ibm.com/software/tivoli/governance/servicemanagement/welcome/process_reference.html, accessed on November, 2007

[IBM, 2008] IBM: Rational Rose - Product line. http://www-01.ibm.com/software/awdtools/developer/rose/index.html, accessed on February, 2008

[Ionescu-Graff, et al., 2005] Ionescu-Graff, Newman, Chu, Trivedi, Tang, and Zhu, "Quantifying the value proposition of advanced fault management systems in MPLS core networks," Bell Labs Technical Journal, vol. 10, pp. 157 - 167, 2005.

[ISACA, 2008a] ISACA: COBIT 4.1 Executive Summary and Framework. http://www.isaca.org/AMTemplate.cfm?Section=Downloads&Template=/ContentManagement/ContentDisplay.cfm&ContentID=34172, accessed on August, 2008

[ISACA, 2008b] ISACA: Common Objectives for Information and related Technology (COBIT 4.1). http://www.isaca.org/cobit, accessed on April, 2008

[ISACA, 2008c] ISACA: Servicing IT Governance Professionals. http://www.isaca.org/, accessed on August, 2008

[ISO/IEC, 2004] ISO/IEC, "Schematron ISO/IEC FDIS 19757-3," 2004.

[ITAA, 2008] ITAA: Information Technology Definition Aggregation. http://www.itaa.org/es/docs/Information%20Technology%20Definitions.pdf, accessed on August, 2008

[ITGI, 2008a] ITGI, Mapping of ITIL v3 with COBIT 4.1: IT Governance Institute, 2008a.

[ITGI, 2008b] ITGI: IT Governance Institute. http://www.itgi.org/, accessed on August, 2008

[itSMF, 2008] itSMF: The IT Service Management Forum Portugal. http://www.itsmf.pt/, accessed on August, 2008

[Jacobson, 1995] Jacobson, "The Confused World of OOA & OOD," JOOP, September 1995.

[Jones, et al., 2006] Jones, and Desai, "The Reference Guide To Data Center Automation," 2006.

[Jutras, 2007] Jutras, "The Total Cost of ERP Ownership in Mid-Size Companies," July, 2007.

[Juurakko, 2004] Juurakko, "Measuring and Managing The Total Cost Of Ownership For TETRA Networks," 2004.

[Kaimann, 1974] Kaimann, "Coefficient of network complexity," Management Science, vol. 21, pp. 172-177, 1974.

[Kaimann, 1975] Kaimann, "Coefficient of network complexity: Erratum," Management Science, vol. 21, pp. 1211-1212 1975.

[Kantin, et al., 2006] Kantin, Nick, and Sullivan, "The Future Sales Force - A Consultative Approach," 2006.

[Kendall, 1962] Kendall, Rank Correlation Methods: orton.catie.ac.cr, 1962.

[Kimfong, et al., 2003] Kimfong, and Phillip: Strategic decisions on technology selections for facilitating a network/systems laboratory using real options \& total cost of ownership theories. In: Proc. of Proceedings of the 4th conference on Information technology curriculum, Lafayette, Indiana, USA. ACM (2003)

[Kirwin, et al., 2002] Kirwin, Mieritz, and D'Angelo, "The Total Cost of Ownership Index: Defining the Database," 16 October, 2002.

[Kirwin, 2003a] Kirwin, "Management Update: Total Cost of Ownership Analysis Provides Many Benefits," IGG-08272003-01, 2003a.

[Kirwin, 2003b] Kirwin, "CIO Update: To Control TCO, It Must Be Measured and Managed," InSide Gartner 16 April, 2003b.

[Kirwin, et al., 2005] Kirwin, and Mieritz, "Control Distributed Computing TCO by Keeping an Eye on Complexity Creep," G00129518, August, 2005.

[Lavazza, 2007] Lavazza: Beyond Total Cost of Ownership: Applying Balanced Scorecards to Open-Source Software. In: Proc. of International Conference on Software Engineering Advances, Varese (Italy). IEEE Computer Society (2007)

[Logan, 2004] Logan, "Monitoring and State Transparency of Distributed Systems," Snowbird, Utah, USA 22 September, 2004.

[MacCormack, 2003] MacCormack, "Evaluating Total Cost of Ownership for Software Platforms: Comparing Apples, Oranges and Cucumbers," April, 2003.

[Machuca, 2006] Machuca, "Expenditures Study for Network Operators," Technische Universität München, Arcisstrasse 21, D-80290 München 2006.

[McCabe, 1976] McCabe, "A complexity measure," IEEE Transactions on Software Engineering, vol. 4, pp. 308-320, December 1976.

[McGuinness, et al., 2004] McGuinness, and Harmelen, "OWL Web Ontology Language Overview," W3C, Recommendation 10 February, 2004.

[Merriam-Webster, 2008] Merriam-Webster: Complexity definition. http://www.merriam-webster.com/thesaurus/complexity, accessed on February, 2008

[Mertins, et al., 2008] Mertins, Ruggaber, Popplewell, and Xu, "An Approach for the Evaluation of the Agility in the Context of Enterprise Interoperability " in Enterprise Interoperability III: Springer London, 2008, pp. 3-14.

[Microsoft, 1999] Microsoft, "Microsoft Business Value - Windows vs. LINUX Total Cost of Ownership Overview," 1999.

[Msadek, 2003] Msadek, "Managing technology to reduce total cost of ownership and secure assets," DataBus, July 2003.

[MSDN, 2008] MSDN: Windows Management Instrumentation. http://msdn.microsoft.com/en-us/library/aa394582.aspx, accessed on July, 2008

[MSFT, 2003] MSFT, "Active Directory LDAP Compliance," October, 2003.

[MSFT, 2004] MSFT, "Overview of the System Definition Model (SDM)," Microsoft Corporation April, 2004.

[MSFT, 2005] MSFT: Dynamics Systems Initiative (DSI). http://www.microsoft.com/windowsserversystem/dsi/default.mspx, accessed on March, 2005

[MSFT, 2007] MSFT, "Managing Smart: Driving the Cost Out of IT Infrastructure," Microsoft Corporation 2007.

[MSFT, 2008a] MSFT: Microsoft Operations Framework 4.0. http://www.microsoft.com/mof, accessed on March, 2008

[MSFT, 2008b] MSFT: Service Models: The Three Key Relationships. http://technet.microsoft.com/en-us/library/bb977447(TechNet.10).aspx, accessed on January, 2008

[Novell, 2008] Novell: Why Choose Novell eDirectory? http://www.novell.com/products/edirectory/whychoose.html, accessed on August, 2008

[Novotný, 2004] Novotný: 'CASE Tool for developing XML Schemas and XSLT', Faculty of mathematics, physics and informatics - Comenius University, 2004

[O'Brien, 2003] O'Brien, "Management Update: IT Asset Management Is Mandatory, Not Optional," InSide Gartner 20 August, 2003.

[Objecteering, 2008] Objecteering: **Objecteering**. http://www.objecteering.com/, accessed on April, 2008

[ODP, 2008] ODP: The Open Directory Project. http://www.apple.com/server/macosx/technology/opendirectory.html, accessed on August, 2008

[OGC, 2000] OGC: the IT Infrastructure Library (ITIL). http://www.itil-officialsite.com/home/home.asp, accessed on January, 2008

[OGC, 2002] OGC, IT Infrastructure Library (ITIL) - Planning to Implement Service Management (Version 2). London: The Stationery Office, 2002.

[OGC, 2007a] OGC, IT Infrastructure Library (ITIL) - Service Strategy (Version 3). London: The Stationery Office), 2007a.

[OGC, 2007b] OGC, IT Infrastructure Library (ITIL) - Service Transition (Version 3). London: The Stationery Office), 2007b.

[OGC, 2007c] OGC, IT Infrastructure Library (ITIL) - Service Design (Version 3). London: The Stationery Office), 2007c.

[OGC, 2007d] OGC, IT Infrastructure Library (ITIL) - Continual Service Improvement (Version 3). London: The Stationery Office), 2007d.

[OGC, 2007e] OGC, IT Infrastructure Library (ITIL) - Service Operation (Version 3). London: The Stationery Office), 2007e.

[OMG, 2004] OMG, "Unified Modeling Language (UML) Specification : Infrastructure, version 2.0," 2004.

[OMG, 2007a] OMG: UML Infrastructure specification OMG, The Object Management Group (2007a)

[OMG, 2007b] OMG: UML Superstructure specification OMG, The Object Management Group (2007b)

[OMG, 2007c] OMG, "MOF 2.0/XMI Mapping, Version 2.1.1," December, 2007c.

[OpenLDAP, 2008] OpenLDAP: The OpenLDAP website. http://www.openldap.org/, accessed on August, 2008

[Opsware, 2006] Opsware, "Selecting a Flexible, Custom Platform to Automate Your Data Center Management," 2006.

[Pascoe, 1966] Pascoe, "Allocation of resources-CPM," Revue Française de Recherche Opérationelle, vol. 38, pp. 31-38, 1966.

[Perry, et al., 2007] Perry, and Gillen, "Demonstrating Business Value: Selling to Your C-Level Executives," 2007.

[Pispa, et al., 2003] Pispa, and Eriksson, "Aligning organizations and their information technology infrastructure: how to make information technology," Production Planning & Control, vol. 14, pp. 193 - 200, 2003.

[Plummer, 2005] Plummer, "Findings From the 'Agility' Research Meeting: IT's Role in Agility Can Be Measured and Improved," 26 September, 2005.

[QUASAR, 2008] QUASAR: QUantitative Approaches on Software Engineering And Reengineering. http://www-ctp.di.fct.unl.pt/QUASAR/index.html, accessed on August, 2008

[Rasmussen, 2006a] Rasmussen, "Electrical Efficiency Modeling of Data Centers," 2006a.

[Rasmussen, 2006b] Rasmussen, "Implementing Energy Efficient Data Centers," 2006b.

[Rekkas, 2008] Rekkas, "Approximate inference for the multinomial logit model," Statistics and Probability Letters, 2008.

[Richters, 2001] Richters: The USE tool: A UML-based specification environment. http://www.db.informatik.uni-bremen.de/projects/USE/, accessed on December, 2007

[Rosenberg, 2004] Rosenberg, "The Myths of usability ROI," September, 2004.

[Rumbaugh, 1996] Rumbaugh, "To form a more perfect union: unifying the OMT and Booch methods," JOOP, vol. 8, January 1996.

[Rymer, et al., 2003] Rymer, and Cormier, "The Total Economic Impact of Developing and Deploying Applications on Microsoft and J2EE/Linux Platforms," September 4, 2003.

[Salle, 2004] Salle, "IT Service Management and IT Governance: Review, Comparative Analysis and their Impact on Utility Computing," June, 2004.

[Sawyer, 2003] Sawyer, "Reducing the Hidden Costs Associated with Upgrades of Data Center Power Capacity," 2003.

[Scott, et al., 2006] Scott, Holub, and Pultz, "Organizing for IT Infrastructure and Operations: Trends and Best Practices," 23 January, 2006.

[Scrimshaw, 2002] Scrimshaw, "Total cost of ownership: A review of the literature," Westminster, London 2002.

[Shackelford, et al., 2006] Shackelford, McGettrick, Sloan, and Topi, "Computing Curricula 2005: The Overview Report," Proceedings of the 37th SIGCSE technical symposium on Computer science education, 2006.

[Sigurdsson, et al., 2004] Sigurdsson, Thorsteinsson, and Stidsen, "Cost Optimization Methods in the Design of Next Generation Networks," in IEEE Communications Magazine: IEEE, 2004, pp. 118-122.

[Sirkemaa, 2002] Sirkemaa: IT infrastructure management and standards. In: Proc. of Coding and Computing, 2002. Proceedings of the International Conference on Information Technology, Las Vegas, pp. 201- 206. IEEE Computer Society (2002)

[Smith, 2003] Smith, "Ontology," in Blackwell Guide to the Philosophy of Computing and Information, Floridi, L., Ed. Oxford: Blackwell Scientific Publications, 2003, pp. 155-166.

[Sophos, 2006] Sophos, "Cutting the cost and complexity of managing endpoint security," July, 2006.

[Steeples, et al., 1993] Steeples, Tai, Fess, and Fletcher, "Cost of Ownership Benefits Using Multiply Charged Ion Implants on Conventional Medium and High Current Implanters," Hudson, Massachusetts 223-228, 1993.

[Stullich, 2006] Stullich, "Oracle Internet Directory," Oracle June,, 2006.

[Sun, 2008] Sun: Sun Java System Directory Server Enterprise Edition 6.3. http://docs.sun.com/app/docs/doc/820-2757/fxjbo?a=view, accessed on August, 2008

[Symons, et al., 2006] Symons, Orlov, Brown, and Bright, "COBIT Versus Other Frameworks: A Road Map To Comprehensive IT Governance," 38442, January 5, 2006.

[Symons, et al., 2008] Symons, Orlov, Brown, and Bright, "IT Governance For The New Ecosystem," 45253, April 23, 2008.

