Towards Assessing Performance in Service Computing

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Abstract. Enterprises increasingly choose to focus on core competences and often outsource different services in order to achieve set goals. Although extensive research and development work is pursued on service computing, the main focus is on technical aspects. Business and economic issues in the context of service computing receive little attention. The scope of this article is to present preliminary results of an on-going research project aiming at advancing research in the area of economic performance assessment in service computing by developing a conceptual framework and metrics useful for economic performance analysis. Issues addressed in this article pertain to synthesize and discuss economic theories and approaches relevant for modeling and assessing the economic performance in service computing (e.g., game theory, graph theory, transaction cost economics, decision theory), emphasizing their strengths and weaknesses. Research challenges are then briefly discussed.

Keywords: Service computing; performance assessment.

1 Introduction

Services represent a major part of the IT industry. Nowadays enterprises increasingly prefer to focus on their core areas and often outsource services in order to attain their goals. Services computing support services' modeling, creation and management.

Extensive research is currently being pursued on service computing (and cloud computing). However, most research and development work focuses on technical aspects related to services. So far, relatively scarce research work has been pursued on services' analytic modeling, auditing and performance measurements. Economic aspects on service computing are of interest for both service providers and service users.

Although several advantages of service computing are claimed, formal models, frameworks or tools to quantify its economic benefits (e.g., for service providers and service users) are not yet available. Several questions are still unanswered, e.g.: How can services be assessed (from an economic perspective)? How to predict services' performance? Which are the most relevant economic theories and approaches to support the formal definition and (economic) performance assessment in service computing?

These issues are tackled in this article. The scope of this article is to present preliminary results of an on-going research project aiming at advancing research in the

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area of economic performance assessment in service computing by developing an analytical model, conceptual framework and metrics useful for economic performance analysis. Issues addressed in this article pertain to:

- synthesized theories and approaches useful for service computing formal modeling and economic performance assessment;
- discuss research challenges on assessing performance in service computing.

The rest of this article is organized as follows. The next section briefly introduces the concept of service computing. Section three refers to ways for economic performance modeling and measurements in the context of service computing. An approach for service computing modeling is then presented. Current research challenges on the economics of service computing are discussed in Section four. The article concludes with a section addressing the needs for further research.

2 Service Computing: A Brief Overview

2.1 Introduction

Services represent autonomous and platform-independent computational entities, which can be described, published, discovered, and dynamically assembled to deploy distributed interoperable systems (e.g., [1], [2]). As emphasized in [3], service-oriented computing promotes the idea of assembling application components in a network of services to create dynamic business processes and agile applications that cross different geographically distributed computing platforms and organizations. The Service Oriented Architecture (SOA) allows services to communicate and exchange information between distributed systems; it provides means for service providers to offer services, and service users to discover services.

Web services are services that make use of the Internet as communication platform, and open Internet-based standards, such as: Simple Object Access Protocol (SOAP[1]) to exchange data; Web Service Description Language (WSDL[2]) to describe services; Business Process Execution Language for Web Services (BPEL4WS[3]) to specify business processes and interaction protocols [1][4]. Service providers can register their services in a public service registry using the Universal Description Discovery and Integration (UDDI[4]). Web services are currently regarded as the most promising service-oriented computing technology [5].

Transaction policies for service-oriented computing are discussed in [6]. The authors argue for the use of declarative policy assertions to advertise and match support for different transaction styles. A system support for transaction coupling models as the policy-based contracts guiding transactional business process execution is also advanced. The impact of using advanced transaction meta-models for Web services is

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[1] SOAP, http://www.w3.org/TR/soap/
[2] WSDL, http://www.w3.org/TR/wsdl
[3] BPEL4WS, http://www.ibm.com/developerworks/library/specificaion/ws-bpel/
[4] UDDI, http://www.uddi.org and http://www.oasis-open.org/committees/uddi-spec

analyzed in [7]. A meta-model for defining arbitrary advanced transaction models is also introduced.

