Service Network Modeling and Performance Analysis

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***Abstract* — Services play an important role in business interactions among partnerships forming value-creating service networks. A central problem in service network design is to analyze participants' behavior and optimize their value. In this paper, we propose a simulation model to evaluate the long-term impact of changes to resources and predict the performance of service networks. Successful predictions of the future behavior of service networks help analysts improve service network's functionality.**

Keywords- service networks; value optimization; performance analysis

I. INTRODUCTION

The growth of service economies coupled with the evolution of information technology have increased the complexity of service companies in a world of interactions and partnerships. We observe that large and vertically integrated firms are replaced by value-creating service networks. Service networks consist of interdependent companies that use social and technical resources and cooperate with each other to create value [1], [2], [3].

Fig. 1 depicts the anatomy of a car repair service network comprised of five interrelated levels. In particular, the top level defines end-to-end processes connecting service provisions of several service providers (Original Equipment Manufacturer (OEM), Car Dealers and Clients [4]). In this way a service network can be partitioned into a set of discrete business services that completely process service client requests. Fig. 1, shows that an end-to-end process such as car repair is subdivided into composite service processes such as diagnosing the problem to be repaired, ordering part replacements and perform the repair. The order process shown in Fig. 1 is a composition of several atomic services (see corresponding level) such as investigating failure symptoms, identifying parts, ask advise from technicians, and ordering the appropriate (possibly upgraded) parts. Software and human services can be routinely mapped to atomic services, and can be selected, customized and combined into aggregated service applications. The software service may be deployed on a software service infrastructure, which may for example be a distributed cloud environment, providing the capabilities required for enabling the development, delivery, maintenance and provisioning of services as well as capabilities that monitor, manage, and maintain QoS such as security, performance, and availability.

Clearly, the trend will be to move to high-value service networks where business process interactions give rise to new service analytics models and techniques that will help to pro-actively manage services and pinpoint areas for improvement.

Various approaches have been proposed to measure the performance of service networks [5], [6], [7]. Most of the research has focused on describing models that represent inter-organization exchanges. In [5], a quantifiable approach of value calculation is proposed that connects value with expected revenues. In contrast, Biem and Caswell [6] describe building block elements of a value network model and design a network-based strategy for a prescriptive analysis of the value network. Allee [7] provides a systematic way for approaching the dynamics of intangible value realization, interconvertability, and creation. Biem and Caswell [6] and Allee [7] use qualitative methods to describe value in a service network in contrast to Caswell et al. [5] that calculates that calculates value in a quantifiable manner. The above approaches do not study strategic behavior of network participants that would result in value optimization.

In this paper, we study the impact of strategic changes on the performance both at the level of the network as well as its participants. In particular, we introduce an analytical model and associated simulation tool to optimize value. Comparing to previous work that has been done, we improved the estimation techniques and we used a powerful

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simulation tool to perform our experiments and analyze dynamic "what-if" questions such as: what is

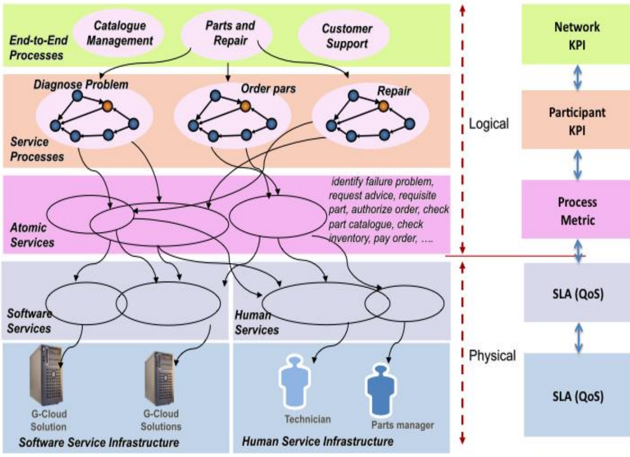

Figure 1. The anatomy of service networks.

the impact of setting optimal – for one participant - prices on the performance of the other participants as well as the entire network? What is the impact on the performance if a new participant suddenly enters the service network? Are there any equilibrium strategies among the participants that eliminate their conflicts of interests?

