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A Study of Citizen-centred E-government Service System
An Agent-Based Approach

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Abstract

E-government is a rapidly emerging research field in recent decades. Benefits of deploying E-government service are obvious in the sense that more flexible services are provided to satisfy citizens' divergent needs and the service quality is improved through integrated services. However the adoption rate of E-government is still relatively low, especially for transactional services. Extant works on E-government have examined this phenomenon from various perspectives by using both qualitative and quantitative research methods. However, there is a lack of empirical study that could investigate this phenomenon from a service system perspective by identifying and integrating the involved stakeholders and their relations as a holistic system.

In this thesis, we propose to apply a "bottom-up" approach, agent-based simulation, to investigate the citizen-centred E-government service system from such a perspective. We've built a conceptual model to identify the characteristics of heterogeneous stakeholders, their adaptive behaviours, and the interaction mechanisms among them. By implementing an agent-based model based on the conceptual model, we are enabled to examine citizens' divergent E-government adoption behaviours in different scenarios, to evaluate the cost-effectiveness of supporting strategies and to optimize resource allocation in terms of user support among different social groups.

On citizen side, we've applied agent-based modelling to investigate how citizens from different social groups choose channels to utilize certain kind of governmental services over time. In addition, we have investigated the influence of the adaptive learning within communities that are composed of citizens with different preferences on E-government adop-

tion, and explored the effectiveness of supporting policies in a long-term perspective. With respect to the E-government service adoption, we assume that learning within communities which focuses on the competence and practice of individuals connected by strong ties is more common than that via social network which emphasizes relations among members with weak ties. On the other side, the spread of information/knowledge on E-government might also influence the learning process, and further affect the adoption behaviour indirectly. Understanding such dynamic learning mechanism is crucial to the investigation of divergent citizens' adoption behaviour of E-government services, thus potentially important to the evaluation and design of supporting policies as well. This model enables the understanding of a wide range of possible adoption behaviours under different scenarios, and the exploration of to what extent the variant supporting policies are effective.

On public sector side, in order to encourage more citizens to utilize E-government services, there are many kinds of user support provided, though the effectiveness might vary among different social groups. Due to limited resources, if more resources are allocated to social groups who are not favoured by E-government service, it is very possible that in turn other social groups will not be satisfied and thus further influences the adoption rate. Therefore how to allocate the limited resources in an optimized way such that all the social groups are satisfied is a challenging and meaningful research problem. We've resolved those conflicted objectives and achieved a set of Pareto optimal allocation of the resources among different social groups by using agent-based approach with multi-objective genetic algorithm.

In addition, we've analysed the simulated data from both macro-level and micro-level perspectives. Not only the macro-level E-government adoption phenomenon could be analysed, but also the community-level dynamics are scrutinized. Insight and knowledge gained from the result analysis could help policy makers understand citizens' divergent needs more comprehensively and design better E-government systems to entice more citizens.

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Contents

Chapter 1

Introduction

1.1 Citizen-centred E-government systems

It is hard to give a clear definition of what E-government system is, although it has been immersed in people's lives for years. Generally speaking, the purpose of E-government is to promote transparency, convenience, and effectiveness to citizens. As defined by UN and American Society for Public Administration (ASPA), E-government is "utilizing the Internet and the world-wide-web for delivering government information and services to citizens [87]", from which we could see that the basic element of E-government system is to deliver public services by applying web technologies. In literature, researchers are prone to capture this phenomenon from different aspects and define it accordingly, thus no common definition is agreed. Several reasons are accounted for this difficulty of defining E-government systems, especially from the perspective of citizens who are the primary users of such systems. First of all, unlike the objectives of E-government, which are relatively clear to define, there is a lack of the description of involved stakeholders' activities and the specific technology deployed in such systems. Therefore, the meaning of E-government that stems from its particular deployed context such as dominant social groups and enacted E-government related strategies is blurred and overlooked [95]. Secondly, for citizens with distinctive characteristics and background, E-government may hold different meanings and

most of the citizens might not grasp the overall clear image of E-government [85]. Since the ultimate purpose of E-government systems is to provide better services to citizens, understanding such systems with an emphasis on citizens' divergent background, preference and expectation of public services is important and key to improve the service provision process and the service quality. In reality, poor design of E-government systems that only aligns with common practice and does not consider the desire of citizens fail to entice citizens [67, 70]. Comprehending and designing use-centric public service are remained complicated and challenging along with the continuous service diffusion among citizens and the changing of policy-making, therefore adopting new perspective and applying new methodology to investigate this phenomenon is necessary to provide new insights for policy makers.

1.1.1 A service system perspective

E-government is a relatively new research field, thus closely associated with other research realms, such as information systems and public administration [44]. Most of extant works on E-government systems examine different aspects of this phenomenon, for instance, E-government service adoption and diffusion process, and governance issues from either end-user sector or public governor perspectives [32, 16, 62, 89, 92]. There are few systematic empirical studies which view E-government system from a holistic view [25, 6] and especially from a citizen-centred service system perspective.

However, E-government system is not only about the information technology deployed in public sectors to facilitate public administration, rather it is a service provision process that involves both citizens as the service receiver and the government as the service provider. Undoubtedly, citizens with divergent background and different views of E-government play the key role in making E-government systems meaningful and successful [4]. On one hand, citizens with divergent background might influence services in both direct and indirect ways [24]. Specifically, pressures from users to improve the efficiency and usability of services have direct influence on the service provided, while interaction

between citizens and the government, together with its resulted adoption rate have indirect impact in the sense that even the innovation provided by government departments is affected by what is expected from the user side [6]. In fact, users may transfer their unique experience while dealing with the services to the service provider, and eventually enhance the service in certain degree [8]. On the other hand, regarding organizational concerns, innovation related decisions reflect the vision and strategy of public sectors, and limited resources are subject to relocation among different social groups. The physical system should satisfy individual's needs, rather than the opposite case. Therefore, besides the basic user-friendly requirements of E-government systems, there should be more considerations on diverse citizens' behaviours of using various services, which will have impact on the service design. Furthermore, government should help different groups of citizens conquer the usage barriers, and policy and supporting strategy design should take citizen's needs and reflection into account as well, which makes the E-government services more complicated and challenging to understand and design [6].

Therefore in order to understand the underlying dynamic service delivery process and interactions among stakeholders, various elements of the system should be defined, integrated and analysed [5], such as citizens, organizational resources, social-cultural context, strategy and initiatives [94]. Service can be defined as "the application of competence and knowledge to create value between providers and receivers" [34, 81]. A service system should not only involve technology, people and organization, but also the shared knowledge and social context. For service, dynamic process is more important than static entities [14, 90, 20], and customers participate in and influence the delivery process directly or indirectly. In this sense, service can also be viewed as "a series of interactions between service provider and clients that result in an observable output [81]." By taking this service system viewpoint, we could understand E-government systems from different angles and gain new insight and knowledge from the investigation [20]. In this work, we will view E-government system from such a service system perspective and investigate it by adopting a holistic view.

1.1.2 Agent-based approach

Regarding E-government research, both traditional qualitative and quantitative method have been applied extensively in this field to capture a particular aspect of this phenomenon [44]. However, neither of them could capture the divergent characteristics of involved stakeholders, their adaptive behaviours to the environment, the dynamic mechanisms of interaction among heterogeneous stakeholders and the resulted macro-level phenomenon, as well as the effectiveness of policy making in long term based on the service provision process simultaneously. Therefore, a new research methodology should be applied to fill the gap left over.

Agent-based modelling (ABM) [33] has been applied extensively in both organizational innovation study and innovation diffusion study respectively [29] to capture the particular macro-level phenomenon resulted from heterogeneous individuals' interactions at the micro-level. It might be more practical to be used to analyse the service diffusion and adoption process from a "bottom up" perspective. In addition, it could be utilized to explore the interactions among involved stakeholders, and to investigate how the interactions lead to collective behaviours. Besides, ABM could be used to evaluate various supporting policies virtually and open new ways of collaboration among stakeholders. In contrast, the prevailing methodology applied to study E-government services diffusion is the quantitative one such as survey that tries to identify key affecting factors of the adoption behaviour and the corresponding causal relationship, which ignores the individual's adaptive behaviours and the dynamic interactions. Therefore, ABM could be a justified way to study the E-government phenomenon and examine different strategies in service diffusion process since the whole process is dynamic and heterogeneous stakeholders are involved. In addition we expect the macro-scale diffusion trend emerged from the interactions among micro-level individuals.

