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# Multiagent System-based Simulation Method of Service Diffusion in Consumer Networks – Application to repeatedly purchased plural services –

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**Abstract.** This paper presents a simulation based analysis method for service diffusion in consumer networks. Services with good qualities do not always diffuse because service quality is often unstable because of the nature of service delivery systems involving human. Consumers cannot also confirm the quality of service before purchase because service has no shape. Therefore, it is necessary to study diffusion process of service by computer simulations to clarify the process of acceptance among consumers in consideration with heterogeneity of consumer utility due to the unstable service quality. This paper proposes a multiagent-based model for diffusion of plural competing services repeated purchased in consumer networks including heterogeneity of consumer utility. It is verified that the heterogeneity of consumer utility and network structure affect service diffusion process in the results of computer simulations. Finally, the diffusion process of services is concluded in terms both of the number of service and repetition of service purchase.

**Keywords:** Service, Diffusion, Simulation

## 1 Introduction

Current vigorous research activities on the fields of Service Science [1], Product-Service System (PSS) [2] and Service Engineering [3] mainly focuses on the design methodologies of services. However, services with good qualities do not always penetrated in the market; not only services design method but also services diffusion analysis method is important to realize services innovation. This paper describes a multiagent system-based simulation method for analysis of service diffusion mechanism in consumer networks.

Because of characteristics of services such as intangibility, inseparability, heterogeneity or perishability, the following influences can be identified in the purchase decisions of consumers; presumably, the utility of a service is more heterogeneous among consumers than utility of a product. Expectations before purchase become heterogeneous because consumers can not check the quality of the

service a priori. The utility from service use also becomes heterogeneous because of the heterogeneity of service quality. This study employs the heterogeneity of consumer utilities.

Externality is also an important factor affecting service diffusion. Externality is definable as a situation by which a certain economic subject affects other subjects without a market, perhaps by word of mouth or through fashion. Because the influence of the externality occurs as a result of interaction among consumers, it is also necessary to consider connections of consumers to study service diffusion. Kawamura created the multiagent-system-based model of the market in which the connection network of consumers is expressed as complex networks [4] based on the early study of network externality [5]. Although those earlier studies investigate consumer connections as well as the externality, they do not consider the heterogeneity of consumer utilities due to the services characteristics.

Previous works [6][7] focused on the service purchased only once such as an Internet connection provider, then, the proposed method was applied to the diffusion of one kind of the service purchased repeatedly [8]. The proposed method is extended and applied to service diffusion process of plural competing services repeatedly purchased in this study. Finally, the diffusion process of services is concluded in terms both of the number of service and repetition of service purchase.

## 2 Service diffusion model

### 2.1 Consumer agent model

A consumer agent is modeled as following; each consumer agent  $i$  has a utility  $U_{im}(t)$  about service  $m$  and a threshold  $T_{im}$  at the simulation step  $t$ . The consumer agent  $i$  purchases a service  $m$  when  $U_{im}(t)$  exceeds  $T_{im}$ :

$$U_{im}(t) \geq T_{im} \quad (1)$$

Consumer agent  $i$ 's utility  $U_{im}(t)$  is defined as

$$U_{im}(t) = R_{im}^{exp}(t) + \sum_{j \in N \setminus \{i\}} g_{jm}(t) y_{im}^j(t) + L_{im}(t) \quad (2)$$

where  $R_{im}^{exp}(t)$  represents the expected utility before purchasing the service  $m$ ;  $g_{jm}(t) y_{im}^j(t)$  signifies the utility acquired through interaction with other consumers.  $N$  is the set of consumers.  $L_{im}(t)$  represents influence from the experience of the previously purchased service  $m$ .

It is assumed that the consumer utilities become heterogeneous among consumer agents according to the characteristics of service; the expected utility becomes heterogeneous because the service quality cannot be confirmed before

purchase by consumers. The actual utility also includes heterogeneity since the service quality is also heterogeneous due to the service provider's ability. To model such heterogeneity of the consumer utilities, normal distribution is introduced as following:

$$\begin{cases} R_{im}^{exp}(t) = N(\alpha, \beta_e), & \text{before the first purchase} \\ R_{im}^{act}(t) = N(\alpha, \beta_a), & \text{after purchase} \end{cases} \quad (3)$$

Furthermore,  $R_{im}^{act}(t)$  affects the expected utility at the next purchase decisions:

$$R_{im}^{exp}(t+1) = \begin{cases} R_{im}^{act}(t), & \text{if } i \text{ purchases service } m \text{ at time step } t \\ R_{im}^{exp}(t), & \text{otherwise} \end{cases} \quad (4)$$