We extend the model presented in [5] and take into consideration the expected costs to estimate the expected value of the network and the various participants. We also improve the methodology used in [5] to provide estimations of revenues and satisfaction measures. Our main contribution is the definition and solution of value optimization problems with respect to service prices.

We observe that participants' value depends on their expected profits. Expected profits express the additional value that will be accrued by the relationship levels a participant develops when it sells goods and services to other participants or to the end customers. This value is related to its intangible assets and on the degree of satisfaction it obtains from its customers. There are many approaches that have been proposed to measure customer satisfaction. In this paper, we use the methodology proposed by Fornell et al., known as American Customer Satisfaction Index [8].

We use the System Dynamics approach [9], [10] to analyze the behavior of a complex system (car repair service network) over time. System dynamics tools allow modelers to succinctly depict complex (service) networks, visualizing processes as behavior-over-time graphs, stock/flow maps, and causal loop diagrams. These models can be tested and explored with computer simulation providing for example better understanding of the impact of policy changes (e.g., through animation of (service) systems) and facilities for sensitivity analysis. Examples of such tools include iThink [10], Vensim [11] and PowerSim [12].

In this paper, we have adopted the iThink tool to investigate the fluctuation of value under different circumstances. The results of these simulations provide predictions about the future of the service network in order to increase its adaptability to the changes of the environment and enable network participants to determine the most profitable co-operations and attract new ones. We show that the interactions among the participants of a network force them to reach equilibrium otherwise the network will collapse.

The remainder of this paper is organized as follows: Section II describes the car repair service system. Section III presents the methodology proposed to estimate value in service systems. In Section IV, we analyze the case study and run experiments to measure its performance. The results of the simulations are presented in Section V. Finally, in Section VI, we provide some concluding remarks.

II. MOTIVATING SCENARIO

The motivating scenario revolves around a service network that links four types of participants: an Original Equipment Manufacturer (e.g., Volvo), Car Dealers (with repair facilities), Suppliers and Customers. In particular, the scenario considers the end-to-end process "Order & Repair" that was already briefly introduced in the introduction.

The scenario that we will use during the remainder of this article is an extension to [5] and basically looks as follows. OEM-franchised dealers may service and repair cars for their clients. Both activities require a car parts catalogue to ensure that repairs can be performed efficiently either in the replacement of parts or repairing after accidents. The part catalogue facilitates efficient installation, operation and lifecycle maintenance of intricate products describing detailed part information that can be fully integrated with other service applications supporting customer support processes, human resource management, and other service provisions.

The quality of the OEM parts, catalogues, and OEM support services influences how many OEM parts will be ordered and used for a car repair and how many parts will be used from Third Party Suppliers (TPS), and how many customers will go to OEM dealers or to TPS dealers. OEM obtains parts from certified supply-chain suppliers (SCS).

The technicians report the car service requirements that may include replacing teardowns, warranty replacements and collision repairs. On the basis of the car diagnosis, a cost estimate will be computed and communicated to the client for authorization. Once authorized the automotive technician will scrutinize failure symptoms, detect faulty parts, order parts and perform the repair. Ordering parts is a complex process that involves asking advice from expert technicians from the OEM, including acquiring information about parts under warranty, and getting approval from the dealer's part manager. The part manager then checks local inventory for the required part, and if necessary checks the stock at the OEM or supplier stocks, and eventually places an order. The

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part manager may either use third-party suppliers or suppliers from certified supply-chain suppliers.

III. The Model

In this section, we introduce our service performance analytics model in support of strategic analysis of service network changes and improvements. Theorizing on service networks, and particularly performance analysis, can be addressed from multiple and often complementary perspectives. In our work, we propose a methodology to calculate value in service systems. We focus on the dynamic environment in which service networks emerge, and especially on connectivity and profitable cooperation that play an important role in value creation. We use our model to investigate network profitability and give answers to the following:

- Determine the conditions under which it is profitable for a firm to participate in the network and identify the factors that influence its value.
- Identify key stone participants (participants that create the most value for the network).
- Determine participants' optimal strategic decisions (cooperating with someone or not, joining the network or not, etc.).