[systems, 2008a] systems: Export package to XMI. http://www.sparxsystems.com.au/EAUserGuide/index.html?exporttoxmi.htm, accessed on April, 2008

[Systems, 2008b] Systems: Enterprise Architect. http://www.sparxsystems.com/products/ea/index.html, accessed on January, 2008

[Takahashi, et al., 2007] Takahashi, Kon, Akiyama, and Jinguji, "A Practical Network Management System Based on an Organization Hierarchy Mobile Agent Model," Network System Development Department, Yokosuka February, 2007.

[Tigris, 2008] Tigris: ArgoUML. http://argouml.tigris.org/, accessed on February, 2008

[Torell, 2005] Torell, "Network-Critical Physical Infrastructure: Optimizing Business Value," 08 February, 2005.

[TriActive, 2001] TriActive, "Calculating Your Total Cost of Ownership," September, 2001.

[Troni, et al., 2005] Troni, and Fiering, "TCO Comparison of Desktops vs. Notebooks, 2005-2006 Update," 13 December, 2005.

[Troni, et al., 2006] Troni, and Silver, "Use Processes and Tools to Reduce TCO for PCs, 2005-2006 Update," 13 January, 2006.

[Troni, et al., 2007] Troni, and Dulaney, "PDA and Smartphone TCO: 2007 Update," G00147540, 10 May, 2007.

[Vanhoucke, et al., 2008] Vanhoucke, Coelho, Debels, Maenhout, and Lv, "An evaluation of the adequacy of project network generators with systematically sampled networks," European Journal of Operational Research, 2008.

[W3C, 2008a] W3C: World Wide Web Consortium. http://www.w3.org/, accessed on August, 2008

[W3C, 2008b] W3C: Service Modeling Language (SML) Working Group. http://www.w3.org/XML/SML/, accessed on August, 2008

[Wang, et al., 2004] Wang, Hu, Yuan, Zhang, and Wang, "Friends Troubleshooting Network: Towards Privacy-Preserving, Automatic Troubleshooting," University of California, Berkeley February, 2004.

[Wang, et al., 2005] Wang, Cao, Kong, Cao, Shen, and Dai, "Linux, Windows NT, and Windows 2000/2003 TCO Research in Enterprise Computing," March, 2005.

[Watt, 2005] Watt: Enhance IT Infrastructure Library service management capabilities. https://www.ibm.com/developerworks/autonomic/library/ws-itil/index.html

[Webster, 2004] Webster, "Getting the most out of ROI and TCO," Nashua, NH03062 16 February, 2004.

[Weill, et al., 2002] Weill, Subramani, and Broadbent, "IT Infrastructure for Strategic Agility," MIT Sloan School of Management, p. 30, April 2002.

[Weill, 2007] Weill, "Compilation of MIT CISR Research on IT Portfolios, IT Savvy and Firm Performance (2000-2006)," 2007.

[Wendy, et al., 1994] Wendy, and Dolores, Software Error Analysis: Silicon Press, 1994.

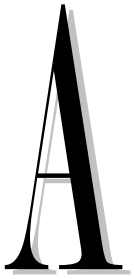
[Wendy, et al., 1995] Wendy, and Dolores, Software Error Analysis: Silicon Press, 1995.

[Wipro, et al., 2007] Wipro, and GCR, "Reducing TCO with Windows Vista - Quantified Savings for Mobile PCs," September, 2007.

[Zachary, et al., 2007] Zachary, Neville, Fowlkes, and Hoffman, "Human Total Cost of Ownership: The Penny Foolish Principle at Work," 2007.

[Zeilenga, 2006] Zeilenga, "Lightweight Directory Access Protocol (LDAP): Technical Specification Road Map," RFC 4510, June, 2006.

[Zhou, et al., 2006] Zhou, Zhang, and Xie, "Virtual Disk based Centralized Management for Enterprise Networks," Pisa, Italy September, 2006.



Appendix A – SDM Definitions

Contents

This appendix presents the more details regarding some of the SDM definitions used in this dissertation.

A.1 Introduction

The first release of the SDM can be used to describe configurations and relationships among elements of a connected system, the *modeled system*. In this dissertation the *modeled system* was IT infrastructures.

A SDM document consists of definitions of the important objects and relationships of the *modeled system*. Definition is the base from which other, more specific definitions are derived, such as *object*, *relationship*, *constraint*, *setting* and *flow*. Each definition is identified by a simple name and can include a description, settings (setting declarations) and values for settings (setting values).

The SDM meta-model is based on an object-relational model. *Object definitions* are used to describe elements that exist in the *modeled system*. *Relationship definitions* are used to identify the links between the objects. The SDM further refines *objects* and *relationships* to capture semantics that are important in the SDM. In particular, objects are divided into *systems*, *endpoints* and *resources* and relationships are divided into *communication*, *containment*, *hosting*, *delegation* and *reference*. In the context of this dissertation we used all object types and the *communication* and *containment* relationships.

A.2 SDM object definitions

Objects are specified via definitions and are used to represent both the logical and the physical aspects of a *modeled system*. In the System Definition Model, objects are divided into three systems, resources and endpoints.

A.2.1 Systems

In the System Definition Model, systems represent collections of resources that perform well-defined tasks and collections of systems that interact to perform well-defined tasks. Interaction among systems must be explicitly modeled using communication relationships.

A.2.2 Resources

Resources represent fundamental units of behavior. Each resource may express dependencies on other resources that it may require to perform its modeled behavior. Resources within a system boundary cannot express dependencies on resources outside that boundary.

A.2.3 Endpoints

Endpoints allow systems to expose communication through communication relationships with other systems. Since resources cannot have dependencies that cross system boundaries, endpoints must be used to model the required interaction that allows a system to operate correctly.

A.3 Relationship definitions

Relationships capture aspects of the interactions that occur among objects. All relationships are binary and directed (apply from one object to another). In addition to capturing the interaction among objects, relationships can place constraints on the objects that participate in the relationship and can flow configuration information between the participants.

A.3.1 Containment relationship

A containment relationship indicates that one object can contain another object. Containment relationships define the composition of and limit the structure of an SDM system model.

A containment relationship also defines the lifetime of an object, the owner of an object and where an object appears in the structure of a *modeled system*. If there is a single parent container for an object, the lifetime of the parent bounds the lifetime of the contained object. A parent is also said to own a contained object. Thus, the parent has control over the visibility of a contained object and can determine whether the object or parts of the object are exposed. Finally, a parent provides contextual information for an object.

A.3.2 Hosting relationship

A hosting relationship defines both an object's lifetime and the environment in which it exists and/or executes.

In order to be instantiated, an object must have at least one host. The instantiated object is said to be a guest of its host object. A hosting relationship creates an instance of a guest object on a host object. The hosting relationship also defines both a host object and the lifetime of an associated guest object. Thus, the lifetime of a guest object is bounded by the lifetime of the host object. A guest can be supported by multiple hosts through multiple hosting relationships.

For a system that contains many resources to be hosted on another system, all of the resources in the guest system must have hosting relationships to at least one resource on the host system.

A.3.3 Communication relationship

Communication relationships are used to model the interaction and communication that occurs among systems. Communication relationships can only be established among systems that expose endpoints. If a communication relationship does not exist between a set of endpoints, then a connection cannot be established between those endpoints.

A.3.4 Reference relationship

Reference relationships are used to capture dependencies between resources or systems that are required for correct operation but are not considered part of the execution environment of the dependent object.

A.3.5 Delegation relationship

A delegation relationship forwards the interaction with a proxy to an object instance that implements the behavior exposed by the proxy. A common example of delegation is forwarding a communication relationship from an endpoint on a parent system to an endpoint on a contained system.

A.4 Setting definitions

Setting definitions are used to create simple value elements, which can then be used to store configuration information. Setting definitions are defined in XSD schemas.

All definitions can expose settings members, which are called “setting declarations” within the XML schema. These members are used to describe the configuration values that are associated with the definition.

A.5 Flow definitions

Flow definitions specify particular transforms applied to values for settings. The latter are called setting instances. Whereas *SettingValue* statements provide static setting instances at design time, flow enables dynamic setting instances.

Flow passes setting instances within an object definition (between members of an object definition) and between participants in relationships. As part of a flow, transformations can be specified that combine, separate, or calculate new setting instances.

A.6 Constraints definition

Constraints are used to model restrictions over the allowed set of relationships in which an instance can participate and to identify restrictions on setting values of members of a definition or on the participants in a relationship. Constraints capture detailed requirements that depend on the configuration of objects involved in a relationship. The three types of constraints are *setting constraint*, *relationship constraint* and *object constraint*.

A.6.1 Setting constraint

A *setting constraint* specifies the possible setting values. All setting constraints use a constraint definition to evaluate the setting values. The constraint definition uses settings declarations (of settings definitions) to identify the values it constrains.

A.6.2 Relationship constraint

A *relationship constraint* specifies the relationships that can or must be present for an object. A relationship constraint is used to constrain the relationships in which an object can participate. A relationship constraint identifies the relationship definition, the object definition of the instance at the other end of the relationship (optional) and the cardinality of the relationship. The constraint is given a name so that it can be identified in error messages. The body of the relationship constraint contains predicates about both the relationship and the instances at the other end of the relationship.

A.6.3 Object constraint

An object constraint specifies the objects that can or must be present in a relationship. An object constraint describes a constraint to one or both of the roles of a relationship. The constraint has a name to aid identification of the constraint in the event that it fails. The constraint contains a list of

settings constraints targeted at the types associated with the roles. It may further constrain the instance to be of an object derived from the definition associated with the role.

A.7 Members

A definition can use other definitions contained within it. Such definitions are called members of the overall definition. Members can be:

- Objects (system, resource, or endpoints);
- Relationships (delegation, communication, reference, hosting, or containment);
- Settings;
- Constraints;
- Flow members.

Members allow a definition to reuse another definition in a way that is customized to its particular application.

A.7.1 Object members

Object members can be declared to be created at the same time that a system is created (value semantics) or can be created by an explicit new operation that occurs at some later time (reference semantics).

A.7.2 Relationship members

Relationship members define the relationships that object members will participate in when they are created. If an object member is contained by its parent, then a containment relationship member will be declared between the member and the containing definition.

If the object member is delegated, then a delegation relationship member would be defined between the object member and a source object member. Communication relationship members can be declared among endpoints that communicate. Dependency relationship members (reference and hosting) can be declared between the dependent and source object members.

A.7.3 Setting members

Setting members are used to identify configuration information that is associated with the definition. Setting members are based on setting definitions.

SettingValue statements can be used to make value assignments by the definition that declares the setting member to define the default values for the setting a definition that extends another definition to provide default or fixed values for the base definition members that reference a definition and through member paths that terminate in the member that references the definition flow along relationships.

A.7.4 Flow members

Flow members are used to define the flow of configuration between members. They collect input values from settings on members, perform some processing on that information and then distribute the results to settings on members.

A.7.5 Constraint members

Constraint members are used to narrow the set of relationships in which a particular object can participate, to narrow the set of objects that can participate in a particular relationship, or to restrict the value of a setting. Constraint memberships identify constraints on an object or relationship that may target the settings of that object or relationship. Constraint memberships may also constrain the interactions associated with that object or relationship.

A.8 Instances

The process of creating instances allows the evaluation of constraints to ensure correctness based on the models.

Instance creation involves construction (through the process of expansion), applying settings (through the process of flow) and validation (through the process of constraint evaluation).

A.9 Managers

Managers are the mechanism by which types and relationships insert custom behavior into the run-time environment. There are several roles that a manager can support for each type that it manages: the manager can participate in the installation of the type, provide a *Common Language Runtime (CLR)* representation of the type, be involved in policy decisions about how bindings between types are resolved and provide the implementation for constraints and flow.

The SDM definition references a manager element inside the same SDM file and identifies the name of the CLR class that supports the definition. The manager in turn references an assembly that contains the class definition. It is that class in the assembly that plays the role of manager for the SDM type.

B

Appendix B – ITILib

Contents

This appendix presents the ITILib, which is the SDM library that contains all the metrics and operations that supports most of the performed ITI evaluations.

Table B.1 presents the most used attributes and has the meta class, the corresponding attributes and the description of each attribute.