It is also assumed that each consumer evaluates a service based on the difference between expectation of and results from the service: consumer  $i$ 's degree of satisfaction is represented as  $S_{im}(t)$ . Referring to the earlier research [9],  $S_{im}(t)$  is formulated based on prospect theory. The formula of  $S_{im}(t)$  is divided into plus-number and minus-number sides around the point that  $R_{im}^{exp}$  and  $R_{im}^{act}$  coincides. The influence of dissatisfaction is greater than the influence of satisfaction. The value of  $S_{im}(t)$  is represented as follows:

$$S_{im}(t) = \begin{cases} f(R_{im}^{exp}, R_{im}^{act}), & \text{if } i \text{ use service } m \\ 0, & \text{otherwise} \end{cases} \quad (5)$$

$$f(R_{im}^{exp}, R_{im}^{act}) = \begin{cases} a^+ \{1 - e^{-\frac{b^+}{a^+}(R_{im}^{act} - R_{im}^{exp})}\}, & (R_{im}^{act} \geq R_{im}^{exp}) \\ a^- \{1 - e^{-\frac{b^-}{a^-}(-R_{im}^{act} + R_{im}^{exp})}\}, & (R_{im}^{act} < R_{im}^{exp}) \end{cases} \quad (6)$$

Therein,  $a^+$  and  $a^-$  represent the values at which equation (6) converges;  $b^+$  and  $b^-$  represent the values of inclination around origin of equation (6).  $|a^-|$  ( $a^- < 0$ ) is set to the larger value than  $|a^+|$  ( $a^+ > 0$ ), so that the influence of dissatisfaction is greater than the influence of satisfaction.

The consumer agent purchasing the service notifies other connected consumers about the effect of the externality. The utility obtained by the externality  $y_{im}^j(t)$  is represented as

$$\begin{aligned} y_{im}^j(t) &= (R_{jm}^{act}(t) + S_{jm}(t))w_{ij} \\ &\quad + (R_{jm}^{act}(t) + S_{jm}(t)) \sum_{x \in N \setminus \{i,j\}} w_{ix}w_{xj} \\ &\quad + (R_{jm}^{act}(t) + S_{jm}(t)) \sum_{x,y \in N \setminus \{i,j\}, x \neq y} w_{ix}w_{xy}w_{yj} \end{aligned} \quad (7)$$

where  $w_{ij}$  represents the degree of closeness between connected consumers, defined as

$$\begin{cases} w_{ij} > 0, & \text{if } i \text{ and } j \text{ are friends} \\ w_{ij} = 0, & \text{otherwise} \end{cases} \quad (8)$$

$$\text{subject to } \sum_{j \in N_i} w_{ij} = 1 \quad (9)$$

where  $N_i$  represents the set of consumers connected to the consumer agent  $i$ .

The effect of the externality is considered until the third term of  $y_{im}^j(t)$  because the value after the fourth term of  $y_{im}^j(t)$  is neglected according to eqs. (8) and (9). Furthermore,  $g_{jm}(t)$  is defined as the following because a consumer who does not purchase the service can not note the effects of the externality:

$$g_{jm}(t) = \begin{cases} 1, & \text{if } j \text{ is using service } m \\ 0, & \text{otherwise} \end{cases} \quad (10)$$

Referring to Guadagni's report about brand choice [10], the influence from the experience of the previously purchased service  $m$ ,  $L_{im}(t)$ , can be defined as

$$L_{im}(t) = \begin{cases} S_{im}(t), & \text{if } i \text{ purchases service } m \text{ first} \\ \lambda L_{im}(t-1) + (1-\lambda)S_{im}(t), & \text{otherwise} \end{cases} \quad (11)$$

where  $\lambda$  represents a weight value between the loyalty at step  $t-1$  and the satisfaction at step  $t$ .

## 2.2 Consumer networks models

This study adopts complex networks [11] to express connections among consumers. The complex networks can model networks in the real world including the networks of the information and communication technology, the biological network, the social network, and so on.

Networks comprise nodes and links: nodes represent consumers and links express acquaintance relations between consumers. In the study of complex networks, three major indices express network features: average distance  $L$ , clustering coefficient  $C$ , and degree distribution. Node  $i$ 's average distance  $L_i$  is the average of distances from node  $i$  to all other nodes; the distance  $d_{i,j}$  is defined as the minimum number of links that an agent passed from node  $i$  to node  $j$ . The clustering coefficient  $C$  is an index to express the group degree of the network. The number of links connected to agent  $i$  is called agent  $i$ 's degree  $k_i$ . The degree distribution is the distribution of degrees of all nodes.

To model connections of consumers, six network models proposed in the research area of complex networks are adopted: a Regular model, Random model

[12], WS model [13], BA model [14], KE-1 model [15], and KE-2 model [16]. In this study, the six models are introduced to express the connection of consumers under the condition; the number of nodes is set to 1000 and the number of links is set to 3000.

### 3 Experimental results and Discussion

#### 3.1 Experimental conditions

The computer simulations are conducted using above mentioned consumer agent and networks models. The number of service purchased by consumers is set to two where  $m = 2$ ; simulations reveal how two kinds of competing services penetrate among consumers. The market model is constructed where the number of consumer agent and the average degree are set to 1000 and six, respectively. The threshold values of consumer agents,  $T_{im}$ , are set by uniform random  $U(3, 6)$ . Values  $a^+$ ,  $a^-$ ,  $b^+$  and  $b^-$  in the equation (6) are determined to make  $S_{im}$  set to  $-3.0$  and  $1.5$  when the difference between  $R_{im}^{act}$  and  $R_{im}^{exp}$  is  $-3.0$  and  $3.0$ . The rate of the innovator consumers that have purchased the service at the initial state is set to 2.5% based on Rogers's theory [17]. The simulation is terminated at time step 50 ( $t_{end} = 50$ ).