We consider the service network as a set B of participants connected through transfer of offerings that delivers value to them. All offerings are treated as services that are composed by participants' interactions and co-operations to provide a final service to a set C of end customers. Let p_{ij} denote the price participant i charges participant j for offering its services and r_{ij} denote the service time of the interaction between participants i and j. Price and time are the main parameters that affect customer satisfaction which is in turn the corner-stone for calculating value as we will see below.

A. Customer Satisfaction

Customer satisfaction measures the willingness of end customers to buy the services offered by the network and influences the increase or decrease of new entries. The calculation of satisfaction $SAT_{ij}(T_N)$ of participant j for consuming services from participant i at the end of the time interval $[T_{N-1}, T_N]$ for our model is a variation of the American Customer Satisfaction Index (ACSI) [9] and basically described as follows. ACSI is operationalized through three measures: q_1 is an overall rating of satisfaction, q_2 is the degree to which performance falls short of or exceeds expectations, and q_3 is a rating of performance relative to the customer's ideal good or service in the category. Without loss of generality, we quantify the above measures using the following formula:

$$q_k = [(\beta_k/p_{ij})0.6 + (\gamma_k/r_{ij})0.4],\ k=1,2,3, \qquad (1)$$

where [x] denotes the integer part of x and β_ks, γ_ks are the parameters that determine the effect of price p_{ij} and time t_{ij} respectively on q_k. In our analysis, we use the following function (see [8] for further details) to calculate the satisfaction:

$$SAT_{ij}(T_N)=(w_1q_1+w_2q_2+w_3q_3-w_1-w_2-w_3)/(9w_1+9w_2+9w_3), \qquad (2)$$

where w_k are weights that indicate the importance of each measure q_k.

B. Participants' Value

We consider that an economic entity within a service network has value when it satisfies the entity's needs and its acquisition has positive tradeoff between the benefits and the sacrifices required. We emphasize on the gains or losses captured by the relationships between participants in order to compute value. Our focus is on the methodology in [5], but with a different view of the utilization of relationships between the participants. We define the expected profits $Ep_{ij}(T_N)$ of participant i due to its interaction with participant j to be the expected value of participant i in the next time interval $[T_N, T_{N+1}]$ increased (or decreased) by the percentage change of the expected satisfaction $ESAT_{ij}(T_N)$ in the next time interval and is given by:

$$Ep_{ij}(T_N)=(ESAT_{ij}(T_N)/ESAT_{ij}(T_{N-1}))(ER_{ij}(T_N)-EC_{ij}(T_N)), \qquad (3)$$

where $ER_{ij}(T_N)$ and $EC_{ij}(T_N)$ are the expected revenues and costs respectively for the next time interval. Thus, the value $V_i(T_N)$ of participant i at the end of time interval $[T_{N-1},T_N]$ is the sum of its revenues and the expected profits minus the costs that come from its relationships with all other participants. The total value of the network is the sum of the value of each participant.

C. The Mechansim for Value Calculation

In this subsection we present our value-based model that provides a mechanism to calculate value divided in various hierarchical levels. Fig. 2 (generated by iThink) shows the upper level of the hierarchy and visualizes the basic elements of our framework. We use the example of Section II to simplify our description. Each node represents a module that calculates the value of a participant. Arrows represent dependencies between modules. Each module encloses a sub-system that calculates the value of the module (second hierarchical level). Complex variables inside the module are presented as modules too. Fig. 3 shows the dealer's value calculation process. The green arrows show the impact a module has on another module (e.g., dealer's expected profits increase as dealer's revenues increase). The module dealer's cost in the third hierarchical level is depicted in Fig. 4.

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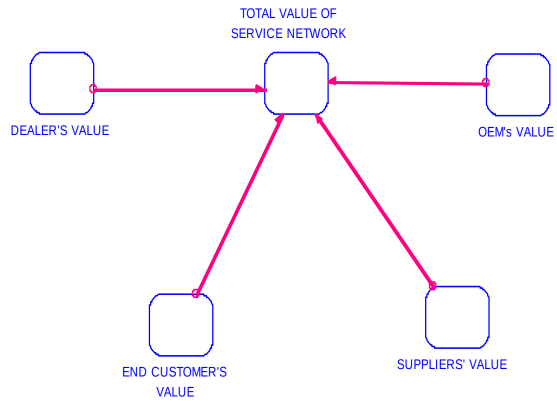

Figure 2. First hierarchical level of value mechanism.