Service Level Agreements (SLAs) are signed between parties, as a service contract, in order to define services and set (performance) service parameters. Approaches to SLA support (e.g., insurance approach, provisioning approach, adaptive approach) are discussed in [8]. A business-aware Web service transaction model that allows expressing and blending business and quality of service (QoS) aware transactions based on business agreements from SLA and business functions is described in [9].

Research challenges in the context of service-oriented computing are described in [1] and a research roadmap for service oriented computing is presented in [2]. The authors launch four main research themes (regarded as architectural layers):

- *Service foundations* (e.g., service-oriented middleware backbone that realizes the runtime infrastructure for the SOA). Major research challenges in this area are: dynamically reconfigurable runtime architectures, end-to-end security solutions, infrastructure support for data process integration and semantically enhanced service discovery.
- *Service composition* refers to roles and functionality for aggregating various services into a single service. Composability analysis for replaceability, compatibility, and process performance; dynamic and adaptive processes; QoS-aware service composition; and business-driven automated compositions are indicated as critical research challenges in this area.
- *Service design and development*, where engineering of service applications, flexible gap-analysis techniques, service versioning and adaptability, and service governance are considered major research challenges.
- *Service management and monitoring*, where self-configurating, self-adapting, self-healing, self-protecting management services are pointed as major research challenges.

2.2 Related Work on Service Assessment and Monitoring

Research on service assessment and monitoring is mainly related to technical issues. The most common metrics associated to services are related to the quality of service (QoS). QoS represents a combination of different qualities or properties of a service, such as [10]: availability (that is the percentage of time a service is operating), security (which is related to the existence of an authentication mechanism offered by the service, confidentiality, data integrity, non-repudiation, and resilience to denial-of-service attacks), response time (e.g., the time a service takes to respond to a certain request), throughput (e.g., the rate to which a service can process requests). Such metrics are of interest for both service providers and service users. For service providers, for example, the values of such metrics are of interest when implementing priority-based admission mechanisms [11]. As emphasized in [2], approaches that attempt to calculate the QoS by collecting quality ratings from the users of the service and then combining them are not sufficient for deriving a reliable quality measure for a service. Cloud computing[5] brings the promise of providing a QoS guaranteed dynamic computing environment (e.g., [13]).

SLA defines the QoS attributes and guarantees a service. Concerning SLA monitoring, several approaches have been developed. An automated and distributed SLA monitoring engine is presented in [14], and a SLA management system built upon business objectives in presented in [15]. As emphasized in [2] and [16], research activities need to focus on using QoS metrics for selecting services and establishing trust among business partners. This emphasizes the need to concentrate on defining, collecting and calculating specific metrics for service monitoring.

However, service monitoring and assessment should not focus only on measurements related to technical characteristics (e.g., service availability). Economic issues on services (e.g., cost of a service, attained payoff) should be also analyzed and quantified, since they represent critical indicators for service providers and service users.

3 On the Economics of Service Computing

3.1 Background

Research and development work on the economics of service computing is scarce. Economic aspects of a utility computing service[6] are analyzed in [18], focusing mainly on service pricing, resource flexing and costs related to preventive security measures. Although the model used is quite simple (e.g., only limited groups of costs have been considered, such as: maintenance and upgrading), the authors illustrate its use in business decisions.

A methodology (price-at-risk) that considers uncertainty in the pricing decision is presented in [17]. The proposed methodology is aimed at optimizing the expected Net Present Value (NPV), and a numerical example is described to support this methodology. The main weakness of this work is the fact that it is around the NPV, which is an indicator often considered unreliable since it exhibits anomalous behavior (e.g., [19]). The impact of service execution is analyzed from a business perspective in [20], where services execution is adjusted and optimized based on state business objectives.

The issue of economic performance assessment in the context of service computing is of utmost importance for service providers and service users. Adequate models and metrics need to be developed. As emphasized in [21], new approaches and models (e.g., for performance assessment) do not have to be completely different from existing paradigms and economic analysis, since certain measures do not necessarily deny earlier (traditional) approaches. As consequence, existing paradigms, frameworks, models and metrics should be synthesized and analyzed in the context of service computing.