Table B.1 — Most used attributes defined in SDM library

Meta class	Attributes	Used to
Definition	*Name: String*	Identify the name of the object. E.g. every site and server has a name.
	objectClass: String	*Identify the object class (e.g. Site, Server, nTDSConnection, etc.)*
	CreationDate: Date	Identify the date of creation.
	ChangedDate: Date	Identify the last changed date.
ContainmentDefinition	*ParentDefinition: SystemDefinition*	The *ParentDefinition* is used to specify the instance that contains the member.
	MemberDefinition: ObjectDefinition	The *MemberDefinition* attribute is used to specify the instance that is contained.
CommunicationDefinition	*ClientDefinition: EndpointDefinition*	The attribute *ClientDefinition* identifies the server that is the source of the information.
	ServerDefinition: EndpointDefinition	The attribute *ServerDefinition* identifies the server that is the destination of the information.
	ReplInterval: Integer	The attribute *replInterval* is used to specify the number of minutes between each exchange of data, due to a bandwidth constraints for example.
	Cost: Integer	Attribute used to specify the cost of specific connection. Is frequent to have more than one connection to same place (e.g. for backup purposes.) each with a different cost. The connection with the minimum cost is used by default.
Information	*Comments: String*	Used to provide more information regarding the purpose of the SDM document. All these attributes are optional and can be seen in the example of Fig. 3.4 (line 6 to line 11).
	CompanyName: String	
	Copyright: String	
	FriendlyName: String	
	Trademark: String	
Date	*day:Integer*	Used to register the *day, month* and *year* of creation and last change of every ITI object.
	month:Integer	
	year:Integer	

Table B.2 presents all the operations defined in each meta class. There is also a reference where can be obtained more details.

Table B.2 — Operations defined in SDM library

Meta class	Operation	Description
ObjectDefinition	*ContainmentDef()*	Page 153 (Fig. B.3)
	Container()	Page 153 (Fig. B.4)
SystemDefinition	*Site()*	Page 158 (Fig. B.12)
	IsServer()	Page 162 (Fig. B.22)
	nextServerPath()	Page 157 (Fig. B.11)
	longestPath()	Page 157 (Fig. B.11)
	comparePaths(lgPath: Set(SystemDefinition), path: Set(SystemDefinition))	Page 157 (Fig. B.11)
	Connections()	Page 159 (Fig. B.15)
	NTDSConnections()	Page160 (Fig. B.16)
	SiteLinks()	Page *160* (Fig. B.17)
	SystemMembers()	Page 158 (Fig. B.13)
	SiteServers()	Page 158 (Fig. B.13)
	ResourceMembers()	Page 159 (Fig. B.14)
	SiteSubnets()	Page 159 (Fig. B.14)

Meta class	Operation	Description
	Intrasite_connections()	Page 161 (Fig. B.18)
	Intersite_connections()	Page 161 (Fig. B.18)
	IncomingSiteLinks()	Page 161 (Fig. B.19)
	OutgoingSiteLinks()	Page 161 (Fig. B.19)
	ConnectedSites()	Page 162 (Fig. B.20)
	ServerSite()	Page 163 (Fig. B.23)
	InputEndpoints()	Page 163 (Fig. B.24)
	OutputEndpoints()	Page 163 (Fig. B.24)
	ConnectedServers()	Page 164 (Fig. B.25)
	Intraserver_FanIn()	Page 164 (Fig. B.26)
	Intraserver_FanOut()	Page 164 (Fig. B.26)
	EndpointMembers()	Page 165 (Fig. B.28)
	IncomingConnections()	Page 166 (Fig. B.29)
	OutgoingConnections()	Page 166 (Fig. B.29)
	FanIn()	Page 166 (Fig. B.30)
	FanOut()	Page 166 (Fig. B.30)
	SSEN()	Page 165 (Fig. B.27)
	SSBN()	Page 167 (Fig. B.32)
	STF()	Page 94 (Fig. 5.16)
	CCM()	Page 87 (Fig. 5.13)
	HKM()	Page 89 (Fig. 5.14)
	SMF()	Page 97 (Fig. 5.18)
ResourceDefinition	*IsSubnet()*	Page 167 (Fig. B.33)
	SubnetSite()	Page 167 (Fig. B.33)
EndpointDefinition	*IsInput()*	Page 153 (Fig. B.2)
	IsOutput()	Page 153 (Fig. B.2)
ContainmentDefinition	*ContainmentMembers()*	Page 162 (Fig. B.21)
CommunicationDefinition	*IsNTDSConnection()*	Page 160 Fig. B.16
	IsSiteLink()	Page 160 (Fig. B.17)
	IsConnectionInternalInSite(theSite: SystemDefinition)	Page 169 (Fig. B.37)
	IsConnectionIncomingInSite(theSite: SystemDefinition)	Page 169 (Fig. B.37)
	IsConnectionOutgoingInSite(theSite: SystemDefinition)	Page 169 (Fig. B.37)
	IsIncoming(target: SystemDefinition)	Page 170 (Fig. B.38)
	IsOutgoing(target: SystemDefinition)	Page 170 (Fig. B.38)
	Client()	Page 170 (Fig. B.39)
	Server()	Page 170 (Fig. B.39)
Date	*isBefore(t:Date)*	Page 154 (Fig. B.5)
	isAfter(t:Date)	Page 154 (Fig. B.5)
	isEqual(t:Date)	Page 154 (Fig. B.5)
	isBetween(startDate: Date, endDate: Date)	Page 154 (Fig. B.5)
	yearsSince(t:Date)	Page 154 (Fig. B.5)
ITIOperations	*Sites()*	Page 158 (Fig. B.12)
	Servers()	Page 162 (Fig. B.22)
	Subnets()	Page 168 (Fig. B.34)
	Sitelinks()	Page 168 (Fig. B.34)
	Connections()	Page 159 (Fig. B.15)
	TotalSites()	Page 158 (Fig. B.12)
	TotalServers()	Page 162 (Fig. B.22)
	TotalSubnets():	Page 168 (Fig. B.34)
	TotalSitelinks()	Page 168 (Fig. B.34)
	TotalConnections()	Page 159 (Fig. B.15)
	SitesName()	Page 158 (Fig. B.12)
	ServersName()	Page 162 (Fig. B.22)
	SubnetsName()	Page 168 (Fig. B.34)
	SitelinksName()	Page 168 (Fig. B.34)
	ConnectionsName()	Page 159 (Fig. B.15)
	TotalAddedSitesInPeriod(firstDate: Date, lastDate: Date)	Page 155 (Fig. B.6)
	TotalAddedServersInPeriod(firstDate: Date, lastDate: Date)	Page 155 (Fig. B.7)
	TotalAddedSubnetsInPeriod(firstDate: Date, lastDate: Date)	Page 156 (Fig. B.8)

Meta class	Operation	Description
	TotalAddedSitelinksInPeriod(firstDate: Date, lastDate: Date)	Page 157 (Fig. B.10)
	TotalAddedConnectionsInPeriod(firstDate: Date, lastDate: Date)	Page 156 (Fig. B.9))
	TotalAddedSitesNameInPeriod(firstDate: Date, lastDate: Date)	Page 155 (Fig. B.6)
	TotalAddedServersNameInPeriod(firstDate: Date, lastDate: Date)	Page 155 (Fig. B.7)
	TotalAddedSubnetsNameInPeriod(firstDate: Date, lastDate: Date)	Page 156 (Fig. B.8)
	TotalAddedSitelinksNameInPeriod(firstDate: Date, lastDate: Date)	Page 157 (Fig. B.10)
	TotalAddedConnectionsNameInPeriod(firstDate: Date, lastDate: Date)	Page 156 (Fig. B.9)
	TotalChangedSitesInPeriod(firstDate: Date, lastDate: Date)	Page 155 (Fig. B.6)
	TotalChangedServersInPeriod(firstDate: Date, lastDate: Date)	Page 155 (Fig. B.7)
	TotalChangedSubnetsInPeriod(firstDate: Date, lastDate: Date)	Page 156 (Fig. B.8)
	TotalChangedSitelinksInPeriod(firstDate: Date, lastDate: Date)	Page 157 (Fig. B.10)
	TotalChangedConnectionsInPeriod(firstDate: Date, lastDate: Date)	Page 156 (Fig. B.9)
	TotalChangedSitesNameInPeriod(firstDate: Date, lastDate: Date)	Page 155 (Fig. B.6)
	TotalChangedServersNameInPeriod(firstDate: Date, lastDate: Date)	Page 155 (Fig. B.7)
	TotalChangedSubnetsNameInPeriod(firstDate: Date, lastDate: Date)	Page 156 (Fig. B.8)
	TotalChangedSitelinksNameInPeriod(firstDate: Date, lastDate: Date)	Page 157 (Fig. B.10)
	TotalChangedConnectionsNameInPeriod(firstDate: Date, lastDate: Date)	Page 156 (Fig. B.9)

B.1 Generic ITILib operations

We have defined a set of ITI operations in ITILib to support the quantitative evaluation of infrastructures. This section presents operations that we classified as generic, because most of them are used to support others. Fig. B.1 presents an example of generic operations, which are used to support other operations.

ITILib: Generic operations to identify type of objects

```
1  IsServer():Boolean = objectClass = 'server'
2
3  IsSite(): Boolean = objectClass = 'site'
4
5  IsSubnet(): Boolean = objectClass = 'subnet'
6
7  IsSiteLink(): Boolean = objectClass = 'siteLink'
8
9  IsNTDSConnection(): Boolean = objectClass = 'nTDSConnection'
```

Fig. B.1 — objectClass attribute in ITILib operations

There are five similar operations defined in Fig. B.1 (lines 1, 3, 5, 7 and 8). Because they are Boolean, when invoked these operations return true or false, depending on the condition. The attribute *objectClass* was defined by us in the SDM schema to clear identify each type of ITI object and for simplicity reasons.

The *CommunicationDefinition* relationship is used to represent communication links for *sites* and *servers*. Both send and receive data trough endpoints. *IsInput()* and *IsOutput()* are boolean operations created with the purpose of identifying if a given connection are used to receive information or to send information.

ITILib: Check the type of communication definition

```
1  IsInput(): Boolean =
2          CommunicationDefinition.allInstances->exists(ServerDefinition = self)
3
4  IsOutput(): Boolean =
5          CommunicationDefinition.allInstances->exists(ClientDefinition = self)
```

Fig. B.2 — *IsInput() and IsOutput()* ITILib operation

The *ServerDefintion* and *CientDefinition* attributes introduced in section 3.7 are used to identify the source and destination of the information.

The *ContainmentDef()* operation is defined in class ObjectDefinition and is used to identify all containment relationships for a specified object. This operation relies on the operation *first* that, as the name implies, returns the first element.

ITILib: All instances contained in a particular object

```
1  ContainmentDef(): ContainmentDefinition = ContainmentDefinition.allInstances
2                  select(MemberDefinition = self)
3
```

Fig. B.3 — *ContainmentDef()* ITILib operation

The operation *Container()*, uses the *ContainmentDef()* ITILib operation to identify all container relationships for a specific *SystemDefinition* object.

ITILib: Operation to identify the parent container of an object

```
1  Container(): SystemDefinition = ContainmentDef().
2          ParentDefinition.oclAsType(SystemDefinition)
```

Fig. B.4 — *Container()* ITILib operation

To allow the analysis of the ITI objects we defined a set of operations that can be used to work with dates. The class Date defined in Fig. B.5 has four operations, *isBefore()*, *isAfter()*, *isEqual()* and *isBetween().*

ITILib: Operations to work with dates

```
1   class Date
2       attributes
3         day:Integer
4         month:Integer
5         year:Integer
6       operations
7         isBefore(t:Date): Boolean =
8          if self.year = t.year then
9            if self.month = t.month then
10             self.day < t.day
11           else
12             self.month < t.month
13           endif
14         else
15           self.year < t.year
16         endif
17
18        isAfter(t:Date): Boolean =
19         if self.year = t.year then
20           if self.month = t.month then
21             self.day > t.day
22           else
23             self.month > t.month
24           endif
25         else
26           self.year > t.year
27         endif
28
29        isEqual(t:Date): Boolean =
30         self.year  = t.year and self.month = t.month and self.day   = t.day
31
32       isBetween(startDate: Date, endDate: Date): Boolean =
33         self.isEqual(startDate) or
34         self.isEqual(endDate) or
35         self.isAfter(startDate) and self.isBefore(endDate)
36  end --Date
```

Fig. B.5 — Class *Date()* defined in ITILib

The operation *TotalAddedSitesInPeriod()* (defined in line 1 and line 2 of Fig. B.6) receives two dates as input and returns the number of sites added to the ITI between these two dates. Notice that this operation relies on the operation *isBetween()* defined earlier in class *Date*.

ITILib: Countable or sizing operations using dates to identify added objects

```
1   TotalAddedSitesInPeriod(firstDate: Date, lastDate: Date): Integer =
2                                   Sites()->select(CreationDate.isBetween(firstDate, lastDate))->size
3
4   TotalAddedSitesNameInPeriod(firstDate: Date, lastDate: Date): Bag(String) =
5                                   Sites()->select(CreationDate.isBetween(firstDate, lastDate)).Name
6
7   TotalChangedSitesInPeriod(firstDate: Date, lastDate: Date): Integer =
8                                   Sites()->select(ChangedDate.isBetween(firstDate, lastDate))->size
9
10  TotalChangedSitesNameInPeriod(firstDate: Date, lastDate: Date): Bag(String) =
11                                  Sites()->select(ChangedDate.isBetween(firstDate, lastDate))->Name
```

Fig. B.6 — Total *sites* added and changed in periods

The operation *TotalAddedSitesNameInPeriod() (*defined in line 4 and line 5) is similar to the previous operation, however instead of return the number of *sites* added, return the name of the *sites* added to the ITI in the specified dates.