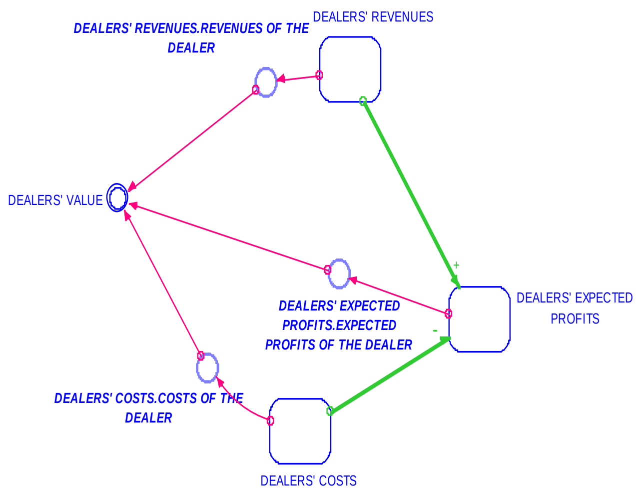

Figure 3. Second hierarchical level – dealer's value.

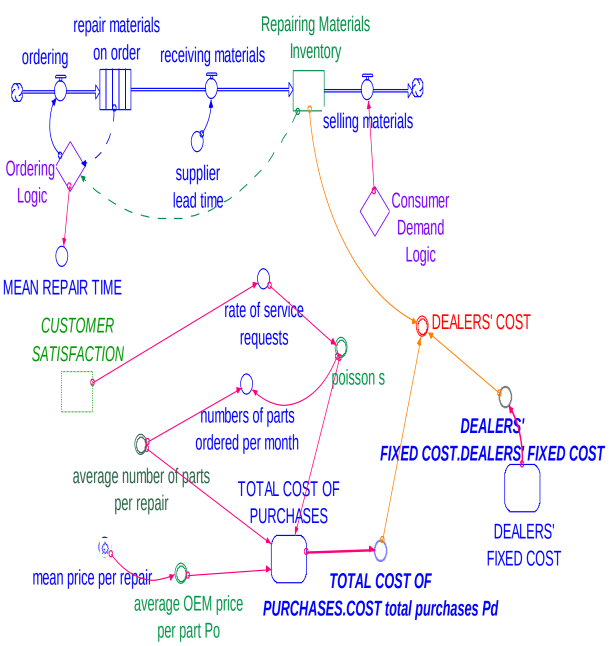

Figure 4. Third hierarchical level – dealer's cost.

IV. Simulation Experiments to the Car Repair Service System

We perform simulation experiments to analyze our model making use of 4 scenarios. First, we apply our approach to the car repair service system (Section II) to examine the network's evolution over time. We represent technicians, the parts manager, and the help desk experts as economic entities, each of which is offering its labor as a service to the service system. We measure rates of offerings and payment flows per month over a period of about 30 months. End customer service requests denoted by s are strongly affected by end customer satisfaction, since satisfied customers attract new customers to enter the network. Without loss of generality, we consider that the service requests are produced by the Poisson distribution with mean es being the output of the function:

$$es = -a_1SAT^2 + a_2SAT, \qquad (4)$$

where $a_2>2a_1>0$ so that es is an increasing function of SAT in the range [0,1]. (We have chosen (4) because the rate of increase of es decreases with respect to SAT.) We also consider that the number of technicians is a function of the number of service requests; we take that the number of technicians increases linearly with the number of service requests. We calculate the value of each participant as a function of price and time and determine its optimal level with respect to price. The equations of revenues and costs for the dealer, the OEM and the suppliers are taken from [5]. As opposed to [5] that calculates value for a given mean repair price and time, we optimize value with respect to mean repair price and time.