Simulations are executed under three conditions that each expected utility and actual utility is set to the value shown in Table 1 due to the difference of heterogeneity using normal distribution.

**Table 1.** Experimental Condition

	Service 1		Service 2	
	$R_{i1}^{exp}$	$R_{i1}^{act}$	$R_{i2}^{exp}$	$R_{i2}^{act}$
Condition 1	3	3	$N(3, 0.5^2)$	$N(3, 0.5^2)$
Condition 2	3	3	$N(3, 1^2)$	$N(3, 1^2)$
Condition 3	$N(3, 0.5^2)$	$N(3, 0.5^2)$	$N(3, 1^2)$	$N(3, 1^2)$

#### 3.2 Results and discussion

The results of the experiments are shown in Table 2. Values in the table represent resultant average diffusion rate in 100 trials obtained by dividing the number of purchased consumers by the total number of consumers at the end of the experiments. In the point of average diffusion rate, every results in the three experimental conditions shows that service with lower heterogeneity (service 1) can obtain higher diffusion rate than the service with higher heterogeneity (service 2) although the service with higher heterogeneity can obtain higher diffusion rate in some trials. These results are in contrast with the previous

**Table 2.** Experimental Result

Network model		Regular	Random	WS	BA	KE-1	KE-2
Condition 1	Service 1	51.43	70	68.78	67	46.31	58.61
	Service 2	40.72	30.00	29.77	33.00	40.62	36.25
	Total	92.15	100	98.55	100	86.93	94.86
Condition 2	Service 1	81.47	100	98.10	85.00	68.11	88.72
	Service 2	8.30	0	0.63	14.76	15.34	5.69
	Total	89.77	100	98.73	99.76	83.44	94.41
Condition 3	Service 1	66.61	68.00	95.72	63.00	51.07	76.02
	Service 2	13.62	31.50	1.99	36.39	19.61	12.53
	Total	80.23	99.49	97.71	99.34	70.68	88.55

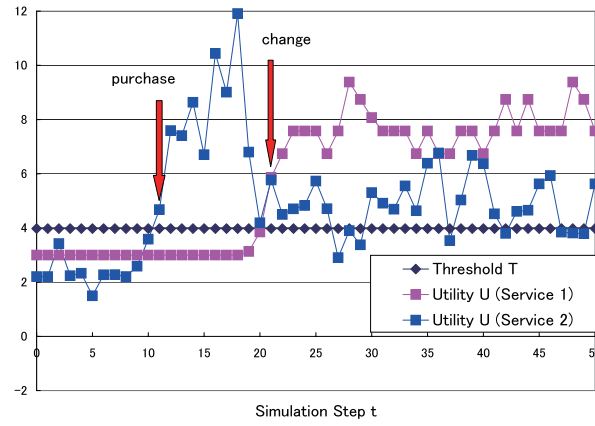
experimental results in the case of diffusion process of one kind of service; more heterogeneous service could obtain higher diffusion rate.

Fig. 1 represents transition of the consumer utilities who changes the purchased service from Service 2 to Service 1 during a simulation under the condition 2 and Regular network model. In the early stage of the simulation, the consumer purchases Service 2 with higher heterogeneity of consumer utility. In turn, as the simulation progresses, because of the effect of dissatisfaction with the service and the influence of the externality from the connected other consumers, the consumer stops buying Service 2 and starts purchasing Service 1 with homogeneous consumer utility. The experimental results reveal that services with more homogeneous utility tends to penetrate in the market with plural services purchased repeatedly.

As a summary of simulation results in the proposals, Table 3 concludes service diffusion from the viewpoints both of the number of services diffused and the repetition of purchase. In the single service market, service with heterogeneous consumer utility diffuses among consumers regardless of frequency of purchase. However, too much heterogeneity of consumer utility ends in no diffusion. In the case of plural competing services, service with heterogeneous consumer utility penetrates among consumers, which is purchased only once. In turn, service with homogeneous consumer utility diffuses in the case of repeated purchased services. These results reveal that service provider needs to develop the new services with taking into account the characteristics of the services from the viewpoints of the existence of the plural services and the frequency of purchase.

**Table 3.** Summary of service diffusion

	Single service	Plural services
Service purchased only once	Service diffuses with properly heterogeneous consumer utility	Service diffuses with heterogeneous consumer utility
Service purchased repeatedly		Service diffuses with homogeneous consumer utility



**Fig. 1.** Consumer changes service purchased (Condition 2, Regular model)

## 4 Conclusion

In this study, a multiagent-based simulation method of service diffusion was proposed, which was modeled by using multiagent system and consumer's communication networks based on complex networks. Heterogeneity of consumer utilities composed by expected and actual utilities of service were also introduced. The proposed method was applied to the repeatedly purchased plural service market. Computer simulation results revealed that diffused services are difference from the viewpoint of the service market; the number of the services and the frequency of purchase.

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