1.2 Contribution statements

As discussed above, we aim to scrutinize the E-government phenomenon from a service system perspective by applying agent-based approach. The micro-level characteristics of involved stakeholders, individuals' adaptive behaviours, interactions among stakeholders, as well as the resulted macro-level phenomenon are under investigation. Profound and advancing understanding and insight on the dynamic behaviours of this service system in both micro-level and macro-level are expected to inspire better designed systems and strategies. The objectives of this thesis are stated as follows,

1. Propose an integrated conceptual model of citizen-centred E-government system to capture and identify the involved heterogeneous stakeholders, and to define their characteristics, behaviour rules, mechanisms of interaction and boundary conditions in order to examine and understand the system more profoundly and thoroughly.

2. Construct the agent-based model to understand citizens' divergent channel selection behaviours of public services. Properties of public services, characteristics of citizens with different background, and their adaptive selection behaviours are captured and simulated to examine how those aspects will influence the E-government adoption behaviour in long term. Learning mechanisms among citizens are also integrated and experimented. E-government supporting strategies are expected to be proposed and evaluated based on citizens' behaviours.

3. Optimize resource allocation in terms of user support among citizens with different background based on the citizen-side modelling. Insight and advices on how to allocate the scarce resource in order to satisfy the needs of different social groups simultaneously would be gained for policy makers.

4. Analyse the simulated data from both the macro-level perspective, i.e. adoption of E-government across citizens with divergent background, and the micro-level perspective, i.e. dynamic change of communities' properties. The latter is enabled par-

ticularly by agent-based approach and new insight into the underlying micro-level dynamics that lead to macro-level phenomena is expected.

1.3 Organization

To tackle the research problems and to achieve the objectives proposed above, this thesis is organized as in Fig. 1-1. In Chapter 2, we will review the relevant literature on E-government service systems from both methodological and theoretical perspectives. A brief review on innovation diffusion study and agent-based approach will be provided as well. In Chapter 3, conceptual model of the service system will be presented through which involved stakeholders are identified, explained and integrated, and individual's abstract adaptive behaviours and interactions among stakeholders are presented. In Chapter 4, citizen-side modelling, i.e. citizens' channel choice of public services, will be constructed and discussed. Properties of public services, characteristics of citizens, and adaptive learning process within communities are modelled and their influence on the adoption of E-government are examined, based on which supporting strategies are proposed and evaluated. On the other side, the government-side resource allocation optimization problem among different social groups will be discussed and tackled in Chapter 5. Resulted simulation data analysis will be conducted in both macro-level and micro-level in Chapter 6. In the last chapter, we conclude this thesis and suggest some potential future research problems. The overall structure is as illustrated in the following Fig. 1-1.

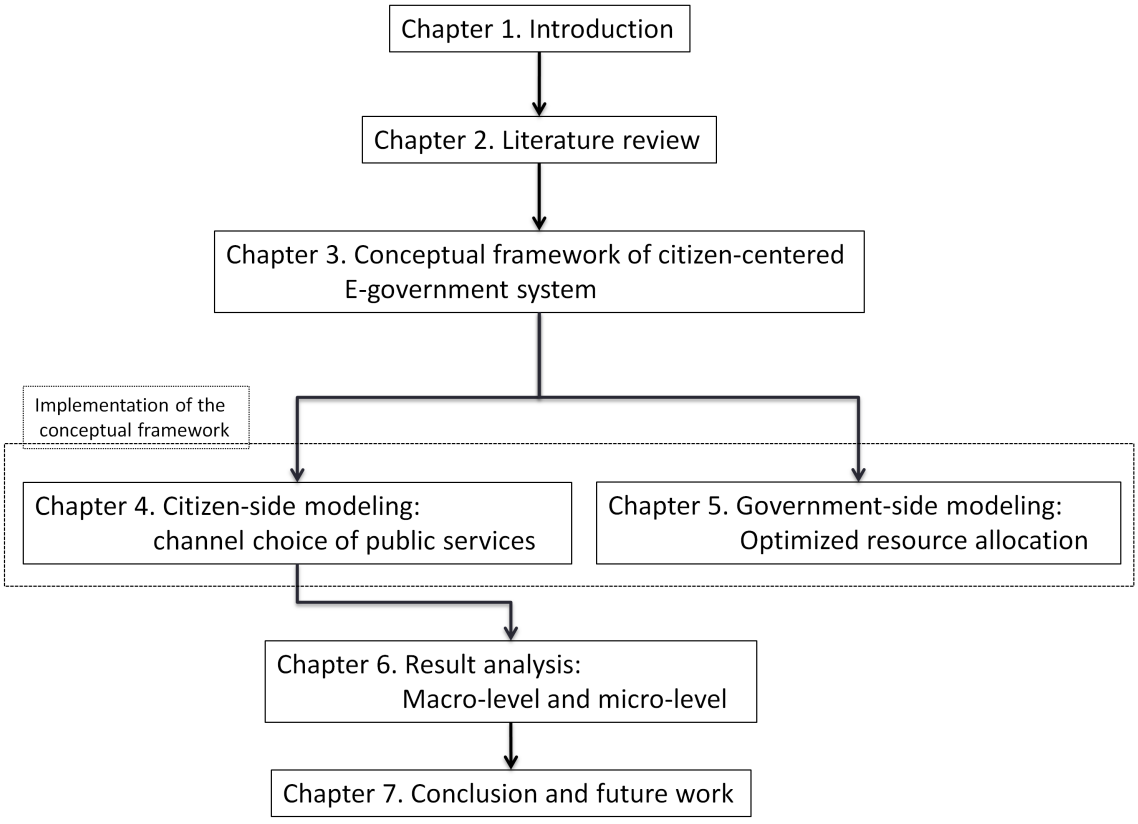


Figure 1-1: Thesis structure

Chapter 2

Background

In this chapter, we will give a general background introduction of E-government systems, including its definition and development in past decades followed by its research methodological and theoretical foundation in literature, from which we could posit this study. In addition, agent-based approach and especially the justification of its application in this work will be discussed.

2.1 E-government Definition and Development

In literature, researchers try to study E-government phenomenon from three major perspectives: what is E-government, what is the evolvement of E-government service and what do citizens expect from E-government [32]. In the following we will discuss them in sequence.

2.1.1 E-government definition

Generally the purpose of E-government is to promote transparency, convenience, and effectiveness to citizens. As defined by UN and American Society for Public Administration (ASPA), E-government is "utilizing the Internet and the world-wide-web for delivering government information and services to citizens [87]". The basic element of E-government system is to deliver public services by applying web technologies. However, there is no

clear and well-recognized definition of E-government yet in literature [43]. Different definitions are proposed from various angles and trying to grasp different aspects of this phenomenon [95]. Some researchers regard E-government as the application of web technologies to promote government services efficiently and effectively [10], and the government is virtually organized through agencies who are structured and enabled by the web technologies [28]. Additional technology deployed besides web technologies may include database, multimedia, and so on [50]. On the other hand some researchers regard E-government as the electronic means that enable interactions between the government and the receivers of public services, such as citizens, private sectors, and other public administrations [66]. There are several reasons for this difficulty of defining E-government. According to Yildiz [95], first of all, besides the general purpose of E-government, there is no clear description of stakeholders' activities involved and no specific technology confirmed. Therefore the meaning of E-government might depend on its particular context such as dominant social groups and enacted E-government related strategies. Second, for different classes of citizen, E-government may have different meanings and most of the citizens might not grasp the overall clear image of E-government [85]. The same phenomenon means different things and can be defined alternatively to reflect a particular issue of it, such as cost-effectiveness and transparency [38]. Yildiz [95] also argued that it is not the advancing technology defining what E-government is, rather it is the service delivery process and key players' behaviours making us understand the "evolving nature of the E-government concept" better [95, pp.10] [51, 48].

Therefore, without identifying the involved stakeholders and exploring the process through which the services are delivered to end-users, as well as the social context and environment, one could not profoundly and thoroughly understand the E-government phenomenon.