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[5] In [12], a cloud is defined as a type of parallel and distributed system consisting of a collection of inter-connected and virtualized computers which are dynamically provisioned and presented as aggregated computing resources based on SLAs set by negotiating parties.

[6] Utility computing services deliver information services when needed, e.g., customers pay for what they use [17].

3.2 State-of-the-Art on the Economics of Service Computing

An extensive literature survey has been conducted. The most relevant theories and approaches which can be relevant for the economic performance assessment in service computing were identified and are briefly described below.

Game Theory. Game theory is a branch of applied mathematics that analyzes players who choose different actions in an attempt to maximize their payoffs (e.g., [21]). A cooperative game allows the formation of coalitions: players join forces based on a binding agreement. Main fields of application are: economic systems, biology, philosophy, and computer systems. The modeling approach of game theory is highly relevant to the concept of service computing, e.g., monotonicity and super-additivity properties, Shaply value. In a service computing environment, coalitions comprise service provider(s), service client(s), and service broker(s), and their agreements are enforced in SLA(s).

Graph Theory. A (directed) graph is a set of objects called vertices (or nodes) connected by (directed) edges. A common definition of a graph (e.g., [22]) is:
$G = (V,E)$, where the sets V are vertices (or nodes), and E edges, respectively. Graph theory has been applied in network analysis, mathematics, and computer science. Graph theory is relevant for service computing analysis because organizations (e.g., service clients, providers or brokers) are the nodes of a graph, and the relationships established between organizations (e.g., stipulated in the SLA) are in fact the edges, to which different weights and directions can be associated.

Transaction Cost Economics (TCE). TCE (e.g., [23], [24]), is mainly used to explain economic issues when resources specificity plays a critical role. It is relevant for service computing modeling since it includes costs which are often ignored, e.g., search costs: costs associated with searching for an appropriate service provider.

Petri Nets. According to Murata [25], a Petri Net is a 5-tuple:

$PN = (P, T, F, W, Mo)$, where P is a finite set of places, T is a finite set of transactions, F is a set of arcs, W is a weight function, and Mo is the initial marking. Main fields of application of Petri nets are: computer science, network analysis, production control. In the context of service computing, service providers and service clients can be regarded as place nodes; transition nodes can be, for example, organizations initiating a certain service. Although applied in several domains, Petri nets have certain limitations, such as: the execution of Petri nets is nondeterministic; lack of compositionality; lack of locality.

Social networks. A social network [26] is a social structure comprised of actors (*nodes*) indicating the way by which they are connected (*ties*). Social networks have been applied to study how companies interact. In the context of service computing, social networks can provide ways for companies (e.g., service providers) to gather information, prevent competition, or conclude in setting prices. Social networks can provide general insight for relationship between service provider and clients during the negotiation and setting up of the SLA.

Decision Theory. Given a decision problem, decision theory makes use of probability theory to recommend optimal decisions, or an option that maximizes (expected) utility. Fields of application include: economics, artificial intelligence. According to [27], a decision problem presumes: an association of a set of outcomes with each action; a measure U of outcome value which assigns a utility $U(\omega)$ to each outcome $\omega \in \Omega$; a measure of the probability of outcomes conditional on actions $Pr(\omega/a)$ denoting the probability that outcome ω is obtained after action $a \in A$. Based on these elements, the expected utility $EU(a)$ is defined in [27] as the average utility of the outcomes associated with an alternative, weighting the utility of each outcome by the probability that the outcome results from the alternative:

$EU(a) = \int_{\Omega} U(\omega) \Pr(\omega / a) d\omega$. Decision theory is relevant for service computing, especially when decision makers (e.g., service providers) need to make forecasts (e.g., concerning resource utilization).

The above-mentioned theories and approaches bring certain advantages and limitations when applied to service computing economic analysis. Formal representation, advantages and limitations for each of these theories relative to service computing, are summarized in Table 1. Other approaches are also relevant. For instance, consumer theory and producer theory, imperfect competition theories can be applied for understanding the role of certain actors in the context of service computing. Microeconomics could be relevant for setting appropriate service pricing.