Instead of knowing the number or the name of the *sites* added to the ITI in a specified period, it may be required to identify the number of changes in *sites* or the name of the *sites* changed in a specified period. The following operations *TotalChangedSitesInPeriod()* and *TotalChangedSitesNameInPeriod()*, allow us to do this.

The same requirements may be necessary for *servers*. It may be interesting to know the number or the names of *servers* added or changed in a specified period of time.

ITILib: Countable or sizing operations using dates to identify changed objects

```
1   TotalAddedServersInPeriod(firstDate: Date, lastDate: Date): Integer =
2                                   Servers()->select(CreationDate.isBetween(firstDate, lastDate))->size
3
4   TotalAddedServersNameInPeriod(firstDate: Date, lastDate: Date): Bag(String) =
5                                   Servers()->select(CreationDate.isBetween(firstDate, lastDate)).Name
6
7   TotalChangedServersInPeriod(firstDate: Date, lastDate: Date): Integer =
8                                   Servers()->select(ChangedDate.isBetween(firstDate, lastDate))->size
9
10  TotalChangedServersNameInPeriod(firstDate: Date, lastDate: Date): Bag(String) =
11                                  Servers()->select(ChangedDate.isBetween(firstDate, lastDate)).Name
```

Fig. B.7 — Total *servers* added and changed in periods

As for *sites* and *servers*, the same applies to *subnets*. It may be interesting to know the number or the names of *subnets* added or changed in a specified period of time.

ITILib: Countable or sizing operations to identify added objects of type subnet

```
1   TotalAddedSubnetsInPeriod(firstDate: Date, lastDate: Date): Integer =
2                                   Subnets()->select(CreationDate.isBetween(firstDate, lastDate))->size
3
4   TotalAddedSubnetsNameInPeriod(firstDate: Date, lastDate: Date): Bag(String) =
5                                   Subnets()->select(CreationDate.isBetween(firstDate, lastDate)).Name
6
7   TotalChangedSubnetsInPeriod(firstDate: Date, lastDate: Date): Integer =
8                                   Subnets()->select(ChangedDate.isBetween(firstDate, lastDate))->size
9
10  TotalChangedSubnetsNameInPeriod(firstDate: Date, lastDate: Date): Bag(String) =
11                                  Subnets()->select(ChangedDate.isBetween(firstDate, lastDate)).Name
```

Fig. B.8 — Total *subnets* added and changed in periods

To understand what connections were changed or created in specified period of time, the same principles were applied to connections among servers.

ITILib: Countable or sizing operations to identify changed objects of type subnet

```
1   TotalAddedConnectionsInPeriod(firstDate: Date, lastDate: Date): Integer =
2                                   Connections()->select(CreationDate.isBetween(firstDate, lastDate))->size
3
4   TotalAddedConnectionsNameInPeriod(firstDate: Date, lastDate: Date): Bag(String) =
5                                   Connections()->select(CreationDate.isBetween(firstDate, lastDate)).Name
6
7   TotalChangedConnectionsInPeriod(firstDate: Date, lastDate: Date): Integer =
8                                   Connections()->select(ChangedDate.isBetween(firstDate, lastDate))->size
9
10  TotalChangedConnectionsNameInPeriod(firstDate: Date, lastDate: Date): Bag(String) =
11                                  Connections()->select(ChangedDate.isBetween(firstDate, lastDate)).Name
```

Fig. B.9 — Total *connections* added and changed in periods

To identify *sitelinks* added or changed in the ITI in a specified period of time, we have created the following operations.

ITILib: Countable or sizing operations to identify added objects of type sitelink

```
1   TotalAddedSitelinksInPeriod(firstDate: Date, lastDate: Date): Integer =
2                                   Sitelinks()->select(CreationDate.isBetween(firstDate, lastDate))->size
3
4   TotalAddedSitelinksNameInPeriod(firstDate: Date, lastDate: Date): Bag(String) =
5                                   Sitelinks()->select(CreationDate.isBetween(firstDate, lastDate)).Name
6
7   TotalChangedSitelinksInPeriod(firstDate: Date, lastDate: Date): Integer =
8                                   Sitelinks()->select(ChangedDate.isBetween(firstDate, lastDate))->size
9
10  TotalChangedSitelinksNameInPeriod(firstDate: Date, lastDate: Date): Bag(String) =
11                                  Sitelinks()->select(ChangedDate.isBetween(firstDate, lastDate)).Name
```

Fig. B.10 — Total *sitelinks* added and changed in periods

ITILib: operations used to work with paths

```
1   nextServerPath(): Set (SystemDefinition) =
2                                   self.ConnectedServers().ConnectedServers()->asSet-> excluding(self)
3
4   longestPath(): Set(SystemDefinition) =
5               self.comparePaths(oclEmpty(Set(SystemDefinition)), oclEmpty(Set(SystemDefinition))) ->
6               excluding(self)
7
8   comparePaths(lgPath: Set(SystemDefinition),  path: Set(SystemDefinition)): Set(SystemDefinition) =
9           if self.nextServerPath()->isEmpty() then
10              if path->size+1 > lgPath->size then
11                 path->including(self)
12              else
13                 lgPath
14              endif
15          else
16             self.nextServerPath()->iterate(elem: SystemDefinition; acc:  Set(SystemDefinition) =
17                     path->including(self) | if acc->excludes(elem) then
18                                                 elem.comparePaths(lgPath, acc)
19                                             else
20                                                 if acc->size > lgPath->size then
21                                                    acc
22                                                 else
23                                                    lgPath
24                                                 endif
25                                             endif)
26          endif
```

Fig. B.11 — Paths ITILib operations

B.2 ITILib operations for sites

We have defined in ITILib a set of operations to quantitative evaluate different aspects of ITI objects of 'site' kind. The operation with the name *Sites()* (line 1 and 2 of Fig. B.1) return all ITI objects of 'site' kind that are present in an ITI. In the context of SDM, objects of 'site' kind are represented as instances of type *SystemDefinition*. The operation *Sites()* rely on the operation *IsSite()* described earlier to identify from all instances of type *SystemDefinition* those that are of the 'site' kind. The operation IsSite() looks into the value of the attribute objectClass to select the *SystemDefinition* objects of the 'site' kind.

ITILib: Operations defined for sites

```
1   Sites(): Set(SystemDefinition) =
2           SystemDefinition.allInstances -> select(IsSite())
3
4   SitesName(): Bag(String) =
5                       Sites().Name
```

Fig. B.12 — *Sites()* ITILib operation

The operation *SitesName()* (defined in line 4 and 5) was created to identify the name of objects of 'site' kind. The attribute *Name* is indirectly inherited from the *definition* meta class as presented in the list of attributes of Table B.1.

As presented earlier in the Table 3.3 the objects of type *SystemDefinition* can correspond to ITI objects of 'server' kind or to ITI objects of site 'kind'. The operation *SystemMembers()* (defined in line 1 to 7 of Fig. B.13), identify the *servers* for a given *site*.

ITILib: Operations defined for sites

```
1   SystemMembers(): Set(SystemDefinition) =
2       if (IsSite()) then
3           ContainmentDefinition.allInstances-> select(ParentDefinition = self).
4           MemberDefinition.select(oclIsKindOf(SystemDefinition)). oclAsType(SystemDefinition)->asSet
5       else
6           oclUndefined(Set(SystemDefinition))
7       endif
8
9   SiteServers() : Set(SystemDefinition) =
10                          SystemMembers()
```

Fig. B.13 — *SystemMembers()* ITILib operation

All the ITI *servers* must belong to a *site*, so to identify the *servers* of a given *site*, we used the *ContainmentDefinition* relationship as presented in line 3 and 4. The operation *SiteServers()* defined in line 9 and 10 was created to simplify the usage of the operation *SystemMembers()*.

Since all ITI *subnets* must belong to a *site*, we used a similar process to identify the ITI objects of 'subnet' kind for a given *site* (Fig. B.14). The main difference reside in the utilization of the object of type *ResourceDefinition* instead of *SystemDefinition*.

ITILib: Operations defined for sites

```
1   ResourceMembers(): Set(ResourceDefinition) =
2       if (IsSite()) then
3           ContainmentDefinition.allInstances->select(ParentDefinition = self).MemberDefinition.
4           select(oclIsKindOf(ResourceDefinition)).oclAsType(ResourceDefinition)->asSet
5       else
6           oclUndefined(Set(ResourceDefinition))
7       endif
8
9   SiteSubnets() : Set(ResourceDefinition) =
10                                  ResourceMembers()
```

Fig. B.14 — *SiteSubnets() and ResourceMembers()* ITILib operations

The operation *SiteSubnets()* defined in line 9 and 10 was created to simplify the usage of the operation *ResourceMembers()*.

The operation *Connections()* was created to identify all the connections among servers and sites in ITI. The *CommunicationDefinition* relationship display the results of rely on the operation *IsSite()* described earlier to identify from all instances of type *SystemDefinition* those that are of the 'site' kind. The operation *IsSite()* looks into the value of the attribute *objectClass* to select the *SystemDefinition* objects of the 'site' kind.

ITILib: Operations defined for sites

```
1   Connections(): Set(CommunicationDefinition) =
2                       CommunicationDefinition.allInstances
3
4   ConnectionsName(): Bag(String) =
5                       Connections().Name
```

Fig. B.15 — *Connections()* ITILib operation

The operation *ConnectionsName()* (defined in line 4 and 5) was created to identify the name of objects of 'Connection' kind. The attribute *Name* is indirectly inherited from the *definition* meta class as presented in the list of attributes of Table B.1.

The operation *Connections()* returns objects of *CommunicationDefinition* relationship type, which can be objects used to communicate with *servers* or *sites*. The *NTDSConnections()* operation (defined in line 1 and 2) returns only the connections used to communicate with *servers*.

ITILib: Operations defined for sites

```
1  NTDSConnections(): Set(CommunicationDefinition) =
2                                        Connections()->select(IsNTDSConnection())
3
4  IsNTDSConnection(): Boolean = objectClass = 'nTDSConnection'
```

Fig. B.16 — *NTDSConnections()* ITILib operation

IsNTDSConnection() is a boolean operation that returns true if the value of the attribute *objectClass* is 'nTDSConnection'. The value 'nTDSConnection' is used to identify the connections among servers.

The operation *Sitelinks()* (defined in line 1 and 2 of Fig. B.17) returns objects used to communicate with *sites*. This operation rely on *IsSiteLink()* boolean operation to identify is a particular connection is related with sites.

ITILib: Operations defined for sites

```
1  Sitelinks(): Set(CommunicationDefinition) =
2          CommunicationDefinition.allInstances->select(IsSiteLink())
3
4  IsSiteLink(): Boolean = objectClass = 'siteLink'
```

Fig. B.17 — *Sitelinks()* and *IsSiteLink()* ITILib operations

The value 'siteLink' of attribute *objectClass* in *IsSiteLink()* operation is used to identify the connections among sites.

In ITI *sites* with more than one *server*, as the ones presented is some of the case studies, the *servers* can communicate to *servers* in the same *site* or they can communicate with servers in other *sites*. The operation *Intrasite_connections()* (defined in line 1 to 6 of Fig. B.18) was created to identify the objects of 'connection' kind to other *servers* in the same site.

ITILib: Operations defined for sites

```
1   Intrasite_connections() : Set(CommunicationDefinition) =
2                                 if (IsSite()) then
3                                     NTDSConnections()->select(IsConnectionInternalInSite(self))
4                                 else
5                                     oclEmpty(Set(CommunicationDefinition))
6                                 endif
7
8   Intersite_connections() : Set(CommunicationDefinition) =
9                                  if (IsSite()) then
10                                         IncomingConnections()->union(OutgoingConnections())
11                                 else
12                                         oclEmpty(Set(CommunicationDefinition))
13                                 endif
```

Fig. B.18 — *Intra* and *Intersite_connections()* ITILib operations

The operation *Intersite_connections()* (defined in line 8 to 13 of Fig. B.18) was created to identify the objects of 'connection' kind to *servers* in another site.

From the list of connections among *sites* in an ITI, the *IncomingSiteLinks()* operation (defined in line 1 to 6 of Fig. B.19) returns only those connections that are incoming (used to receive information) from another *sites*.

ITILib: Operations defined for sites

```
1   IncomingSiteLinks() : Set(CommunicationDefinition) =
2                                 if (IsSite()) then
3                                    SiteLinks()->select(IsIncoming(self))
4                                 else
5                                    oclEmpty(Set(CommunicationDefinition))
6                                 endif
7
8   OutgoingSiteLinks() : Set(CommunicationDefinition) =
9                                 if (IsSite()) then
10                                   SiteLinks()->select(IsOutgoing(self))
11                                else
12                                   oclEmpty(Set(CommunicationDefinition))
13                                endif
```

Fig. B.19 — *incoming and outgoing_connections* ITILib operations

The *OutgoingSiteLinks()* operation (defined in line 7 to 13) returns only those connections that are outgoing (used to send information) to another *sites*.