2.1.2 E-government service evolvement

There are different ways to categorize E-government services. From the interactivity level point of view, the online services can be divided into static information provision, one-way (government to customer) interaction, mutual interaction and transactional service [6]. The services could be further summarized into two categories: information provision service and transactional service [92]. Compared with sheer information provision services, transactional services which involve online electronic transaction are more sophisticated and require more procedures to complete. On the other hand, according to Layne and Lee [57] the services can be divided into the following stages from the evolutionary point of view. In initial stage, governmental website containing certain government information is classified and open to the public, thus only one-way communication is guaranteed. The second stage is evolved to two-way communication in which online transaction is provided. The third stage is the vertical integration of central and local public sectors by sharing the information resource via database. Normally, modification and improvement on the service delivery process is required. The final stage is the horizontal integration in which different functional areas are integrated horizontally and delivered via one single portal [32].

Gil-Garcia et al. [32] also argued that there is a trend of E-government movement from national level to local governments along with the system evolution, and the stages will vary across different administration level. It is very possible that the E-government service is already mature in national level, whilst still at initial stage amongst the local governments [42]. Furthermore, the target citizens, administrative process and technological sophistication will be different at each evolvement stage [45], and the divergent demand and pressure from end-users, i.e. citizens and private sectors, might influence the features of initiatives [32].

2.2 Methodology review

With respect to the E-government research field, Heeks and Bailur [44] summarised that although most of the works don't have an explicit underlying epistemological stance as well as a clearly stated methodology, the prevailing but not explicitly stated epistemology stances are positivism, social constructionist and somewhere in-between. Accordingly, both qualitative and quantitative method are applied in this field. In the following we will briefly review the methodology applied in E-government research with the underlying epistemological stance.

2.2.1 Quantitative studies

Regarding E-government research, positivism stance implies an objective or realism ontology which presumes that there actually exist pivotal factors that may influence the E-government development and are controlled by the underlying causal laws [44]. Orlikowski and Baroudi [69] identified features of positivism studies as "evidence of formal propositions, quantifiable measures of variables, hypotheses tested, and the drawing of inferences about a phenomenon from the sample to a stated population". The researchers holding this stance seek to find measurable pivotal variables including technological, social, and psychological issues which might influence E-government relevant outcomes, and to figure out the corresponding causal relationships, thus acquire knowledge from it. Accordingly, an empiricist epistemology will be placed by which the data gathered during the research are considered as being independent of the researchers who are observing and experimenting to acquire knowledge of such underlying causal relations [44]. Under such epistemological stance, quantitative research method, such as large scale questionnaire and survey are primarily adopted.

Some of this group of works focus on the technical issues that might influence user's (both citizens and business sectors in different countries) adoption behaviour of different E-government services, whilst some others focus on the social and psychological factors.

In Venkatesh et al.'s work [92], they conducted a web-based survey and identified four key factors that affect citizen's intention of using transactional E-government services, which are usability, computer resource requirement, technical support provision, and secure provision. Schaupp et al. [75] evaluated the influence of factors such as performance expectancy, effort expectancy, trust, risk, social influence, and supporting facilities on U.S. taxpayers' intention of using E-file. Lean et al. [58] conducted an exploratory study examining the Malaysian' intention of using E-government and concluded that trust, perceived usefulness, perceived advantage and image have positive effect whilst perceived intention has a negative effect. For business sectors, Gunasekavan and Ngai [41] examined the adoption of E-procurement in Hong Kong. Some of the works focus on the influence of E-government services assimilation on organizational structure and business value creation. Hossain et al. [47] proposed a theoretical model to investigate the influence of E-government assimilation on business value creation in organizations.

By holding this deterministic view and conducting quantitative studies, researchers could observe and identify key factors which influence the outcome, and explore the underlying causal laws in different cases. However, this kind of empirical study ignores the dynamic process and interactions among stakeholders which also play a key role in the phenomenon. In addition, the particular social context is missing which is critical for E-government research and the result would be relatively hard to be generalized.

2.2.2 Qualitative studies

In contrast, social constructivism stance implies a subjective ontology by which the meaning of objects (even physical objects) assigned by different stakeholders matters most. Under this stance, the focus of E-government research is to understand the meaning of this phenomenon constructed by each individuals when confronting E-government services. It is assumed that the subjective understanding and interest of researchers will not be detached from the meaning construction process neither [44]. Qualitative research methods such as unstructured interview and documentation analysis are widely applied.

Kamal et al. [53] deployed a qualitative multiple case study approach to examine the role of different stakeholders, their perception of technology integration solutions in UK local governments, and their involvement in the adoption process. The reason of why those aspects are vital to such technology integration projects was also discussed. Cordella and Iannacci [16] proposed an e-Government enactment framework to analyse the intricacies involved in the deployed technology which is viewed as the carrier of e-Government purposes. The complex relations among technologies and political logics were also examined to investigate how they shape the e-Government initiatives.

Most of the qualitative studies apply theory-based case study that aim to understand the recursive relationship among information technology, organizational structure and social context, and how the information technology is designed and deployed to achieve the long-term interest inscribed in e-Government initiatives [62]. However, the qualitative modelling that relies on verbal interpretation is too flexible to provide rigorous quantifiable result due to its inherited flexibility characteristic. Therefore, in order to achieve a better understanding of the relationships, consequences and dynamic processes, appropriate empirical research method is needed to complement the theoretical framework.

By briefly reviewing the methodologies, both quantitative and qualitative one, applied in E-government research realm, we could see that a new methodology which could capture the divergent characteristics of heterogeneous stakeholders, their adaptive behaviours, and their interactions, and analyse the macro-level phenomenon raised from micro-level interactions is needed to fill the research gap, and agent-based modelling (ABM) [33] naturally fits into the position. ABM has been used extensively in both organizational innovation study and innovation diffusion study respectively [29]. It could be a new and justified way to study the E-government phenomenon and to examine different strategies along with the service diffusion process since the whole process is dynamic and heterogeneous stakeholders are involved. The position of this research in terms of methodology is illustrated in the following Table 2.1. Entry “Macro-level” and “Micro-level” under the result analysis column refer to the result analysis from macro-level and micro-level perspective respectively.

Table 2.1: Position of this thesis in E-government literature: Methodology

	Research objective				Result analysis		
	Service adoption	IT in Gov.	Resource allocation	Policy design	Policy evaluation	Macro level	Micro level
Quan.	◯					◯	
Qual.		◯		◯		◯	
ABM	◯		◯	◯	◯	◯	◯

Notes. Quan.:Quantitative study; Qual.: Qualitative study; ABM: this thesis

2.3 Theory review

According to Heeks and Bailur's study [44], although they expected that various theories from other disciplines might be applied in E-government research, the result was quite surprising that most of the lens used were stage model-based and category-based which focus on the evolvement stage and features of E-government web sites respectively. Theories and frameworks from governance literature, and models and schemas from information system literature contribute most to the E-government research [44]. Theories built only from and for E-government studies are expected. Within the "theories" applied, the dominant ones are from two major fields: IT adoption/diffusion and IT in organizations. In the following they will be discussed respectively.

2.3.1 Innovation adoption

With respect to information systems deployed in E-government context, besides the technical development considering security issues [52], the adoption and diffusion process of E-government services have attracted most of the attention. There is a group of work focusing on the technological aspect of E-government and trying to study the phenomenon through innovation adoption and assimilation, and various factors are analysed to examine their influence on citizens' intention to adopt the services, such as trust, governmental leadership and different measurements of services provided [9, 61, 58]. However, although we

admit that the technology installed in public sectors change the way of how public services are delivered to the public in certain degree and that of communication among involved stakeholders, the information technology itself does not define what E-government system is [95]. In the following we will review some classic innovation diffusion models in literature.

Macro-level diffusion model

By 1970s, there have been several main innovation diffusion models constructed. Afterwards, innovation diffusion models focus on improving them to fit into different contexts [65]. Macro-level diffusion models, such as Roger's innovation diffusion model [73] and Bass's diffusion model [64], focus on collective behaviors of adoption and aim to forecast the first-time adoption and evaluate the market penetration. A large body of mathematical models have reflected a general "Bell shape" curve for period-by-period adoption and a "S-shape" curve for cumulated adopters [84]. The most famous model considering both internal and external influences is Bass's model [64] which captures both homogeneous population's desire to innovate p and to imitate others q that drive the adoption behaviours.