With these considerations, a graph theoretic approach has been developed to better understand a service computing environment, supporting services characterization and economic modeling. A service computing environment is regarded as a multi-directed graph, where the nodes are represented by the organizations which perform different roles, e.g., service provider, service client, service broker.

Definition 1. Service: S

$$S = (N, E, T, M). \tag{1}$$

S = service;
N = set of nodes (organizations) and
N is a 3-touple: $N = (S_P, S_C, S_B)$, where: S_P = Service provider; S_C = Service client; S_B = Service broker[7];
E = set of edges, representing directed lines connecting organizations in the business environment, which reflect of relationships between two nodes (e.g., between S_P and S_B, or S_P and S_C);
T = the time of analysis;
M = set of metrics to be monitored.

The environment in which different S_P, S_B, and S_C collaborate and compete constitutes the Service Computing Business Environment (SCBE).

[7] The concepts of S_P, S_C, S_B have been detailed in [28]. Accordingly, S_B are trusted parties that oblige S_P to respect privacy laws or industry best practices. A S_B keeps track of available S_P, and may add additional information, e.g., concerning reliability, trust-worthiness, QoS.

Table 1. Approaches to service computing modeling and formal definition[8]

Theory/ model/ approach	Definition and basic elements	Main strengths for service computing modeling and formal representation	Main limitations for service computing modeling and formal representation
1.Game theory	-A game is a function: $v:2^N \rightarrow R$ -Players; strategies; specification of payoffs for each strategy profile.	-Easy to define types of relationships among service client, provider, broker. -Shapley value -SLA negotiation - SLA supports coalition formation	-Lack of formal models, metrics and tools to assess and monitor economic parameters. -Shapley value can be used only in particular cases. -Several axioms and theorems in game theory assume that coalitions consist in disjunctive sets.
2.Graph theory	-Graph: $G = (V,E)$; V=nodes, E=edges.	-Service providers, service clients and service brokers and their relationships can be represented as a graph for analysis. -Algorithms	-Often not able to model real world situations.
3.TCE	Particular focus on transaction costs.	-Strategic costs related to SLA.	-Other costs involved in service computing are not included.
4.Petri nets	-5-Tuple (P, T, F, W, Mo, K); P=places; T=transitions; F=flow relation; Mo=initial marking; W=arc weights; K=capacity restrictions.	-A service computing environment can be represented as a Petri net for certain analyses.	-Lack of locality and compositionality
5.Social networks	-Nodes -Ties	-Relationships among service providers, clients, brokers).	-Extensive focus on social aspects among nodes.
6. Decision theory	- ω-outcome; U(ω)-utility; Pr(ω/a); a-action; EU-expected utility: EU(a)= $\int_{\Omega} U(\omega) \Pr(\omega / a) d\omega \cdot$	-Forecasting (e.g., resource use of service providers).	-Often difficult to obtain reasonable estimates.

Figure 1 succinctly portraits these concepts. The SCBE is formed by 9 entities (e.g., with the role of S_P, S_B, and S_C). Similar to graph theory, entities are represented as nodes, which are directed edges reflecting specific business relationships among them. The relationships between entities are reflected in the SLA and correspond to the observation time, T. Some service providers (e.g., S_{P4}) may not have any service client. Different from game theory where coalitions comprise disjunctive sets, this view on business relationships states that any entity (e.g., S_P, S_B, S_C) can have different types of relationships with other organization(s) (e.g., service providers may offer to the same client different types of services, and each business relationship is reflected in a different SLA).

[8] Following the approach presented in [21].