Depending on the ITI topology, a *site* may be connected to one or more *sites.* The *ConnectedSites()* operation is used to identify these *sites*.

ITILib: Operations defined for sites

```
1   ConnectedSites() : Set(SystemDefinition) =
2               if (IsSite()) then
3                   IncomingSiteLinks().Client()->union(OutgoingSiteLinks().Server())->asSet
4               else
5                   oclEmpty(Set(SystemDefinition))
6               endif
```

Fig. B.20 — *ConnectedSites()* ITILib operations

ContainmentMembers() operation is used to identify *subnets* for a given site. The objects returned are from *ResourceDefinition* type.

ITILib: Operations defined for sites

```
1   ContainmentMembers(): Set(ResourceDefinition) =
2                   ResourceDefinition.allInstances->select(Container() = self.ParentDefinition)
```

Fig. B.21 — *ContainmentMembers()* ITILib operation

B.3 ITILib operations for servers

We have defined in ITILib a set of operations to quantitative evaluate different aspects of ITI objects of 'server' kind. The operation with the name *Servers()* (line 1 and 2 of Fig. B.22) return all ITI objects of 'server' kind that are present in an ITI. In the context of SDM, objects of 'server' kind are represented as instances of type *SystemDefinition*. The operation *Servers()* rely on the operation *IsServer()* described earlier to identify from all instances of type *SystemDefinition* those that are of the 'server' kind.

ITILib: Operations defined for servers

```
1   Servers(): Set(SystemDefinition) =
2           SystemDefinition.allInstances -> select(IsServer())
```

Fig. B.22 — *Servers()* and *IsServer()* ITILib operations

The operation *IsServer()* looks into the value of the attribute *objectClass* to select the *SystemDefinition* objects of the 'server' kind.

Every server in the ITI, must have a parent of the "site" kind. This relationship is expressed with *ContainmentDefinition* relationship type. The *ServerSite()* operation returns the site for a given server.

ITILib: Operations defined for servers

```
1  ServerSite(): SystemDefinition =
2      if (isServer()) then
3          ContainmentDefinition.allInstances->select(MemberDefinition = self).ParentDefinition.
4          select(oclIsKindOf(SystemDefinition)).oclAsType(SystemDefinition)->asSequence->first()
5      else
6         oclUndefined(SystemDefinition)
7      endif
```

Fig. B.23 — *ServerSite()* ITILib operation

As explained in section 3.7 the communication among *servers* or *sites* require the existence of endpoints, which can be classified as input or output, depending if they are used to receive or to send information. *InputEndpoints()* and OutputEndpoints() operations of Fig. B.24 identify the type of endpoints.

ITILib: Operations defined for servers

```
1  InputEndpoints(): Set(EndpointDefinition) =
2                          EndpointMembers()->select(e: EndpointDefinition | e.IsInput())
3
4  OutputEndpoints(): Set(EndpointDefinition) =
5                          EndpointMembers()->select(e: EndpointDefinition | e.IsOutput())
```

Fig. B.24 — *Input* and *outputendpoints* ITILib operations

In an ITI *servers* are connected in the sense that they communicate. The number of *servers* that a specific *server* is connected to differs from ITI to ITI and is dependent of the topology. The *ConnectedServers()* operation returns the servers connected to a given server.

ITILib: Operations defined for servers

```
1   ConnectedServers() : Set(SystemDefinition) =
2               if (IsServer()) then
3                 IncomingConnections().Client()->union(OutgoingConnections().Server())->asSet
4               else
5                 oclEmpty(Set(SystemDefinition))
6               endif
```

Fig. B.25 — *ConnectedServers()* ITILib operation

When multiple *servers* exists in the same *site*, each *server* in the *site* can send or receive information from multiple *servers* as illustrated in the presented case studies. The *Intraserver_FanIn()* and *Intraserver_FanOut()* operations return the number of connections used to receive information from another *servers* in the same *site* and to send information to *servers* in the same *site*.

ITILib: Operations defined for servers

```
1   Intraserver_FanIn(): Integer =
2                   if (IsServer()) then
3                     ServerSite().Intrasite_connections()->select(IsIncoming(self)) -> size
4                   else
5                       0
6                   endif
7
8   Intraserver_FanOut(): Integer =
9                   if (IsServer()) then
10                    ServerSite().Intrasite_connections()->select(IsOutgoing(self)) -> size
11                  else
12                      0
13                  endif
```

Fig. B.26 — *Intraserver FanIn* and *FanOut* ITILib operations

The *SSEN()* operation is based on the *SiteServers()* operation defined in Fig. B.13 and is used to count the number of servers in a *site*.

ITILib: Operations defined for servers

```
1   SSEN(): Integer =
2           if (IsSite()) then
3               SiteServers()->size
4           else
5               0
6           endif
```

Fig. B.27 — *SSEN()* ITILib operation

B.4 ITILib operations for sites and servers

EndpointMembers() operation is applicable to *servers* and *sites* and returns the connections (*nTDSConnection* or *siteLink*) for *servers* or *sites*.

ITILib: Operations defined for sites and servers

```
1   EndpointMembers(): Set(EndpointDefinition) =
2       if (IsServer() or IsSite()) then
3           ContainmentDefinition.allInstances->select(ParentDefinition = self).MemberDefinition.
4           select(oclIsKindOf(EndpointDefinition)).oclAsType(EndpointDefinition)->asSet
5       else
6           oclUndefined(Set(EndpointDefinition))
7       endif
```

Fig. B.28 — *EndpointMembers* ITILib operations

IncomingConnections() operation (defined in line 1 to 10 of Fig. B.29) return objects of type relationship definition. This operation can be applied to *servers* or *sites* and returns the connections used to receive information. If a *site* is provided the incoming connections relatively to the current *site* are returned otherwise the incoming connections relatively to the *server* are returned.

OutgoingConnections() operation (defined in line 12 to 21 of Fig. B.29) also returns objects of type relationship definition and can be applied to *servers* or *sites*. This operations is used to return the connections used to send information.

ITILib: Operations defined for sites and servers

```
1   IncomingConnections() : Set(CommunicationDefinition) =
2     if (IsSite()) then
3         NTDSConnections()->select(IsConnectionIncomingInSite(self))
4      else
5        if (IsServer()) then
6           NTDSConnections()->select(IsIncoming(self))
7         else
8           oclEmpty(Set(CommunicationDefinition))
9         endif
10     endif
11
12  OutgoingConnections() : Set(CommunicationDefinition) =
13     if (IsSite()) then
14        NTDSConnections()->select(IsConnectionOutgoingInSite(self))
15     else
16        if (IsServer()) then
17           NTDSConnections()->select(IsOutgoing(self))
18        else
19           oclEmpty(Set(CommunicationDefinition))
20        endif
21     endif
```

Fig. B.29 — *Incoming and OutgoingConnection()* ITILib operations

FanIn() and *FanOut()* operations of Fig. B.30 widely used in ITI complexity analysis chapter are used to count the number of connections used to receive information (*FanIn()*) and the number of connections used to send information (*FanOut()*). This operation can be applied to *servers* or *sites*.

ITILib: Operations defined for sites and servers

```
1   FanIn(): Integer =
2           Connections()->select(IsIncoming(self)) -> size
3
4   FanOut(): Integer =
5           Connections()->select(IsOutgoing(self)) -> size
```

Fig. B.30 — *FanIn()* and *FanOut()* ITILib operations

B.5 ITILib operations for subnets

The *SubnetSite()* operation allows the identification of the site corresponding to a given subnet. This operation searches all containment relationships where the member is the subnet and returns the site.

ITILib: Operations defined for subnets

```
1   SubnetSite(): SystemDefinition =
2               if (isSubnet()) then
3                   ContainmentDefinition.allInstances->
4                   select(MemberDefinition = self).ParentDefinition.
5                   (oclIsKindOf(SystemDefinition)).oclAsType(SystemDefinition)->
6                   asSequence->first()
7               else
8                 oclUndefined(SystemDefinition)
9               endif
```

Fig. B.31 — *SubnetSite()* ITILib operation

The *SSBN()* operation relies on *SiteSubnets()* operation (defined in Fig. B.14) to count the *subnets* in a specified *site*.

ITILib: Operations defined for subnets

```
1   SSBN(): Integer =
2           if (IsSite()) then
3               SiteSubnets()->size
4           else
5               0
6           endif
```

Fig. B.32 — *SSBN()* ITILib operation

To list all existing *subnets*, which are from type *ResourceDefinition* the concept is similar to sites and servers, however instead of using *SystemDefinition* we have to use *ResourceDefinition* and look for subnet in the value of the attribute *objectClass*.

ITILib: Operations defined for subnets

```
1   Subnets(): Set(ResourceDefinition) =
2           ResourceDefinition.allInstances->select(IsSubnet())
```

Fig. B.33 — *Subnets()* and *IsSubnet()* ITILib operations

B.6 ITILib operations for SiteLinks

It may be important to identify the name of all existing sites within an ITI. The following operations make that possible.

ITILib: Operations defined for sitelinks

```
1   SitelinksName(): Bag(String) = Sitelinks().Name
2
3   Sitelinks(): Set(CommunicationDefinition) =
4           CommunicationDefinition.allInstances->select(IsSiteLink())
```

Fig. B.34 — *Sitelinksname() and Sitelinks()* ITILib operations

From the list of all existing connections in the ITI, we may want to know to what server does one specific connection belongs to.

ITILib: Operations defined for sitelinks

```
1   EndpointServer(): SystemDefinition =
2       if (objectClass = 'nTDSConnection') then
3           ContainmentDefinition.allInstances->select(MemberDefinition = self).ParentDefinition.
4           select(oclIsKindOf(SystemDefinition)).oclAsType(SystemDefinition)->asSequence->first()
5       else
6           oclUndefined(SystemDefinition)
7       endif
```

Fig. B.35 — *EndpointServer()* ITILib operation

Every server in the ITI has one or more connections to other servers. To identify all connections of a specific server we created the operation *ServerConnections().*

ITILib: Operations defined for sitelinks

```
1   ServerConnections() : Set(EndpointDefinition) =
2                         if (objectClass = 'server') then
3                           self.EndpointMembers()
4                         else
5                           oclEmpty(Set(EndpointDefinition))
5                         endif
6
7   EndpointMembers(): Set(EndpointDefinition) =
8                         if (objectClass = 'server') then
9                           ContainmentDefinition.allInstances->
10                            select(ParentDefinition = self).MemberDefinition.
11                            select(oclIsKindOf(EndpointDefinition)).
12                            oclAsType(EndpointDefinition)->asSet
13                          else
14                            oclUndefined(Set(EndpointDefinition))
15                          endif
```

Fig. B.36 — *ServerConnections() and EndpointMembers()* ITILib operations

B.7 ITILib operations for Connections

In the communicationdefinition we already defined operations such as isNTDSConnection() to identify the connections of the servers and IsSiteLink() to identify the connections among sites. However in the cases with more than one server per site, we may also want to identify the connections to other servers in the same site and the connections to servers in other sites. In order to achieve this we have created the *IsConnectionInternalInSite()* and IsConnectionOutgoingInSite() predicates. The latter rely on the operations Client() and Server() to help on the identification.

ITILib: Operations defined for sitelinks

```
1   IsConnectionInternalInSite (theSite: SystemDefinition): Boolean =
2                                 (Client().ServerSite() = theSite) and (Server().ServerSite() = theSite)
3
4   IsConnectionIncomingInSite(theSite: SystemDefinition): Boolean =
5                                 (Client().ServerSite() <> theSite) and (Server().ServerSite() = theSite)
5
6   IsConnectionOutgoingInSite(theSite: SystemDefinition): Boolean =
7                                 (Client().ServerSite() = theSite) and (Server().ServerSite() <> theSite)
```

Fig. B.37 — *IsConnectionInternalInSite() and IsConnectionOutgoingInSite()* ITILib operations

ITILib: Operations defined for sitelinks

```
1  IsIncoming(target: SystemDefinition): Boolean = Server() = target
2
3  IsOutgoing(target: SystemDefinition): Boolean = Client() = target
4
5  Client(): SystemDefinition = ClientDefinition.Container()
5
6  Server(): SystemDefinition = ServerDefinition.Container()
```

Fig. B.38 — *IsIncoming() and IsOutgoing(), Server() and Client()* ITILib operations

ITILib: Operations defined for sitelinks

```
1  Client(): SystemDefinition = ClientDefinition.Container()
2
3  Server(): SystemDefinition = ServerDefinition.Container()
```

Fig. B.39 — *Client() and Server()* ITILib operations

C

Appendix C – The SDM Schema

Contents

This appendix presents simple types, complex types and attributes groups of the SDM schema and a short description of each object. During this dissertation we have used just some of these objects. These objects allow the creation of files with the sdm extension to represent SDM objects such as systems, endpoints and resources. To better understand the SDM schema we provide also a class diagram (divided in four parts due the size), where we can take a look into the relations between all these objects.