On the other side, heterogeneous individuals are considered in Roger's model [73]. Individuals are categorized as innovators, early adopters, early majorities, late majorities and laggards of which the percentage is a normal distribution, thus creating the S-shape adoption curve [65]. Better educated, richer people and the ones with higher social status will tend to have a lower adoption threshold, thus higher adoption rate.

This set of macro-level models is useful when the market penetration or market share of innovations in macro-level are the primary interests of study [77]. However, public services are different from innovations in the sense that service adoption is a long-term and dynamic process along with which the end-users could learn from their past experience or the environment, and their feedback will influence the service provision directly or indirectly. We clearly realize the difference between innovation diffusion and service diffusion, as well as the similarities, therefore only some concepts are borrowed and we will apply

social learning dynamics [19] to capture the adaptive learning behaviours of citizens.

Micro-level consumer's behaviour model

For micro-level consumer's adoption models, there is a set of well-defined social-psychological theories, amongst which Technology Acceptance Model (TAM) [17], Theory of Planned Behaviour (TPB) [26] and Unified Theory of Acceptance and Use of Technology (UTAUT) [93] are influential. This set of psychological-social models has the common characteristics that all try to construct the intention as the predicator of behaviours [98]. Regarding E-government research, this kind of construct has been empirically validated as well [75, 58, 41, 9].

On the other side, a set of explanatory models such as consumer diffusion paradigm is established as well [30]. According to this school of research, adoption of innovations depends on three major aspects: individual's characteristics, perceived properties of innovation and social influence that pose on individuals. When marketing strategies are the primary interests of study, this set of micro-level models is particularly useful [77].

Regarding E-government research, Tung and Rieck [86] proposed a theoretical framework based on diffusion of innovation theory, network externalities, adoption barriers and influence from social aspects to analyse the E-government adoption among business organizations in Singapore. Extensive frameworks based on adoption theories and models from information system literature are proposed in literature [79, 54, 88, 76] and we will not go into each of them here. Different from other innovations, extant E-government services will be improved in terms of efficiency and quality, also gradually new services will emerge and be delivered during the assimilation period [6]. Shareef et al. [80] argued that classic innovation adoption model, such as diffusion of innovation theory (DOI), technology adoption model (TAM) and theory of planned behaviour (TPB) are not capable to reflect the comprehensive citizens' adoption behaviour. In addition, along with the development of service levels critical influential factors might differ and should be defined separately.

Although researchers argue that compared with TAM related theory, TRA-based theo-

ries which study the intention and behaviour of users are more suitable for E-government studying since they do not only consider the service itself but also the social context[6], this kind of theory focuses only on the causal relationship underlying the phenomenon, rather than the dynamic service delivery process. The rich and meaningful interactions among stakeholders are simplified or ignored.

In summary, although both macro-level and micro-level model are extensively studied and applied in literature, they are static ones and there is a missing link between the micro-level behaviours to the macro-level phenomenon. Agent-based approach is well suited to link these two parts [98]. In this work, by applying agent-based approach we could link the citizen's adaptive behaviours to the macro-level adoption behaviour of different social groups and evaluate the supporting strategies. The comparison of those models are summarised as in the following Table 2.2.

Table 2.2: Comparison of innovation diffusion models

	Subjects of model		Result analysis		
	Heterogeneous agents	Agent's learning ability	Policy evaluation	Macro level	Micro level
Bass [64]				◯	
DOI [73]	◯			◯	
TAM [17], TPB [26], UTAUT [93], etc.	◯				◯
ABM	◯	◯	◯	◯	◯

Note. ABM: this thesis

2.3.2 Governance

Another set of frameworks adopted in E-government field is from government literature, such as public administration and political science. Governance should not be defined as a physical entity, i.e. government and governing individual citizens. Rather it is a process

about authorities and citizens interacting with each other and guiding themselves [46]. Information and communication technology is becoming very critical in this process and in certain degree changing the administration work of government. E-government system as an emerging information technology application facilitates the governing process and deeper involvement of citizen in public affairs. With respect to E-government research, there are many works devoted to study how E-government system and governance interweaved with each other and how it influences inter-organizational management and external relationship with citizens [46, 21, 47]. In this aspect, theories such as institutional theory [72] and enacted technology framework [27] are applied, although the impact still remains controversial.

Researchers also borrow concept from organizational information technology and e-Business fields [59]. However E-government is different from either of those fields due to the monopolistic nature of government [82, 47]. In addition, services provided by E-government are voluntary to use since traditional front desk services are still available as an alternative. In this sense, E-government deserves its own theory and methodology. On the other side, there is a group of works focusing on the design issues of E-government services in either governmental setting or user context by different approaches, such as content analysis, process modelling and output evaluation [11, 21, 91].

This school of research provides insight of understanding E-government phenomenon from the government structure perspective and explores the relations between government, information technology and institutions. However, it still ignores the characteristics of heterogeneous primary users and their valuable feedback to the services which is critical to the success of E-government systems, even from the governance perspective.

2.4 Agent-based simulation

“Simulation is a third way of doing science”, as claimed by Axelrod [7, pp. 5]. He argued that deduction aims to derive logical consequences from a set of premises, whilst induction

explores empirical data searching for any pattern. Different from these two traditional ways of doing science, simulation explores the data that are generated by simulation models embedding a set of pre-defined rules with a set of premises. By modelling a system and inputting specific data, researchers could observe the resulted emergent and unexpected output data even with some simple embedded rules. Across divergent applicable areas, Axelrod [7, pp. 3-4] summarised the purposes of simulation as "prediction, performance, training, entertainment, education, proof and discovery." Rather than rational individuals which are usually assumed in deduction, adaptive behaviours could as well be caught by simulation modelling, through which the contingent consequences raised from non-linear rules could be analysed [7].

Agent-based simulation (modelling) is one of the major paradigms of simulation modelling, which is characterized as a "bottom-up" simulation approach. The main advantage of this simulation method is the capability of capturing micro-level individual's decision making, and interactions among individuals and that with the environment to analyse the resulted macro-level phenomenon, which could aid the understanding of the dynamic underlying processes [7].

Compared with other simulation modelling approach, such as system dynamics, agent-based modelling possesses several features. First, real-world actors, such as individuals, organizations, and public sectors, could be designed as the corresponding computational agents directly such that the results could be interpreted more naturally. Second, heterogeneous agents could be represented and modelled, which are barely feasible for analytical methods to resolve due to the involved complexity. Third, environment could also be modelled from various aspects. Interactions among agents, as well as the one between the environment and agents, could be well simulated. Lastly, adaptive behaviours, especially the adaptive learning at both individual and aggregated level could be modelled through which agents could learn evolutionarily from their past experiences, other agents, and the environment [33].

Regarding the citizen-centred E-government systems, we could infer from the above lit-

erature review on methodologies that agent-based modelling is well suited to the proposed objectives in Section 1.2 and to capture the missing gap left by inductive survey works and the deductive analytical methods.

2.5 Concluding remarks

In this chapter, we review the definition and development stages of E-government systems, as well as the literature of E-government systems from both methodological and theoretical aspects. Agent-based modelling, as the methodology adopted by this work, is reviewed as well. Along with the evolve stages of E-government, service maturity level varies and demands raised from the target citizens are divergent. Without comprehending the stakeholders involved in the system and exploring the underlying dynamic process through which the desired services are delivered to end-users, one could not profoundly and thoroughly understand the E-government phenomenon and propose viable initiatives for a particular social context. That is how we posit this work in literature and propose the research questions we aim to investigate into.

Chapter 3

Conceptual framework

In this chapter, the conceptual framework of the overall agent-based modelling is introduced. First, we identify the stakeholders directly involved in the system, and define them respectively. Those individual parts will be integrated into a holistic system subsequently.

As stated in Section 1.1.1, we emphasized that although public sectors could gain benefits through promoting and developing E-government systems, citizens will gain much more benefits from the services, and influence the services directly and indirectly. E-government systems could be viewed and examined as a series of interactions between public sectors and citizens, while the divergent services provided act as the intermediate point [4].