Second, we use the transformation of the basic model, as in [5], in order to cut costs and increase value. Concisely, a solution provider achieves interoperability between participants' information systems through application software operated by the OEM. The application allows everyone to have access to up-to-date information about parts at any time, as soon as this information becomes available to the data base of the application. The gain from the new IT infrastructure is twofold: repair time is reduced resulting in customer satisfaction increase and OEM's mailing costs are eliminated. We apply our methodology to the transformed network to show that the continuous changes of the environment push the network to restructure itself in order to remain competitive. We determine the time interval in which we observe positive effects in profitability in the transformed network compared to the initial one. We also determine which of the participants benefit from the transformation and which not.

Third, we consider a model in which the group of dealers is replaced by a new one that offers more complementarities to the end customers without increasing the mean repair price. This action seems to be profitable due

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to the increase of the satisfaction of the end customers of the service network. However new dealers have higher costs that may affect service network's value. We examine the value of these dealers and the value of the entire service network provided that OEM chooses to cooperate with them.

Fourth, we investigate Nash equilibrium strategies [13], [14] between OEM and the dealer. We define as a strategy for OEM and the dealers the mean profit rates a and b of selling parts and repair services respectively. Let p_s, p_0, p_d be the mean prices set by the suppliers, OEM and dealers respectively for offering their services. Then it holds that:

$$p_0 = p_s + ap_s = (1+a)p_s, \tag{5}$$

$$p_d = p_0 + bp_0 = (1+b)p_0. \tag{6}$$

We examine the existence of equilibrium strategies considering that the rest of the network participants (apart from OEM and the dealer) do not affect their decisions. We assume that OEM buys parts from certified suppliers at a given price p_s.

V. RESULTS

In this section, we present the simulation results from our analysis. First, we compare the basic model with the transformed one.

A .Value Optimization in Basic and Transformed Network

We show the mean repair price p^* that maximizes the dealers' and OEM's value in Table I.

TABLE I. COMPARISON BETWEEN THE BASIC AND THE TRANSFOMED NEWORK

Value	Model			
	Basic Network		*Transformed Network*	
p*	111 (dealer)	225 (OEM)	116 (dealer)	218 (OEM)
Dealer	51.469.012	34.700.000	46.874.332	34.985.000
OEM	$8500*10^6$	$26793*10^6$	$9100*10^6$	$29990*10^6$

We observe that:

- The dealers' optimal mean repair price in the basic service network is lower than in the transformed service network, since the mean repair time (that affects value) decreases, so the dealer charges his customers less. Consequently, the dealer is forced to increase the mean repair price in order to increase its revenues. Nevertheless, at the optimal mean repair price, dealers' value is less in the transformed network since the customer satisfaction has decreased as well (higher charges).
- OEM's value is much higher in the transformed network than in the basic one. This is explained by the fact that the mean repair time decreases and the customers are more satisfied (at OEM's optimal mean repair price). In addition, OEM in the transformed network has much lower mailing and labor costs.
- In both networks OEM's value at dealer's optimal mean repair price (111 and 116 respectively) is very low compared to OEM's value at his optimal mean repair price. This means that OEM will never be satisfied to offer its services at prices that reach dealer's optimal level.
- Dealers' value at OEM's optimal mean repair price is higher in the transformed network, since OEM's optimal price is lower (218).

Furthermore, the simulation results show that, OEM's value in the transformed network is not higher than that of the basic network from the first month. It dominates after 10-12 months, when both networks offer their final services at their optimal mean repair price (Fig. 5). When both networks offer their services at common prices in the range of 80 to 350, the transformed network dominates the basic network at month 8 to 17.

Finally, the total value of the transformed network (32.190.040.300) is maximized at mean repair price 216 and

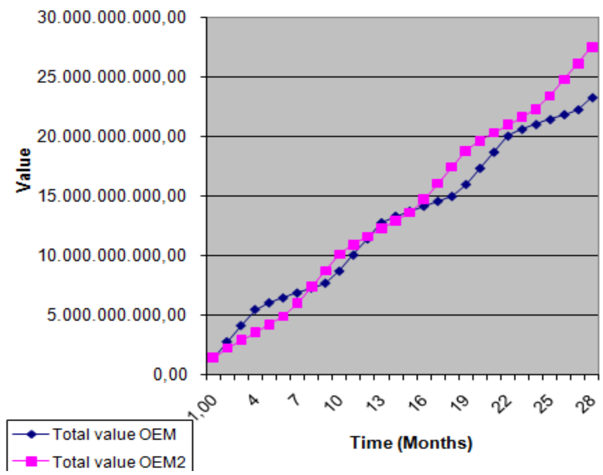

Figure 5. OEM's value in basic (1) and transformed (2) network at common mean repair prices.