C.1 The SDM schema

The SDM elements, simple and complex types and attribute groups and a short description of each of these objects are presented next in Table C.1 to Table C.4.

Table C.1 — SDM schema elements

Element	Description
Comments (Information)	Contains comments about an .sdm file that provides general information about the document.
CommunicationDefinition (ObjectDefinition)	Contains a nested communication definition.
CommunicationDefinition (SystemDefinitionModel)	Contains communication definitions that are contained in the .sdm file.
CompanyName (Information)	Contains the name of the company for which the .sdm file was created.
CompilerVersion (Information)	Contains the version of the compiler that built the .sdmdocument file.
Connection (ObjectDefinition)	Contains a connection relationship member declaration used in the definition of an object.
Connection (RelationshipDefinition)	Contains a connection relationship member used in the definition of a relationship between two members.
ConstraintDefinition (SystemDefinitionModel)	Contains constraint definitions that are contained in the .sdm file.
ConstraintGroup (ConstraintDefinition)	Contains a nested constraint group identifying a manager that provides code to evaluate input values.
ConstraintGroup (ObjectConstraint)	Contains a nested constraint group that is evaluated against the primary object definition.
ConstraintGroup (ObjectDefinition)	Contains a nested group of constraints on the relationships in which instances of an object definition can participate.
ConstraintGroup (RelationshipConstraint)	Contains a nested group of constraints on the values of settings within a relationship or on objects at the other end of a relationship.
ConstraintGroup (RelationshipDefinition)	Contains a nested constraint group that will be evaluated against a relationship definition.
Constraint (ConstraintDefinition	Contains a manager that provides code to evaluate input values.
Constraint (ConstraintGroup)	Contains a constraint member nested within a constraint group.
Constraint (ObjectConstraint)	Contains a constraint member that is evaluated against a primary object definition.
Constraint (ObjectDefinition)	Contains a constraint on the relationships in which instances of an object definition can participate.
Constraint (RelationshipConstraint)	Contains a constraint on the values of settings within a relationship or on objects at the other end of a relationship.
Constraint (RelationshipDefinition)	Contains a constraint that will be evaluated against a relationship definition.
ContainmentDefinition (ObjectDefinition)	Contains a containment definition. This definition can be used by members within the scope of the outer system definition.
ContainmentDefinition (SystemDefinitionModel)	Contains a containment definition that is contained in an .sdm file.
Containment (ObjectDefinition)	Contains a member declaration for a containment relationship.
Containment (RelationshipDefinition)	Contains a containment relationship member.
Copyright (Information)	Contains copyright information for the .sdm file.
DelegationDefinition (ObjectDefinition)	Contains a delegation definition. This definition can be used by members within the scope of the outer system definition.
DelegationDefinition (SystemDefinitionModel)	Contains a delegation definition that is contained in an .sdm file.
Delegation (ObjectDefinition)	Contains a delegation relationship member declaration.
Delegation (RelationshipDefinition)	Contains a delegation relationship member.
Description (Definition)	Contains a description of an object, relationship, constraint, or flow definition.
Description (Information)	Contains a description of an .sdm file.
Description (ManagerDeclaration)	Contains a description of a manager.

Element	Description
Description (Member)	Contains a description of a member in an .sdm file.
Description (StructuralConstraint)	Contains a description of a constraint.
DesignData (Definition)	Contains design surface information about an object, relationship, constraint, or flow definition.
DesignData (Member)	Contains design surface—specific information about a member.
DesignData (StructuralConstraint)	Contains design surface—specific information about a constraint.
DesignData (SystemDefinitionModel)	Contains global design surface information for an .sdm file.
EndpointDefinition (ObjectDefinition)	Contains an endpoint definition. This definition can be used by members within the scope of the outer system definition.
EndpointDefinition (SystemDefinitionModel)	Contains an endpoint definition that is contained in an .sdm file.
Endpoint (ObjectDefinition)	Contains an endpoint member declaration that references an endpoint definition.
Entry (Description)	Contains the text of a description and a description entry.
Facet (SettingMember)	Contains the set of aspects associated with a setting.
FlowDefinition (SystemDefinitionModel)	Contains flow definitions that are contained in an .sdm file.
Flow (ObjectDefinition)	Contains a flow member declaration.
Flow (RelationshipDefinition)	Contains a flow between the instances that participate in a relationship.
FriendlyName (Information)	Contains the friendly name of an .sdm file.
HostingDefinition (ObjectDefinition)	Contains a hosting definition between a host and guest member. This definition can be used by members within the scope of the outer system definition.
HostingDefinition (SystemDefinitionModel)	Contains a hosting definition that is contained in an .sdm file.
Hosting (ObjectDefinition)	Contains a hosting relationship member declaration for an object.
Hosting (RelationshipDefinition)	Contains a hosting relationship member declaration for a relationship.
Import (SystemDefinitionModel)	Contains the namespace that an SDM topic imports and references.
Information (SystemDefinitionModel)	Contains general information about an .sdm file.
Input (ConstraintMember)	Contains a list of inputs to a constraint. An input identifies a path to the source setting value that will be passed to the constraint and constraint setting that will be set as a result. The source setting definition and the constraint setting definition must be compatible.
Input (FlowMember)	Contains a list of paths to setting values that are used as input to a flow.
Manager (SystemDefinitionModel)	Contains the manager used to provide customized behavior to the runtime and to support interaction between the runtime and the modeled system.
ObjectConstraint (ConstraintDefinition)	Contains a constraint on an object.
ObjectConstraint (ConstraintGroup)	Contains a object constraint that is nested within a group of constraints.
ObjectConstraint (RelationshipConstraint)	Contains an object constraint that is evaluated in the context of the matched relationship instance.
ObjectConstraint (RelationshipDefinition)	Contains a constraint on instances that participate in a relationship.
Output (FlowMember)	Contains a list of paths to settings that will be set as a result of a flow. Each output must identify a read-only setting on the flow definition.
ReferenceDefinition (ObjectDefinition)	Contains a reference definition. This definition can be used by members within the scope of the outer system definition.
ReferenceDefinition (SystemDefinitionModel)	Contains a reference definition that is contained in an .sdm file.
Reference (ObjectDefinition)	Contains a reference relationship member declaration.
Reference (RelationshipDefinition)	Contains a reference member declaration specifically used in a relationship definition.
RelationshipConstraint (ConstraintDefinition)	Contains constraints on a relationship.
RelationshipConstraint (ConstraintGroup)	Contains a relationship constraint nested within a group of relationship constraints.

Element	Description
RelationshipConstraint (ObjectConstraint)	Contains a constraint on a relationship defined for an object.
RelationshipConstraint (ObjectDefinition)	Contains a constraint on the relationships in which instances of an object definition can participate.
RelationshipConstraint (RelationshipConstraint)	Contains a relationship constraint that will be evaluated in the context of the target object.
ResourceDefinition (ObjectDefinition)	Contains resource definitions that can be used by members within the scope of the outer system definition.
ResourceDefinition (SystemDefinitionModel)	Contains resource definitions that are contained in the .sdm file.
Resource (ObjectDefinition)	Contains a resource member declaration that references a resource definition.
SettingDeclaration (Definition)	Contains the base definition of a setting member.
SettingDefinitions (SystemDefinitionModel)	Contains an XML schema document that contains setting definitions.
SettingValueList (Definition)	Contains a list of values for a setting on a definition or its base definition.
SettingValueList (Member)	Contains a list of values for settings that correspond to writable settings on a member-referenced type.
SettingValue (Definition)	Contains a value for a setting on a definition or its base definition. A value can only be provided once for a setting declaration within a definition.
SettingValue (Member)	Contains a value for settings that correspond to writeable settings on a member referenced type. If these values are marked as fixed, then they must be used when an instance is created for the member, if they are not fixed, then the values can be overridden by deployment parameters or parameters set by a flow.
Subsystem (ObjectDefinition)	Contains a subsystem member declaration that references a system definition.
SystemDefinitionModel	Defines an .sdm file that provides a strong identity, versioning and localization information for a set of relationships, objects and managers.
SystemDefinition (ObjectDefinition)	Contains a nested system definition. This definition can be used by members within the scope of the outer system definition.
SystemDefinition (SystemDefinitionModel)	Contains system definitions that are contained in an .sdm file.
Trademark (Information)	Contains trademark information for an .sdm file.
Value (SettingValueList)	Contains a value in a list of setting values.

Table C.2 — SDM schema attribute groups

Element	Description
NamespaceIdentity	Contains a namespace (scope) for SDM names.
SettingsAttributes	Contains attributes used to describe the behavior of a particular setting.
SettingValueAttributes	Contains attributes used to control the behavior of setting values.

Table C.3 — SDM schema simple types

Element	Description
CompilationHashType	Defines the pattern used to verify that an SDM file is a valid compiled document when the SDM file is used as a referenced file during the compilation of a different SDM file.
ConstraintEvaluation	Defines values that allow the constraint developer to mark a constraint according to when it should run.
Culture	Defines the value used to specify a language for an .sdm file.
CultureNeutral	Defines the values used to allow an .sdm file to identify its culture as neutral when it does not contain language-specific binaries.
FourPartVersionType	Defines the type of values used to identify a file version by using a four-part numbering system.
MaxOccurs	Defines an upper bound on the number of instances associated with a member.
MinOccurs	Defines a non-negative lower bound on the number of instances associated with a member.
Path	Defines the values used to define a path to a definition or member in the current .sdm file namespace or in an aliased (imported) namespace.
PathList	Defines the values defining a list of paths that resolve to setting values.
Platform	Defines the values used to identify the platform on which an assembly will execute as neutral or with a value from the ProcessorArchitectures simple type.
ProcessorArchitectures	Defines the values used to identify the processor architecture on which an assembly will execute.
PublicKeyTokenType	Defines the value used to identify the public part of a public/private key pair.
PublicKeyType	Defines a value used as a public key that is stored in a signed .sdm file.
QualifiedName	Defines a value used as a name that refers to definitions or members defined in an .sdm files namespace or in an aliased (imported) namespace.
RolesList	Defines values used as a list of names for a role in the relationship that a constraint targets.
SettingMemberAccess	Defines values used to specify whether reading and writing a setting's value is permitted, providing SDM runtime access control and display and editing rules to designers.
SettingMemberSecure	Defines values used to specify whether the value of a setting should be encrypted when stored to an .sdmdocument file and whether tools should log this value during manipulations such as installations.
SettingPath	Defines the value used for a setting member path.
SimpleName	Defines the value used to supply a simple name for members in an SDM definition.

Table C.4 — SDM schema complex types

Element	Description
CommunicationDefinition	Defines the elements used to define client and server member definitions used in communication links.
CommunicationMember	Defines the paths to two endpoint members (client and server) used in a communication relationship in an SDM member definition.
ConstraintDefinition	Defines the elements in a constraint on a defined set of input values.
ConstraintGroup	Defines a group of different constraints to be evaluated together.
ConstraintMember	Defines a set of input values for a particular constraint definition.
ContainmentDefinition	Defines the parent and member definitions in a containment relationship.
ContainmentMember	Defines the path to a child member when it is contained by a parent member.
Definition	Defines the base set of elements for object, relationship, constraint and flow definitions.
DelegationDefinition	Defines a pair of abstract endpoint definitions that participate in a delegation relationship.
DelegationMember	Defines the paths to two members used to set up a delegation relationship.
Description	Defines the elements that contain the information to describe an SDM element.