The common stakeholders of E-government systems are end-users, such as citizens and private sectors (or business organizations), service providers, and employees of the service provider [36]. For the public sector, it is treated as one stakeholder as a whole. We do not distinguish among different departments enrolled in E-government services, although the departmental coordination (or one-stop E-government) is also an important research branch of E-government systems [94, 37, 21]. Employees of the service provider (i.e. staff working for government) are not considered as well, since citizens are the most important part and in certain degree the benefit gained by employees are similar to the ones by customers [36]. In the following sections, we will go into the details of each stakeholder.

3.1 Citizen-side learning and channel selection

The ultimate purpose of E-government is to provide services to citizens and further encourage them to engage in public affairs in future [36]. Amongst target citizens, there is still a gap of usage between citizens with different demographic attributes, such as education, gender, and economic status [36]. Due to the various task complexity inherited in different services, the corresponding target citizens might be different and not all the provided services are universally applicable [92]. Furthermore there is a trade-off between different attributes of services. In certain services, citizens may expect a higher level of security and privacy measures for online transactions, but give up the operations because of the complexity involved in routine procedures and poor usability [92]. In other services, citizens may expect a more convenient and faster process rather than security concerns.

In addition, different citizens have different preference towards attributes of provided public services. Therefore besides demographical categorization (such as age, gender, occupation, etc.) of citizens, they can be furthered categorized according to how they value the defined attributes of services and what their preferences are. The preference will influence how citizens from different social groups evaluate different service channels and further influence the E-government usage behaviours. In addition, different from innovation or product adoption which is a one-time behaviour, E-government services would be evolved with time going, and so will the ability of citizens along with it. Citizens will learn how to use E-government either from their past experience of dealing with it, or from other citizens and the environment. The adaptive learning process is involved to evolve citizens' ability of using E-government.

Therefore, we will not design citizens as traditional rational agents who pursue to maximize their utilities, rather they are rule-based heterogeneous agents who will learn at individual-level and behave according to the their predefined rule of action. In this work, with respect to the adaptive learning, we modified Deguchi's social learning dynamics analytical model [19] to fit our community-based learning which assumes that citizens will learn from the community. Here the community composed of different kinds of citizens is

treated as the "environment" of the model [33]. Details of the learning mechanism will be discussed in Chapter 4.

3.2 Government-side resource allocation

There are two major objectives for the government side. One objective is to provide different kinds of services on different service channels, and the technical support for E-government, such as FAQ, email and hotline services. In order to minimize the digital gap accounting to attributes such as educational level and sex, the resource allocation in terms of user support will be evolved to satisfy the requirements issued by divergent citizen groups. The other objective is to propose and implement strategies which aim to promote E-government services and to educate citizens on IT facilities or E-government services. Promotion of E-government could be considered as increasing citizen's awareness rate of E-government services and spreading correct information/knowledge of E-government. Educational programs include organizing regular IT workshop within communities, and setting E-government self-help machines at the traditional counter. Since education is a key factor influencing the uptake of E-government services [36], such educational programs are expected to be useful to help citizens mitigate barriers of using E-government services. We assume the government as a single public administration who will apply simple heuristics to allocate resources to different social groups such that they are satisfied simultaneously.

For different countries/regions, services that are suitable for citizens might be different, and accordingly the adopted IT strategies and implemented initiatives for E-government systems might be varied to fit into the local context. Here we only consider the most general ones.

3.3 Public services

According to Gronroos's work [39, 40], the public service provided (transactional service and informational service) could be divided into three categories: core services, facilitating services and supporting services. Core services are the major functional services provided by individual departments such as online transactional service. Facilitating services are aided services that help citizens complete the core services such as computer resources and personal e-certificate that are necessary to do online transactions. Supporting services are value-added services that are often optional [92]. Different services possess their unique attributes of which usability is defined as the attribute of core services and technical support is the attribute of supporting services as defined by Venkatesh et al.'s work [92], .

Different services will be provided on different service channels, such as traditional office counter and E-government websites. Services based on different channels will differ in service attributes, amongst which three major ones are identified and considered in this work, i.e. easier, faster, and better services [36].

3.4 A holistic view

The integrated view of different stakeholders is illustrated in the following Fig. 3-1. Basically different public services are provided on both channels: traditional counter and E-government enabled by the government. For the influence imposed by citizens' behaviour upon government, citizens will choose a particular channel to take up certain services based on their evaluation of each channel which depends on their preference of service attributes, then the resulted adoption rate will influence the resource allocation in terms of user support operated by the government. In contrast for the influence flow from government to citizens, the government will propose and implement supporting strategies to entice more citizens to utilize E-government, such as learning programs and public propaganda helping citizens mitigate the effort of using E-government, which may further influence citizens' channel choice. The intermediate connecting point is citizens' use of different types of

public services.

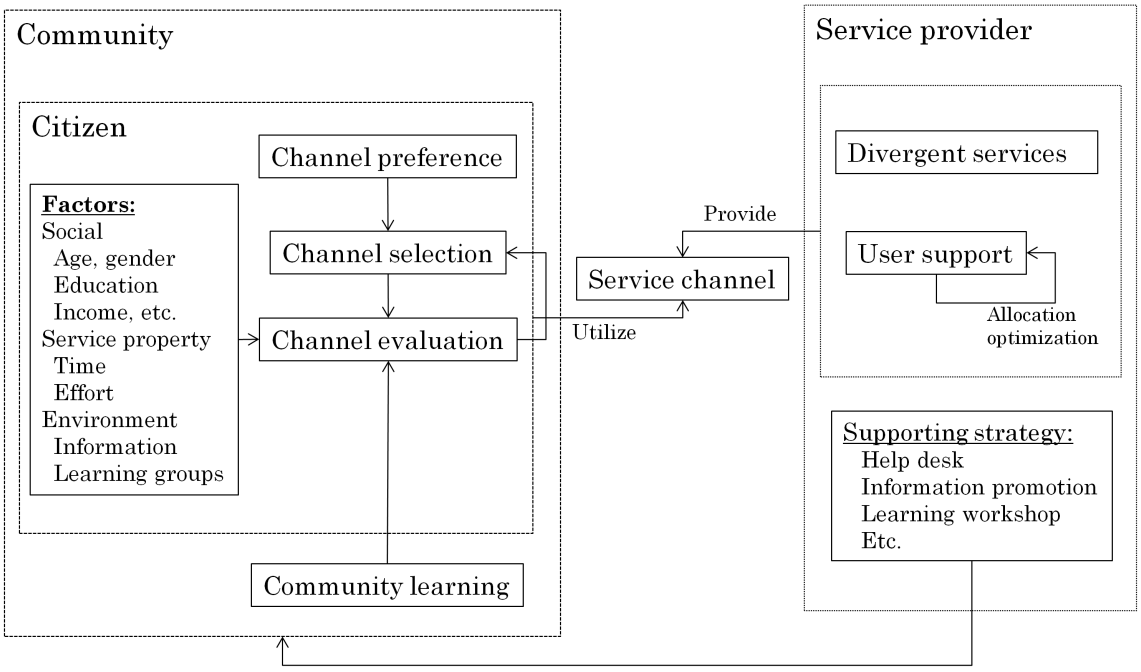


Figure 3-1: Conceptual Framework

3.5 Concluding remarks

In this chapter, we propose the conceptual framework of the overall system. Involved primary stakeholders are identified, abstracted, examined and integrated into a holistic system. In the following Chapter 4 and Chapter 5, agent-based modelling will be constructed based on this conceptual framework, through which the underlying dynamic process are examined and analysed, and E-government supporting strategies are proposed and evaluated.

Chapter 4

Citizens' channel choice

This chapter embraces two parts of the citizen-side modelling, one is citizen's channel choice behaviour based on their past experience, whist the other is the one based on community-based learning. They will be presented respectively in the following sections.

4.1 Introduction

Within the realm of service-oriented innovation studying, E-government is a rapidly emerging research field. This web technology based public services have enabled citizens to take up public services in a more efficient and convenient way. Citizens are liberated from the labour of traffic to traditional service counter and the restriction of office hour thanks to the benefit brought by Internet's $24/7$ services. However according to a survey conducted by Hong Kong Government [1], the adoption rate of easy-going E-government services such as information provision is increasing, while the one of more complex transactional service is still relatively low, especially for social groups that are not favoured by E-government, such as ageing people [78].