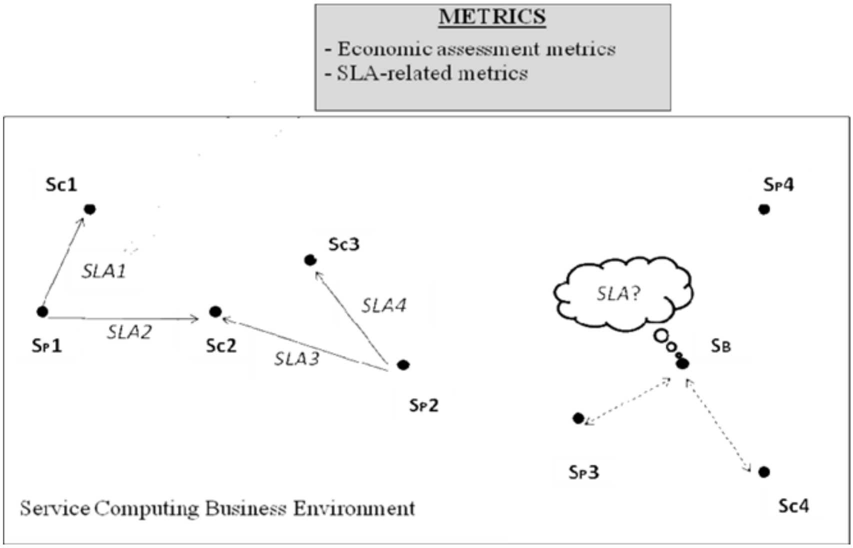

Fig. 1. Pictorial representation of a service business environment

To assess services, metrics related to SLA should be calculated and monitored (e.g., availability, throughput, downtime, response time), as well as metrics for assessing the economic performance (e.g., costs, payoffs, ROI). Models, metrics, methodologies, frameworks and tools for supporting an economic analysis and assessment in a service computing environment are not yet available. However, they would be of utmost importance for SLA negotiation, set up and monitoring, and to support decision making for S_C and S_P (e.g., concerning S_P resource scheduling).

3.3 Economic (Performance) Assessment in the Service Computing Context

In a service computing environment, S_P, S_B, and S_C collaborate and compete, and the relationships between them are characterized by several attributes, some quantifiable (e.g., costs associated with SLA negotiation), while others are difficult to be quantified.

In [21], three main ways to assess the (economic) performance have been emphasized: performance indicators, benchmarking methods, and frameworks. Performance indicators represent quantitative measures. In the context of service computing, performance indicators could support the measurement of specific characteristics related to services, organizations and their relationships, such as: costs (e.g., costs associated with SLA negotiation); QoS metrics; payoffs attained by outsourcing a service instead of in-house development. Benchmarking models can be applied to determine how well an entity (e.g., S_P) is performing compared to others. All four types of benchmarking methods (internal; competitive; functional; generic) can be applied in the context of service computing. Benchmarking assumes there is always an opportunity for improving current situation and the existence of a statistically meaningful sample size, e.g., [29], [21]. Several frameworks for assessing performance have been developed, e.g., Balanced Scorecard [30]. As emphasized in [21], the main limitation of benchmarking methods and frameworks for performance assessment is their total dependence on indicators as reference for analysis and comparison.

Thus, it is critical to develop appropriate metrics to assess performance in the context of service computing. Examples of such metrics are briefly introduced below.

Costs. The costs incurred in a SCBE are the costs associated with all activities related to providing or outsourcing a service. For *service clients*, costs to be considered include: *strategic costs* (e.g., cost of outsourcing the service); *negotiation costs* (e.g., SLA negotiation and re-negotiation costs: a S_C may simultaneously negotiate with different S_P before setting up a SLA with one S_P); *search costs* (e.g., costs incurred in determining if a certain service is available on the market); *legal costs* (e.g., costs due to legal actions when the SLA has not been respected); *costs associated to risks*. For *service providers*, costs may include, among others, *costs associated to service development*; *costs associated to maintenance* (e.g., yearly software upgrade costs); *management costs* (e.g., scheduling of resources).

SLA monitoring metrics, e.g., QoS: availability, throughput, response time.

4 Research Challenges

This section is focusing on research challenges on (economic) performance assessment in the context of service computing.