Element	Description
DescriptionEntry	Defines the elements used to create a description of an SDM member.
DesignData	Defines the element holding a schema instance that identifies and structures data for a design surface.
EndpointDefinition	Defines an SDM endpoint.
EndpointMember	Defines the element that creates a use for an endpoint definition.
Facet	Defines an element that holds the name of a facet of a setting (a subsetting used to read a value from or write a value to a setting).
FlowDefinition	Defines an element that contains a particular transform to be applied to a set of setting values.
FlowMember	Defines the elements that contain one or more input settings, one or more destination settings and a flow definition.
HostingDefinition	Defines elements that contain guest and host member definitions in a hosting relationship.
HostingMember	Defines elements that hold the paths to guest and host members in a hosting relationship.
Import	Defines the elements that contain a namespace to be imported by another namespace and an alias for the imported namespace.
Information	Defines the elements that contain general information about an .sdm document.
Input	Defines an input value for a flow or constraint.
ManagerDeclaration	Defines the elements that contain information used to define a manager.
Member	Defines the elements that contain information about a member definition in an .sdm file.
ObjectConstraint	Defines the elements used to define a constraint on one or both roles of a relationship.
ObjectConstraintGroup	Defines the element that contains a group of constraints on one or both roles of a relationship.
ObjectDefinition	Defines the elements that contain the base information to define the object which abstract and concrete object definitions extend.
ObjectMember	Defines the elements that define an abstract or concrete object definition.
Output	Defines the attributes that create a variation on the ValueTransfer value transfer.
ReferenceDefinition.	Defines the elements that contain the definitions for the source and dependent members in a reference relationship between the members
ReferenceMember	Defines the elements that contain paths to the source and dependent members used to set up a reference relationship.
RelationshipConstraint	Defines the elements that constrain the relationships in which an object can participate.
RelationshipConstraintGroup	Defines the elements that define a group of relationship constraints constraining the relationships in which an object can participate.
RelationshipDefinition	Defines the elements that contain all the information defining the relationship between two members.
RelationshipMember	Defines the relationship that will exist between object members when they are created.
ResourceDefinition	Defines an SDM resource.
ResourceMember	Defines the use for a resource definition.
SettingDefinitions	Defines the elements containing setting definitions used by setting members, including namespace declarations and namespace imports.
SettingMember	Defines the elements and attributes used to define a setting member.
SettingValue	Defines the attributes used in defining a single setting value for a setting declaration.
SettingValueList	Defines the list of attributes and elements used to define one or more setting values for a setting declared as a list.
StructuralConstraint	Defines the elements used to create the structure of a constraint.
SystemDefinition	Defines the attributes that define a system.
SystemMember	Defines a use for a system definition.
ValueTransfer	Defines the elements that contain information used to pass setting values into or out of a flow or constraint.

C.2 SDM Class diagram

To better understand the relations among class in SDM we present in this section (Fig. C.1 to Fig. C.4) a class diagram of the SDM. Due to the size of the class diagram we divide it in four parts.

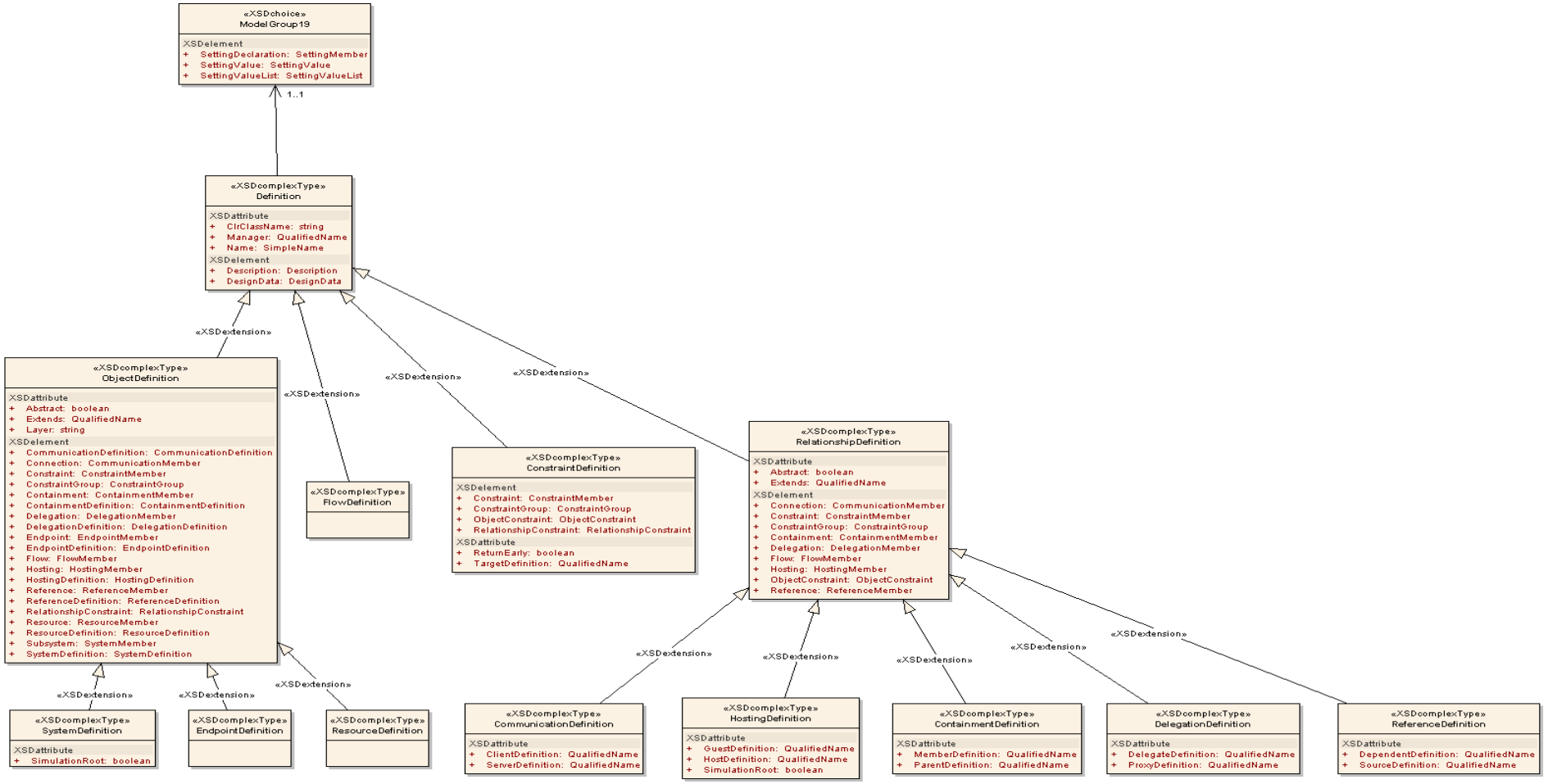


Fig. C.1 — Class diagram (Part I of IV)

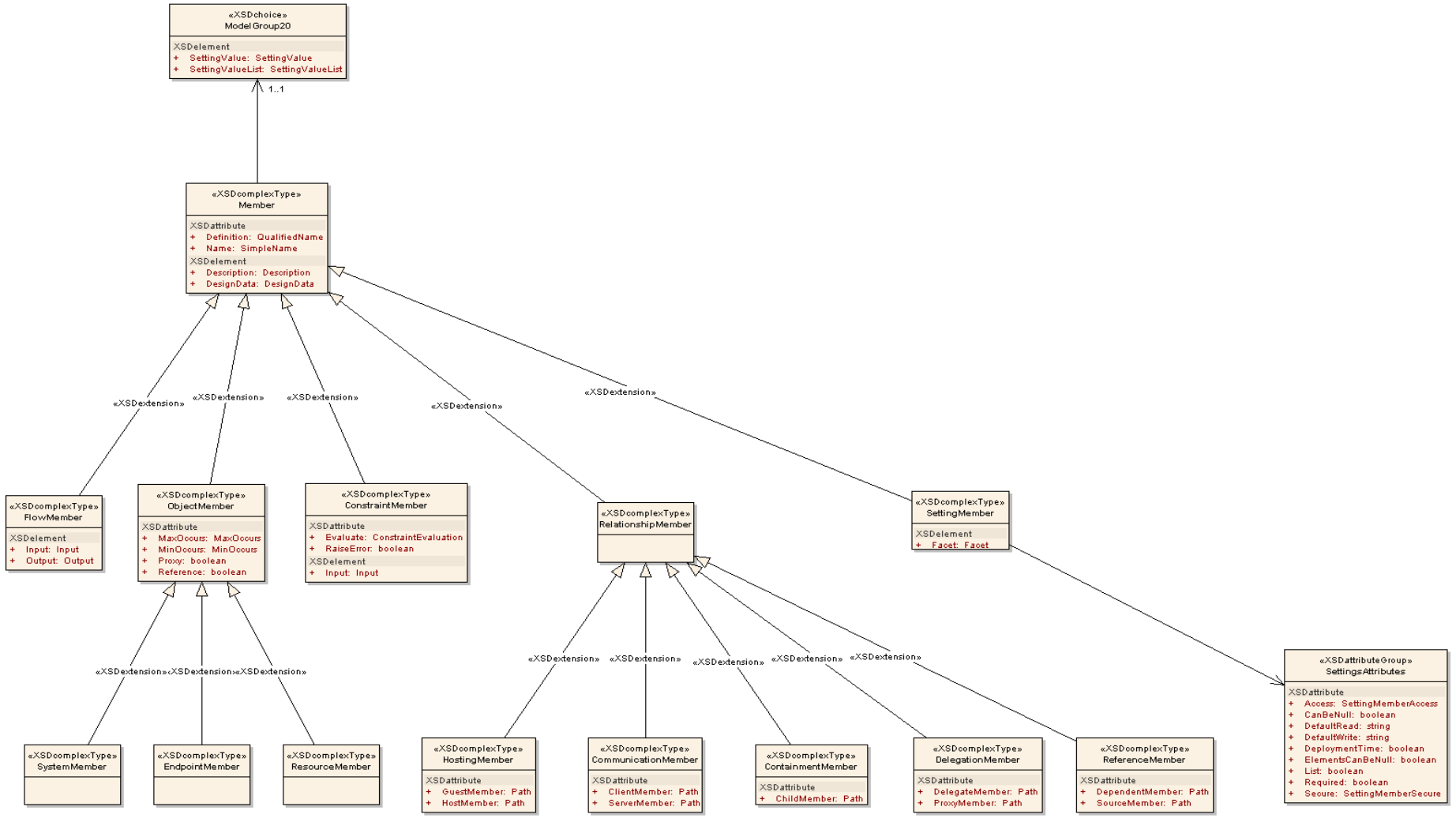


Fig. C.2 — Class diagram (Part II of IV)

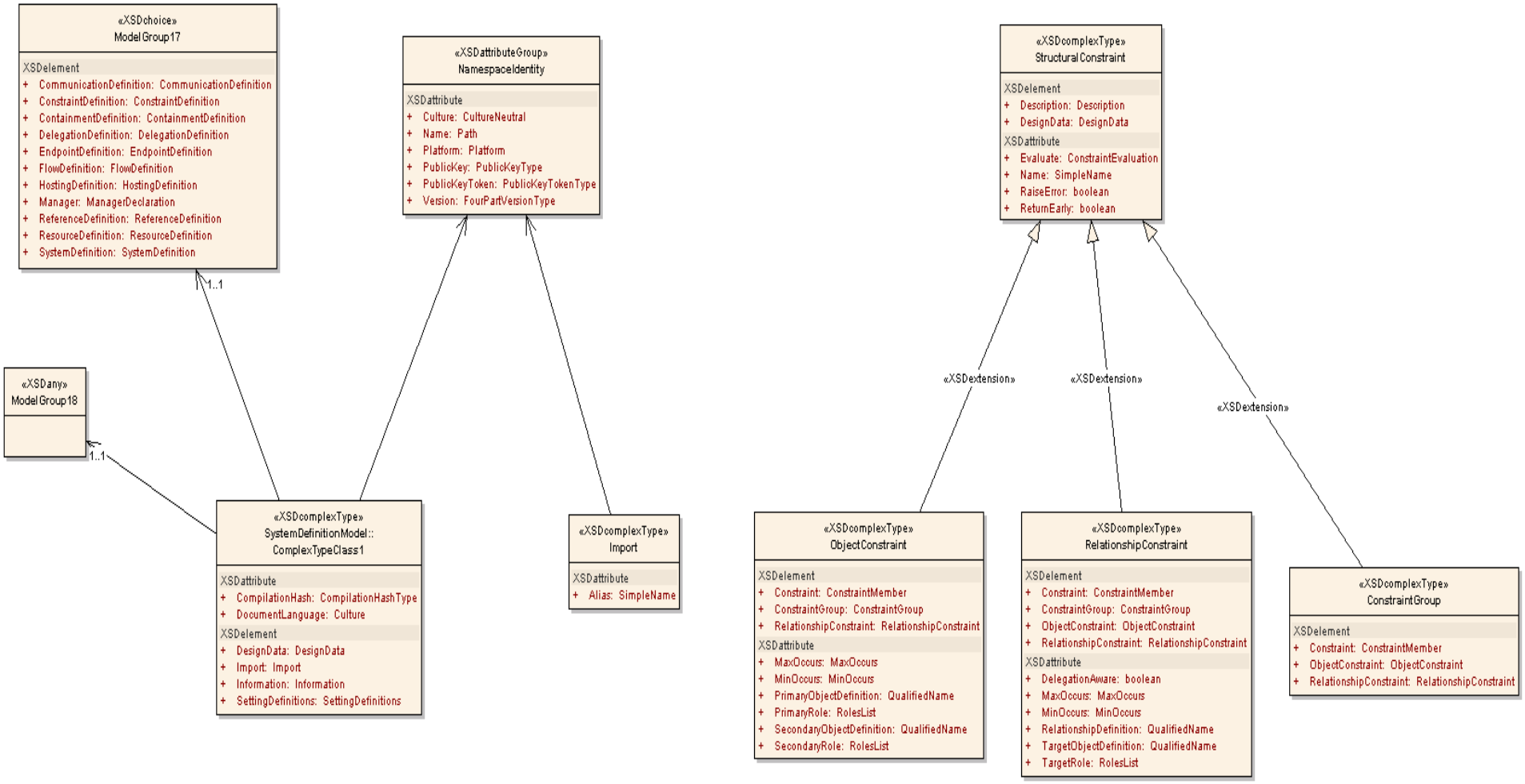


Fig. C.3 — Class diagram (Part III of IV)