As defined by UN and American Society for Public Administration (ASPA), E-government is "utilizing the Internet and the world-wide-web for delivering government information and services to citizens [87]". This electronic means of public service delivery enables the

government to promote transparency, convenience, and effectiveness to citizens. Recently the services have been evolved from the mere static information provision to more value-added services such as transactional services [31], and the services are more flexible to satisfy citizen's needs [92]. Benefit of deploying E-government service is obvious in the sense that the quality is improved through integrated services and the services are more flexible to satisfy citizen's needs [92]. On the other hand, challenges are as well noticed. Researchers claim that most of the E-government systems fail to raise citizens' awareness and thereby to attract them to take up the services [80].

4.1.1 Motivation

In literature, few extant empirical research works focus on the citizens' preference of using E-government services over other traditional means such as visiting the government service counter [71]. Besides, many research works only aim at exploring the factors that could affect citizens' adoption decision of E-government, but not the underlying dynamic adoption process and the particular social context [92, 47, 75, 58, 41]. Service is not a generic and passive notion, rather different service types possess their unique features. Citizens from different social groups might have various needs, demands and preferences of those services, which might further impact their choice of channels to take up different governmental services, such as information provision service and transactional service [63, 92]. Therefore understanding how divergent attributes of the service influence citizens' channel choice of public service delivery across different social groups, and how we can explore the differences and similarities across different social groups in their channel choice with increased awareness rate and technical support, are meaningful and challenging research questions that inspire this chapter. Furthermore a new way to understand how micro-level individual preferences of public service channel lead to macro-level E-government service adoption phenomenon is needed, and agent-based simulation approach is applied.

In addition, social influence and social learning involved in the individual's adoption process of E-government is seldom considered, although it has been studied extensively in

other fields [83]. Different from social network of practice that emphasizes relations among members with weak ties, community-based learning more focuses on the competence and practice of individuals connected by strong ties [56]. With respect to the E-government services adoption, we assume that learning within communities is more common than that via social network. This assumption makes sense in the way that in daily life, a citizen probably will not learn how to use E-government from someone loosely connected. Rather he/she will be influenced by someone who is more closely associated, such as family members or colleagues. As a result with respect to social learning, the effectiveness of learning and its influences on the adoption behaviour might depend on the community in which citizens reside. On the other side, the spread of information/knowledge on E-government might also influence the learning process, and further affect the adoption behaviour indirectly [19, 96].

Therefore understanding such dynamic learning mechanism across different social groups is crucial to the investigation of divergent citizens' adoption behaviour of E-government services, and potentially important to the evaluation and design of E-government supporting policies as well. In order to investigate the influence of learning within communities that are composed of citizens with different characteristics, and to explore the effectiveness of supporting policies in a long-term perspective, agent-based modelling is applied [33].

4.1.2 Chapter organization

Therefore, this chapter is organized as follows. In the first half part of this chapter, i.e. Section 4.2, by simulating the dynamic channel selection behaviors of citizens from different social groups, we aim to understand citizens' preference of channel to utilize certain kind of governmental services over time. In addition, by evaluating different public strategies such as increasing awareness rate of E-government service and providing more technical support, we aim to identity what kind of strategy could be more effective to attract more citizens taking up E-government services.

In the second half of this chapter, i.e. Section 4.3, by considering the social learning occurred within communities based on the simulation of dynamic channel selection be-

haviours, we aim to understand citizens' preference of channel to utilize governmental services over time. In addition, by evaluating different public strategies such as E-government educational program and E-government promotion, we aim to identity what kind of strategies could be more effective to attract citizens taking up E-government services in the long term and be cost-effective as well. This agent-based model could enable the understanding of a wide range of possible adoption behaviours under different scenarios, and the exploration of to what extent the variant supporting policies are effective. In the final section of this chapter, concluding remarks are presented.

4.2 Citizens' basic channel choice

4.2.1 Hong Kong E-government

E-government research has a focus on Western countries, while the Asian E-government systems are still overlooked [41, 58, 86]. In this work, we will take Hong Kong E-government system as the case of analysis and introduce it briefly in the following.

In 1998, Hong Kong "Digital 21" IT strategy was formulated and updated in 2001, which defined the key issues of the development of E-government system. More than 130 public services are provided such that citizens can change their personal particulars, book public leisure and sports facilities, file tax return, subscribe governmental publications, and submit various applications [41]. In addition, smart identity card is issued to facilitate the usage of various services. Furthermore public key infrastructure supported by HK Post as the certification authority can guarantee the integration, authentication, confidentiality and non-repudiation of online transactions. E-certificate is issued to facilitate the authentication of users and to enable various transactional services.

4.2.2 General model assumptions

This section introduces the characteristics of each service provision channel and dynamic behaviours of citizens during the channel selection. In the following, a set of assumptions embedded in this model is presented.

- There are basically two types of public service provision channel: traditional counter service and E-government service. Both transactional service (such as online tax filing) and information provision service in a broad sense, such as governmental website, consulting service, and online booking/reservation service, are provided.

- The basic service provision procedures are similar on both channels. Technical support for E-government is provided by the government in order to facilitate the service provision process. Different services provided on different channels may differ in terms of time and effort designated to complete the process. For instance, transactional service (such as online tax filing) requires more time and effort to complete through both traditional counter service and E-government service.

- Citizens are assumed to be rational in choosing the channel for a particular kind of service. Based on their evaluation of each channel in terms of time and effort, they will choose the most favorite one. Citizens are categorized into different social groups according to sex *(Male/Female)*, educational level *(Secondary/Secondary above)* and economic status *(Economically active/Student/House maker)*, and different social groups may value time and effort differently, which may influence their selection behaviour.

4.2.3 Formal modelling of agents

Service provider agent

Basically, service channels enabled by the government are defined as static agents that provide transactional service and information provision service in terms of time and effort

required to complete the process, as well as the provided technical support. The rationale behind this abstraction is that the governmental services normally can be evaluated by three major aspects: easier service, faster service and better service [36]. Easier service refers to the consumed effort to complete the service. Faster service refers to the time needed to obtain the service result. Better service refers to the technical support received during the service provision process. Those indicators are rather objective in the sense that they address particular attributes which can be controlled by the service provider.

Therefore the service provider agent will be abstracted as $Service = \{S_1, S_2\}$. S_1 indicates the traditional counter and S_2 represents the E-government. Each of $S_i, i \in \{1,2\}$ will be defined as $< T_s, E_s >$, where $T_s, E_s \in \Re^+$. T_s represents the total time of service provision, including the time from locating the service until obtaining the result. E_s represents the total effort required to complete the process, including effort needed to get familiar with the location, to know where to submit the request and how to obtain the result. Technical support TS_s which is only provided by E-government is defined as $< T_{TS}, E_{TS}, Cap_{TS} >$, where $T_{TS}, E_{TS} \in \Re^+$, and $Cap_{TS} \in \mathbb{Z}$. Three kinds of technical support are identified, which are Help website (such as FAQ), Email contact and direct communication (such as face to face communication or phone call). T_{TS} indicates the time required for technical support, and E_{TS} refers to the effort saved by receiving technical support. Cap_{TS} indicates the capacity per time unit enabled by the service provider, i.e. the number of requests could be handled within certain time. The value of T_s and E_s is different between the traditional counter S_1 and E-government S_2, also differs between transactional services and information provision services. Intuitively, the effort required for transactional service is higher than the one for information provisional service. In addition the effort of using traditional counter is lower than the one of using E-government. Time is just the opposite case. Besides, for traditional counter, there is office hour $Time_{open}$ and $Time_{close}$ defined such that the service is only available within this time period. Conceptual value of S_i is shown in Table 4.1.