Analytical Modeling and Economic Performance Assessment and Monitoring. Performance assessment measurements refer to the quantification of performance-related characteristics of services. Such metrics should be calculated in an automatic way. Research in this area should focus on defining models, methodologies, frameworks, metrics and tools to measure (economic) performance characteristics in the context of service computing, e.g., costs. As emphasized in [31], practitioners have almost no support in selecting appropriate metrics for the implementation of SLAs, e.g., concerning automation and compliance with service objectives and IT management processes. Such metrics and tools are useful in many ways, e.g., to identify abnormalities (e.g., to monitor SLA and identify SLA violations). The challenge is not only to define performance metrics, but also to calculate and monitor them in an automated manner, and elaborate *correlations* between these metrics. Such correlations could support, for example, optimization, and identification of its impact, e.g., on S_P resource scheduling decisions.

Risk Analysis. Risk analysis is useful to analyze the effectiveness of resources management policies in achieving the objectives set. Separate risk analysis (e.g., the analysis of a single objective for a particular scenario) and integrated risk analysis (e.g., analysis of multiple objectives) approaches should be performed in the context of service computing.

Interoperability. Interoperability is of utmost importance in service computing for both service providers and service clients, e.g., for enterprise outsourcing a service is critical to attain seamless interoperability between the software/ services outsourced and own software. Research on interoperability should focus not only on technical and information interoperability, but also on economic/ business interoperability aspects.

Holistic Approach. Research on service computing should combine different areas, e.g., computer science/ engineering, economics, mathematics.

5 Conclusions and Future Research Work

In order to achieve their business goals, several enterprises decided to outsource services and focus on their core areas. In a service oriented architecture, services represent self-contained modules that provide business functionalities and are independent of the state and context of other services [28]. Several research and development projects are currently being pursued focusing on service computing. However, most of existing research work is focusing on technical aspects. Research on the economics of service computing is scarce. Adequate analytical methods and tools to quantify the economic benefits of service computing need to be developed.

Economic performance assessment in the context of service computing is a challenge. Metrics and tools to support such an analysis are necessary to assess current (economic) performance, and forecast performance capabilities.

In this article, the results of a brief survey have been presented in Table 1, with the main theories and approaches relevant for service modeling and assessment, e.g., game theory, graph theory, decision theory, Petri nets, transaction cost economics. Their strengths and limitations in the context of service computing have been analyzed. Based on this review and the research pursued so far, types of costs for both service providers and service clients have been identified. Research challenges in this area have been succinctly discussed.

Future research will focus on developing economic performance indicators for service computing assessment, and their validation.

References

1. Papazoglou, M.P., Traverso, P., Dustdar, S., Leymann, F.: Service-Oriented Computing: State of the Art and Research Challenges. IEEE Computer, 64–70 (June 2007)
2. Papazoglou, M.P., Traverso, P., Dustdar, S., Leymann, F.: Service-Oriented Computing: A Research Roadmap. International Journal of Cooperative Information Systems 17(2), 223–255 (2008)
3. Leymann, F.: Combining Web Services and the Grid: Towards Adaptive Enterprise Applications. In: Proceedings CAiSE 2005 Workshops. FEUP Edições, vol. 2, pp. 9–21 (2005)
4. Papazoglou, M.P.: Web Services: Principles and Technology. Prentice-Hall, Englewood Cliffs (2007)
5. Weerawarana, S., et al.: Web Services Platform Architecture: SOAP, WSDL, WS-Policy, WS-Addressing, WS-BPEL, WS-Reliable Messaging, and More. Prentice Hall, Englewood Cliffs (2005)
6. Tai, S., Mikalsen, T., Wohlstadter, E., Desai, N., Rouvellou, I.: Transaction policies for service-oriented computing. Data & Knowledge Engineering 51, 59–79 (2004)
7. Hrastnik, P., Winiwarter, W.: Using advanced transaction meta-models for creating transaction-aware Web service environments. International Journal of Web Information Systems 1(2), 89–99 (2006)
8. Verma, D.C.: Service Level Agreements on IP Networks. Proceedings of the IEEE 92(9), 1382–1388 (2004)
9. Papazoglou, M.P., Kratz, B.: A Business-Aware Web Service Transaction Model. In: Dan, A., Lamersdorf, W. (eds.) ICSOC 2006. LNCS, vol. 4294, pp. 352–364. Springer, Heidelberg (2006)