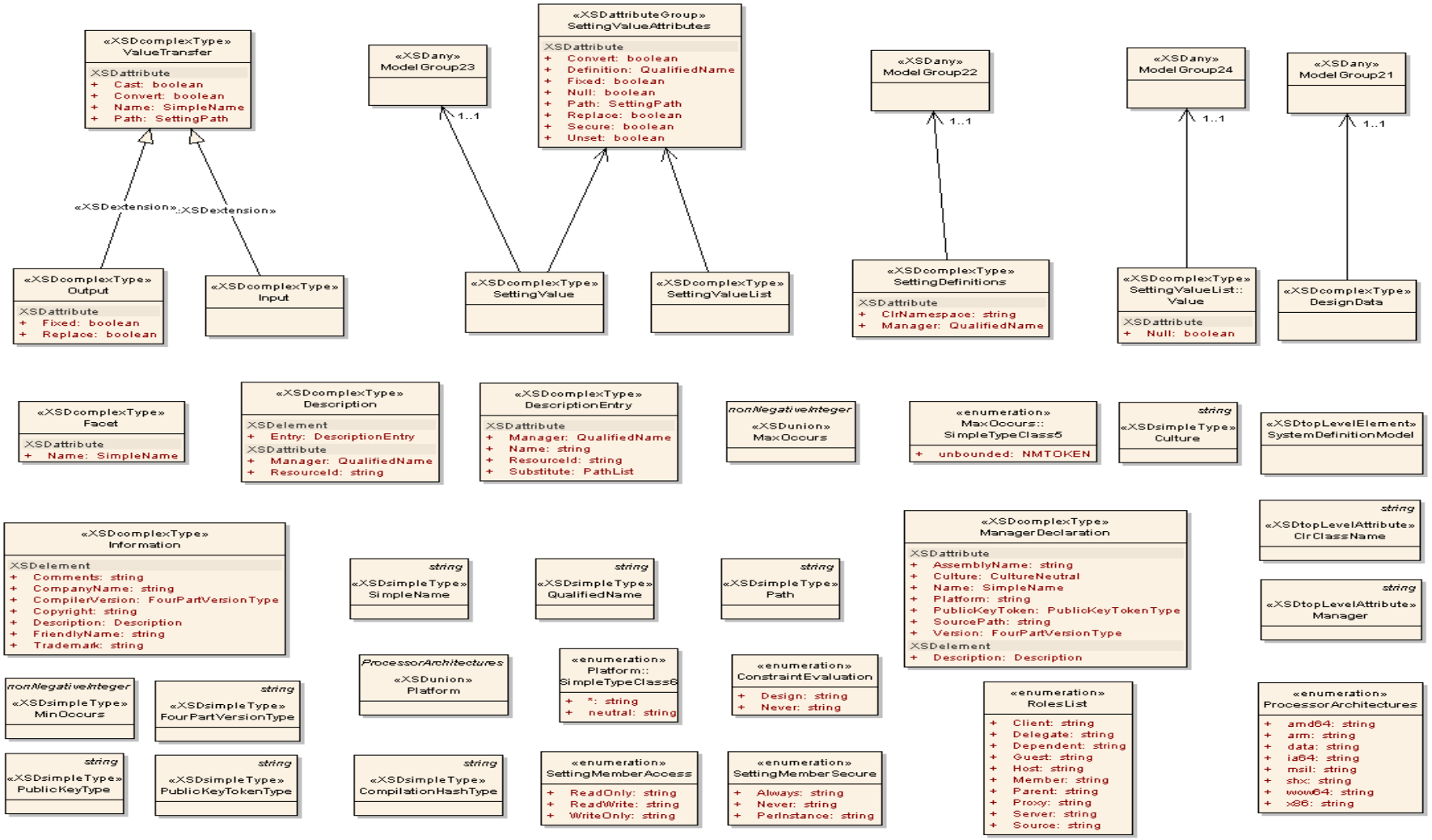


Fig. C.4 — Class diagram (Part IV of IV)

D

Appendix D – Papers and Reports

This appendix has the list of papers and reports analyzed in this dissertation. The papers and reports were sponsored by different entities or organizations in different periods of time. The purpose of this analysis was to select the most complete evaluations for deeper analysis. We have examined each of these documents and we selected those with references to some concepts discussed in this dissertation. The selected documents were presented in section 2.2.

Table D.1 — List of Papers and reports

ID	Reference	Document Name	Date	Sponsored by
1	[Steeples, et al., 1993]	CO Benefits Using Multiply Charged Ion Implants on Conventional Medium and High Current Implanters	1993	IEEE
2	[Gartner, 1997]	Gartner - Next Generation Total Cost of Ownership Methodology	1997	Gartner
3	[Microsoft, 1999]	Microsoft Business Value - Windows vs. LINUX Total Cost of Ownership Overview	1999	Microsoft
4	[Brynjolfsson, et al., 2000]	Computing Productivity Firm-Level Evidence	2000	University
5	[TriActive, 2001]	Calculating Your Total Cost of Ownership	2001	TriActive
6	[Adams, 2002]	Management Update Best Practices to Launch an IT Asset Management Program	2002	Gartner
7	[Kirwin, et al., 2002]	The Total Cost of Ownership Index: Defining the Database	2002	Gartner
8	[David, et al., 2002]	Managing your total IT cost of ownership	2002	ACM
9	[Greschler, et al., 2002]	Networking lessons in delivering 'Software as a Service'—Part I	2002	ACM
10	[Wang, et al., 2004]	Friends Troubleshooting Network Towards Privacy-Preserving, Automatic Troubleshooting	2004	University
11	[Builders, 2002]	Examining TCO for Business Intelligence Solutions	2002	I. Builders
12	[Kirwin, 2003b]	CIO Update To Control TCO, It Must Be Measured and Managed	2003	Gartner
13	[Heine, 2003]	Management Update Five Sure Ways to Reduce IT Asset Costs	2003	Gartner
14	[O'Brien, 2003]	Management Update IT Asset Management Is Mandatory, Not Optional	2003	Gartner
15	[Kirwin, 2003a]	Management Update Total Cost of Ownership Analysis	2003	Gartner
16	[Gartner, 2003]	TCO Distributed Computing - Chart of Accounts	2003	Gartner
17	[Aziz, et al., 2003]	TCO Reduction	2003	IEEE
18	[Kimfong, et al., 2003]	Technology to enable learning Strategic decisions on technology selections for facilitating a network systems laboratory using real options total cost of ownership theories	2003	ACM
19	[Rasmussen, 2006a]	Electrical Efficiency Modeling of Data Centers	2003	APC
20	[Rasmussen, 2006b]	Implementing Energy Efficient Data Centers	2003	APC
21	[APC, 2003b]	Avoiding Costs from Oversizing Data Center and Network Room Infrastructure	2003	APC
22	[APC, 2003a]	Determining TCO for Datacenter and Network Room Infrastructure	2003	APC
23	[Sawyer, 2003]	Reducing the Hidden Costs Associated with Upgrades of Data Center Power Capacity	2003	APC
24	[Rymer, et al., 2003]	The Total Economic Impact of Developing and Deploying Applications on Microsoft and J2EE/Linux Platforms	2003	OSS
25	[DiDio, 2004b, DiDio, 2004a]	Linux, UNIX and Windows TCO Comparison	2004	Yankee Group
26	[Gomolski, 2004]	How to Use IT Cost Metrics Effectively	2004	Gartner
27	[Sigurdsson, et al., 2004]	Cost optimization methods in the design of next generation networks	2004	IEEE
28	[Logan, 2004]	Monitoring and state transparency of distributed systems	2004	ACM
29	[Rosenberg, 2004]	The Myths of usability ROI	2004	ACM
30	[Msadek, 2003]	Managing technology to reduce total cost of ownership and secure assets	2004	Education
31	[Axeda, 2007]	AXEDA - Secure Remote Vendor Access to the Enterprise Data Center	2004	Axeda
32	[Webster, 2004]	Getting the most out of ROI and TCO	2004	DMG
33	[Cybersource, et al., 2004]	Linux vs Windows - Total Cost of Ownership Comparison	2004	Cybersource Pty
34	[Kirwin, et al., 2005]	Control Distributed Computing TCO by Keeping an Eye on Complexity	2005	Gartner
35	[Harris, 2005]	IT Complexity May Be the Reason You're Spending More and gaining less	2005	Gartner

ID	Reference	Document Name	Date	Sponsored by
36	[Troni, et al., 2005]	TCO Comparison of Desktops vs. Notebooks (13 December 2005)	2005	Gartner
37	[Wang, et al., 2005]	TCO Research in Enterprise Computing (Linux, Windows NT and Windows 2000/2003)	2005	CCW
38	[CIOview, 2005]	The Business Value of Migrating from Oracle to SQL Server 2005	2005	CIOView
39	[Castellani, et al., 2005]	Issues around Reducing Cost of Support in a Manufacturing Organization Case	2005	IEEE
40	[Torell, 2005]	Network-Critical Physical Infrastructure Optimizing Business Value	2005	IEEE
41	[Ionescu-Graff, et al., 2005]	Quantifying the Value Proposition of Advanced Fault Management Systems in MPLS Core Networks	2005	IEEE
42	[Bothma, 2005]	Best Practices-in-managing-the-total-cost-of-ownership	2005	SAP
43	[Bothma, 2006]	State of the Art in TCO - Managing TCO	2005	SAP
44	[EMC, 2005]	VmWARE - CLARiiON Integration with VMware ESX Server	2005	EMC
45	[Scott, et al., 2006]	Organizing for IT Infrastructure and Operations	2006	Gartner
46	[Troni, et al., 2006]	Use Processes and Tools to Reduce TCO for PCs, 2005-2006 Update	2006	Gartner
47	[Takahashi, et al., 2007]	A Practical Network Management System Based on an Organization Hierarchy Mobile Agent Model	2006	IEEE
48	[Babey, 2006, Machuca, 2006]	Costs of Enterprise Resource Planning System Implementation - and Then Some	2006	IEEE
49	[Machuca, 2006]	Expenditures Study for Network Operators	2006	IEEE
50	[Zhou, et al., 2006]	Virtual disk based centralized management for enterprise networks	2006	ACM
51	[Scrimshaw, 2002]	Becta Education - Total Cost of Ownership - A review of the literature	2006	Becta
52	[Counsel, 2006]	Security and Identity Access and Management Outlook (Only for the graphs)	2006	Strategic Counsel
53	[Blowers, 2006b]	Data Center Consolidation	2006	HP
54	[HP, 2006a]	Putting a price on document-based business processes	2006	HP
55	[HP, 2006b]	The Top Five Most Common Hidden Infrastructure Costs imaging and printing	2006	HP
56	[Blum, 2004]	INS - Network and Systems Management Total Cost of Ownership	2006	INS
57	[Opsware, 2006]	PSWARE - Selecting a Flexible, Custom Platform to Automate Your Data Center Management	2006	OPSWare
58	[Jones, et al., 2006]	PSWARE - The Reference Guide to Data Center Automation	2006	OPSWare
59	[Sophos, 2006]	sophos - cutting-the-cost-and-complexity-of-managing-endpoint-security	2006	Sophos
60	[Kantin, et al., 2006]	The Future Sales Force - A Consultative Approach	2006	Microsoft
61	[Wipro, et al., 2007]	Reducing TCO with Windows Vista - Quantified Savings for Mobile PCs	2007	Wipro Tech.
62	[Troni, et al., 2007]	Gartner - PDA and Smartphone TCO-2007 Update	2007	Gartner
63	[Jutras, 2007]	The Total Cost of ERP Ownership in Mid-Size Companies	2007	Aberdeen Group
64	[Lavazza, 2007]	Beyond Total Cost of Ownership Applying Balanced Scorecards to Open-Source Software	2007	IEEE
65	[Conley, et al., 2007]	Lowering Cost of Ownership through Predictive Maintenance	2007	IEEE
66	[Ho, et al., 2007]	SEM ADC - How it improves the Cost of Ownership without Risk of Yield Loss	2007	IEEE
67	[Boyle, 2007]	PEAK Technologies -Controlling The Wireless Enterprise And Reducing TCO	2007	Journals
68	[Hurkens, et al., 2006]	Total Cost of Ownership in the Services Sector A Case Study	2006	University
69	[Zachary, et al., 2007]	Human Total Cost of Ownership - The PennyFoolish Principle at Work	2007	IEEE
70	[Gillen, Perry and Waldman, 2007]	IDC - Understanding the Business Benefits Associated with x86 64-bit Windows Server	2007	Microsoft