is higher than that of the basic network (28.593.400.000) which is maximized at mean repair price 223. This is explained due to the fact that end customers are more satisfied and OEM (the keystone participant) has managed to cut costs at a great extend in the transformed network. Moreover, we see that the optimal mean repair price for both service networks is very close to the optimal mean repair price of OEM, since OEM contributes the largest part of the total value of the network.

B. Sensitivity Analysis of the Mean Repair Price

In this section, we investigate the impact of mean repair price changes to the dealers' value. As the mean repair price increases, the difference between the dealers' value in the basic network and that in the transformed network is

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smaller. This is justified by the fact that although the service requests decrease the mean repair price increases resulting in a decrease of the total value as shown in Fig. 6.

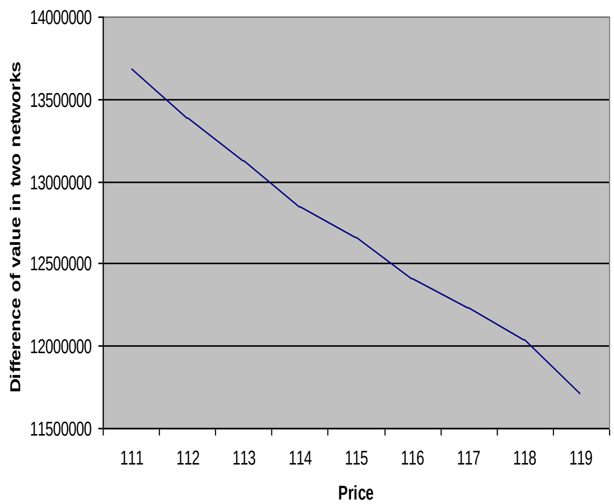

Figure 6. Dealers' difference of value in basic and transformed networks.

C.The Impact of New Entries

We call the network with the new group of dealers as the competitive network. We calculate values in the new scenario at mean repair price 216 which is the optimal price for the transformed network. We investigate the impact of the change of dealers letting the price unchanged so that the end customers are motivated to remain in the network. We show that dealers' value (31.527.812) is lower in the competitive network compared to the transformed one (35.481.031), since the new dealers' cost is higher due to the complementarities they offer. In addition, OEM's value increases (from 29.793.000.000 to 31.713.504.020) due to the increase of the service requests. The total value of the network increases from 32.190.040.300 to 32.792.529.000.

From the above we observe that a change in the network that improves its performance may affect positively some participants and negatively others. Naturally, dissatisfied participants abandon the network causing side effects to the others.

D. Participants' Equilibrium Strategies

We perform two experiments in order to investigate strategic interactions and determine equilibrium strategies of OEM and dealers. In the first experiment we calculate OEM's optimal profit rate at a given profit rate for the dealer. Simulations show that when the dealer increases its profit rate (e.g., from 6% to 10%), OEM's optimal choice is to decrease its optimal profit rate (from 24% to 21%). Conversely, if OEM increases its profit rates (e.g., from 14% to 21%), the dealer optimally decreases its profit rate (from 15% to 10%).

The second experiment calculates a set of equilibrium strategies for OEM and the dealer: at dealer's profit rate of 10% the optimal OEM's profit rate equals 21%. Conversely, at OEM's profit rate of 21% the optimal dealer's profit rate equals 10%.

VI. CONCLUSIONS

In this paper, we proposed a methodology that estimates value in service systems. We applied this methodology to a car repair service network. We run simulation experiments to maximize the value of each participant and the total value of the network. In addition, we defined suitable scenarios to study the internal relationships that are developed inside the service network. Finally, we examined the interactions between the participants inside the service network in order to determine their optimal choices.

Directions for future work include the study of competitive service networks that form oligopolies in order to increase value. Furthermore, additional work is needed on the estimation of value of intangible assets such as knowledge, sense of community, etc.

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