10. Menascé, D.A.: QoS Issues in Web Services. IEEE Internet Computing, 72–75 (November-December 2002)
11. Cherkasova, L., Phaal, P.: Session-based Admission Control: A Mechanism for Peak Load Managementof Commercial Web Sites. IEEE Transactions Computers 51(6), 669–685 (2002)
12. Buyya, R., Yeo, C.S., Venugopal, S., Broberg, J., Brandic, I.: Cloud computing and emerging IT platforms: Vision, hype, and reality for delivering computing as the 5th utility. Future Generation Computer Systems 25, 599–616 (2009)
13. Wang, L., von Laszewski, G., Younge, A., He, X.: Cloud Computing: A Perspective Study. New Generation Computing 28, 137–146 (2010)
14. Sahai, A., Machiraju, V., Sayal, M., van Moorsel, A.P.A., Casati, F.: Automated SLA Monitoring for Web Services. In: Feridun, M., Kropf, P.G., Babin, G. (eds.) DSOM 2002. LNCS, vol. 2506, pp. 28–41. Springer, Heidelberg (2002)
15. Buco, M.J., Chang, R.N., Luan, L.Z., Ward, C., Wolf, J.L., Yu, P.S.: Utility computing SLA management based upon business objectives. IBM Systems Journal 4(1), 159–178 (2004)
16. Maximillien, E.M., Singh, M.P.: Toward Automatic Web Services trust and Selection. In: Proceedings of 2nd International Conference on Service Oriented Computing (ICSOC), pp. 212–221. ACM Press, New York (2004)
17. Paleologo, G.A.: Price-at-Risk: A methodology for pricing utility computing services. IBM Systems Journal 43(1), 20–31 (2004)
18. Degabriele, J.P., Pym, D.: Economic aspects of a utility computing service. HPL-2007-101 Technical Report (2010), `http://www.hpl.hp.com/techreports/2007/HPL-2007-101.html` (accessed on September 30, 2010)
19. Oehmke, J.F.: Anomalies in Net Present Value Calculations. Economics Letters 67, 349–351 (2000)
20. Casati, F., Shan, E., Dayal, U., Shan, M.-C.: Business-oriented management of Web services. Communications of ACM 46(10), 55–60 (2003)
21. Chituc, C.-M., Nof, S.Y.: The Join/ Leave/ Remain (JLR) decision in collaborative networked organizations. Computers & Industrial Engineering 53, 173–195 (2007)
22. Gross, J.L., Yellen, J.: Handbook of graph theory. CRC Press, Boca Raton (1999)
23. Williamson, O.E.: Transaction-cost economics: The governance of contractual relations. Journal of Law and Economics 22(2), 233–261 (1979)
24. Williamson, O.E.: Transaction cost economics. Handbook of New Institutional Economics, pp. 41–65. Springer, Dordrecht (2005)
25. Murata, T.: Petri nets: Properties, analysis and applications. Proceedings of IEEE 77, 541–580 (1989)
26. Barnes, J.A.: Class and committees in a Norwegian Island Parish. Human Relations (2954)
27. Doyle, J., Thomason, R.H.: Background to Qualitative Decision Theory. AI Magazine 20(2), 55–68 (1999)
28. Papazoglou, M.P., van den Heuven, W.-J.: Service oriented architectures: approaches, technologies and research issues. The VLDB Journal 16, 389–415 (2007)
29. Brewer, P.: Putting strategy into balanced scorecard. International Federation for Accountants (2003), `http://www.ifac.org`
30. Kaplan, R., Norton, D.: The Balanced Scorecard – translating strategy into action. Harvard Business School Press, Boston (1996)
31. Paschke, A., Schnappinger-Gerull, E.: A Categorization Scheme for SLA metrics. In: Proceedings MKWI 2006, Passau, Germany, pp. 25–40 (2006)