Table 4.1: Value table of T_s and E_s

T_s/E_s	Transactional service	Information provision service
Traditional counter	$High/High$	$High/Low$
E-government	$Low/High$	Low/Low

Citizen agent

A citizen is an active agent who may take up governmental service (both transactional service and information provision service) through different channels as he/she prefers. Citizen set is defined as $Citizen = \{C_1, C_2, \ldots, C_n\}$, where n is the number of citizens. Each citizen is abstracted as $C_i =< Util_{S_1}, Util_{S_2}, Pref_T, Pref_E, T_c, E_c, L_{exp} >$, where $Util_{S_1}$, $Util_{S_2}$, $T_c, E_c \in R^+$, $Pref_T$ and $Pref_E$ varies between 0 and 1. In addition, we require $Pref_T + Pref_E = 1$. L_{exp} is a list of 0 and 1 which represents the using history of E-government service, 1 indicates success while 0 otherwise. T_c is the total time required for citizens to complete the service including the time to complete the process plus the time spent on technical support. E_c is the total effort consumed to complete the service process successfully, while received technical support would help decrease the effort. $Pref_T$ and $Pref_E$ indicate how the citizen weights time and effort required to complete the service process respectively. Citizens from different social groups are assigned with different values of the weight. The larger the value, the more citizens emphasize the attribute. For instance, a citizen who thinks time is more important than effort will be with a larger value $Pref_T$ compared with $Pref_E$.

For each citizen, he/she will calculate a utility value of either traditional counter or E-government based on time and effort consumed at each iteration, indicated as $Util_{S_i}, S_i \in \{S_1, S_2\}$. The service channel with lower value of utility will be chosen at each time when citizens have to take up a particular service type. Gatignon and Robertson's consumer diffusion paradigm [30] could serve as the theoretical base for this modelling in which the personal characteristics, perceived service properties and external influence are stated

as being influential on the adoption process. The utility value of traditional counter and E-government at each time unit t is updated as follows,

$$Util_{S_1}(t) = Pref_T * T_c(t) + Pref_E * E_c(t) + \varepsilon \tag{4.1}$$

$$T_c(t) = T_s \tag{4.2}$$

$$E_c(t) = E_s \tag{4.3}$$

For traditional counter, we assume that citizens do not need any technical support since they can communicate with the staff directly during the process. So the time and effort required equal to the time and effort defined in Service provider agent. The value of T_s will vary according to different time slots within office hour. For instance in the early morning and late afternoon, the value of T_s will be smaller than the one of other time slots.

$$Util_{S_2}(t) = Pref_T * T_c(t) + Pref_E * E_c(t) + \varepsilon \tag{4.4}$$

$$T_c(t) = T_s + \frac{Num_c(t)}{Cap_{TS}} * T_{TS} \tag{4.5}$$

$$E_c(t) = E_s * P_{EST} - \frac{Num_c(t)}{Cap_{TS}} * E_{TS} \tag{4.6}$$

For E-government, technical support will be provided. $\frac{Num_c(t)}{Cap_{TS}}$ is multiplied to adjust the time and effort required by technical support according to the current situation. $Num_c(t)$ is the number of citizens at time t receiving the technical support and Cap_{TS} is defined as the capacity of technical support within a certain time period. For Help website and Email contact, the value of this ratio is assigned by 1. For direct communication this value is assigned based on the simulation process. ε is a random noise uniformly distributed between 0 and 1. From time to time, the time consumed to complete the service process T_c will not be changed significantly, but the effort of utilizing E-government service will be evolved. E_c will be evolved based on citizens' previous channel choice and corresponding experience.

In the following the way to update the evolved effort rate P_{EST} for E-government at each iteration is explained [3]. Basically the value depends on whether the previous w tries of E-government are successful or not. For each citizen he/she will keep a list to record the history of using E-government service, denoted as L_{exp}. We let Num indicate the length of the list, NoW indicate the number of success of last w tries, and NoS represent the total number of successful tries, while w, Num, NoW, NoS $\in \mathbb{N}$, and $P_{EST} \in R^{+}$. Then P_{EST} will be updated at each iteration as follows,

$$P_{EST} = \begin{cases} 1 - Est & \text{if the current try is successful} \\ 1 + Est & \text{otherwise} \end{cases} \tag{4.7}$$

$$Est = \begin{cases} \text{NoW/w} & \text{if Num} \geq \text{w} \\ \text{(w-Num+NoS/Num)/w} & \text{if Num} < \text{w} \end{cases} \tag{4.8}$$

The dynamic channel selection behavior of citizens at each iteration is shown in Fig. 4-1,

For transactional service provided by E-government, before citizens carrying out the procedures for the first time, they have to go to HK Post to obtain an E-certificate in order to conduct transactional services. This process is only carried out for once, thus omitted in Fig. 4-1. The time and effort for this one-time step will be updated as $T_c(t) = T_s + T_{cert} + \frac{Num_c}{Cap} * T_{TS}$, and $E_c(t) = E_s * P_{EST} + E_{cert} - \frac{Num_c}{Cap} * E_{TS}$. Here T_{cert} and E_{cert} indicate the time and effort consumed to obtain this E-certification respectively.

4.2.4 Simulation model

As discussed in Chapter 2, agent-based simulation [33] will adopted as the methodology. For the agent-based model presented in Section 4.2, it is implemented by simulation language SOARS [2]. SOARS is a type of agent-based simulation framework which is designed for people who wants to carry out agent-based simulation, and prior programming experience is not required [49]. In SOARS [2], the behaviors of a citizen agent are defined

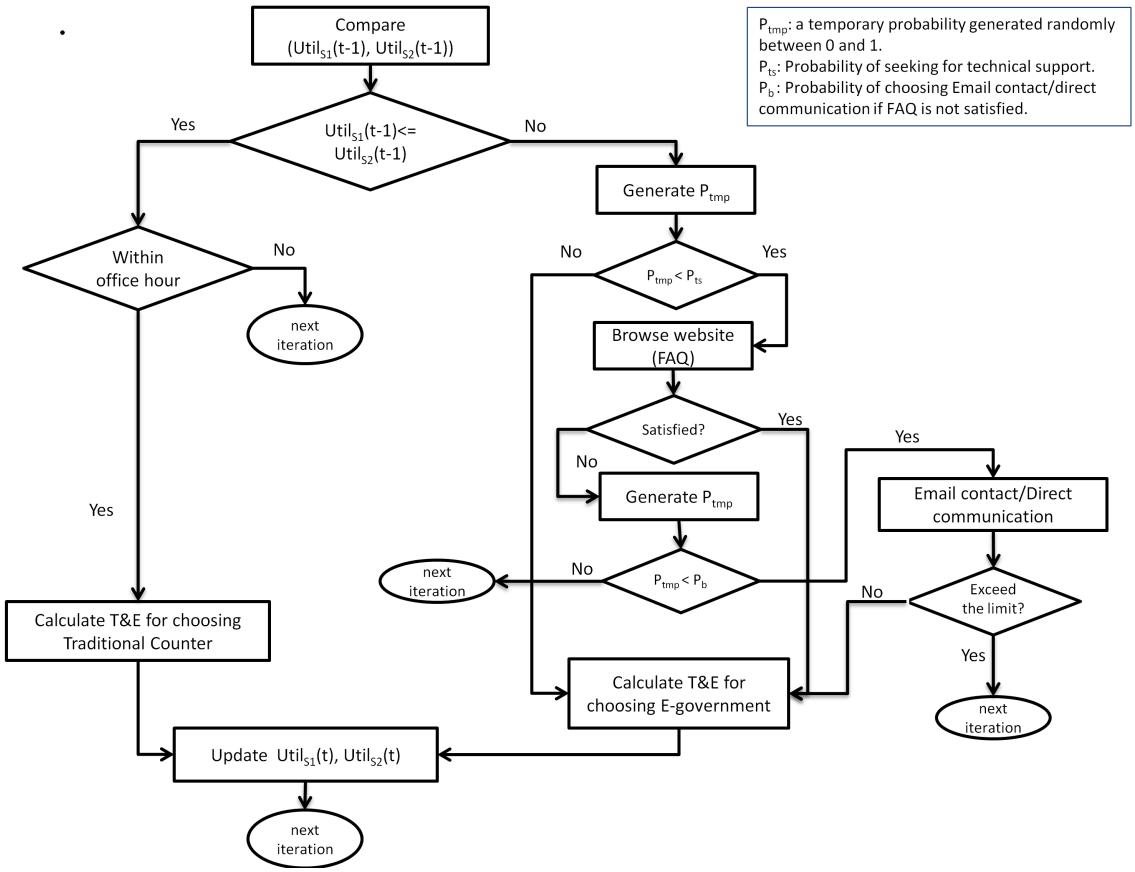


Figure 4-1: Selection behavior of citizens at each iteration

in agent roles. In each role, a set of rules are defined and based on these rules agents will behave accordingly. The rules are defined according to the dynamic selection behavior of citizens as shown in Fig. 4-1. In this work 7 types of role are defined according to sex (Male/Female), educational level (Secondary/Secondary above) and economic status (Economically active/Student/Home maker). Those roles possess same rules but differ in the value of parameters, i.e. $Pref_T$ and $Pref_E$.

The service channels as well as the technical support and HK Post in SOARS are defined as spot. Each simulation iteration represents an hour and within every 24 simulation iterations citizens will go to either traditional counter spot or E-government spot based on their channel choice. In other words, citizens are allowed to make only one channel choice within 24 hours (per day). Since E-government is available for all day, citizens will not be

restricted to use it with respect to time. In contrast, for traditional counter, citizens can only go for it during office hour. If a citizen's decision is traditional counter but the iteration time is out of the office hour, then he/she will wait until the traditional counter is open within the day. With probability P_{ts} they will go to technical support spot for help. Firstly they will browse the website (FAQ), and only go for Email contact and direct communication support if they cannot find answers in the website with probability P_b. Each spot will record the number of citizens who have visited on daily base.

Simulation and parameter setting

For each social group, there will be 500 citizen agents. For each simulation run, $40 * 24$ iterations which represent 40 days (24 hours per day) will be carried out. Citizens will randomly choose one and only one hour to make the decision within each day. Office hour is defined from 9 AM to 5 PM. According to SOARS's characteristic, all simulation results shown in the following subsections are the average value of 40 runs, which could guarantee a reasonable output. Social groups are divided with respect to their preference of time and effort required to complete the process, i.e. $Pref_T$ and $Pref_E$. Social groups with relatively larger value of $Pref_T$ are treated as groups favoured by E-government, whereas the ones with relatively larger value of $Pref_E$ are treated as groups not favoured by E-government, such as citizens with less education. In this work, we set the value $(Pref_T, Pref_E)$ for male as $(0.55, 0.45)$, female as $(0.5, 0.5)$, citizens with secondary above education as $(0.6, 0.4)$, citizens with secondary education as $(0.45, 0.55)$, economically active citizens as $(0.6, 0.4)$, student as $(0.55, 0.45)$, and home maker as $(0.4, 0.6)$. T_s and E_s for different services based on different channels are scaled as real numbers ranging in $(0, 5]$. We assume that technical support will mitigate the effort of using E-government (E_s) by $1/3$, and the effort of acquiring E-certificate E_{cert} is set as half of E_s for transactional services. Initial value of $Util_{S_1}$ is set smaller than $Util_{S_2}$ to indicate a favour of traditional counter at the outset. Probability P_{ts} is set as 10% in scenario 1 and 2, while P_b is set as 50%. All the parameters could be set independently to approximate a particular circumstance, thus in this work the

simulation results are only restricted to the above parameter setting.

4.2.5 Result analysis and discussion

We evaluate this model from two aspects: 1. the daily take up rate of both traditional counter and E-government for 40 days; and 2. the impact of awareness rate and technical support on adoption rate of E-government for transactional service.

Scenario 1

This scenario represents the base scenario. The input data and parameters are not based on empirical data, but estimated ones. In this scenario, at the initial step citizens from different social groups will go for either traditional counter or E-government randomly (i.e. 50% probability of each channel) for a particular service type. Two simulations are carried out, one for transactional service and one for information provision service. This scenario aims to capture the "AS-IS" phenomenon which might indicate the basic E-government adoption situation without any strategy enacted.

In all the following figures, x axis represents the time unit (daily base), while y axis represents the number of citizens choosing a particular channel per day over time. From Fig. 4-2 we could see that for transactional service, the adoption rate of E-government is relatively low for all social groups, especially for social groups not favoured by E-government. Here social groups not favoured by E-government refers to the groups with higher value of $Pref_E$, i.e. citizens with only secondary education and home makers. This result is very similar to the reality that according to No.43 Hong Kong Thematic Household survey (2009) published by the Census and Statistics Department of HKSAR [1], the usage rate of E-government for social groups such as male, citizens with secondary-above education, students and economically active citizens are higher than the one for other social groups. On the other side as shown in Fig. 4-3, for information provision services with relatively low effort required ($1/2$ of E_s for transactional service) and without the extra effort of obtaining E-certificate E_{cert}, the adoption rate of E-government could increase rapidly and

finally be stable. The difference is that for social groups which are not favoured by E-government, the increasing rate will be relatively slow. For this reason, in the following scenarios only transactional service is considered to evaluate different policies.

Scenario 2

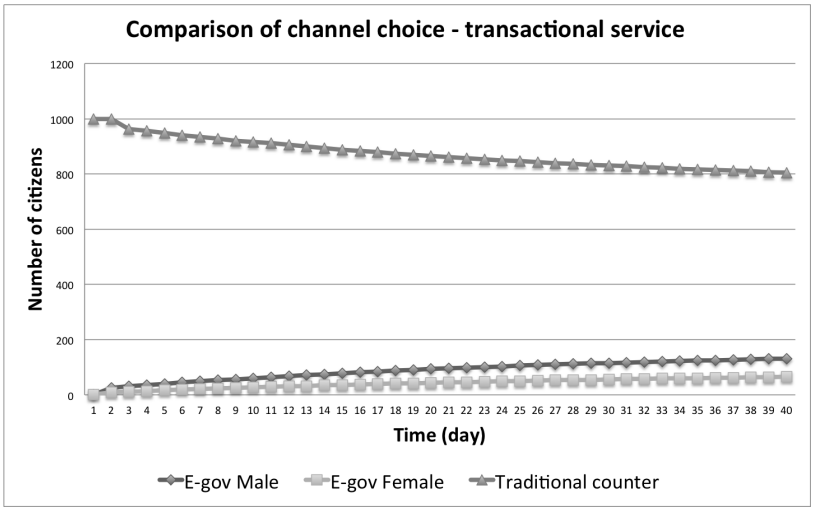
This scenario aims to evaluate the effectiveness of awareness rate on channel choice for transactional service. At initial step, the citizen will go for E-government based on their awareness rate of it, rather than a random choice. The result is compared with the base case in which the initial choice is random. In addition, we increase the probability of acquiring E-certificate which is compulsory for transactional services by 30% as the awareness rate of E-government is increased. The data in Table 4.2 on awareness rate is obtained from No.43 Hong Kong Thematic Household survey (2009) as well [1].

Table 4.2: Value of awareness rate

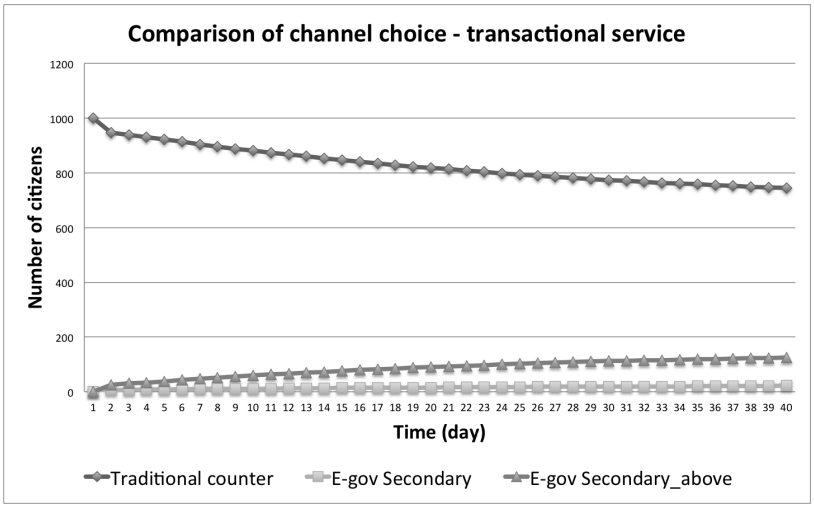
Social group	Awareness rate	Social group	Awareness rate
Male	56%	Eco. active	63%
Female	52%	Student	68%
Secondary edu.	58%	Home maker	35%
Secondary edu. above	81%		

Notes. Eco. active: Economically active; edu.: education

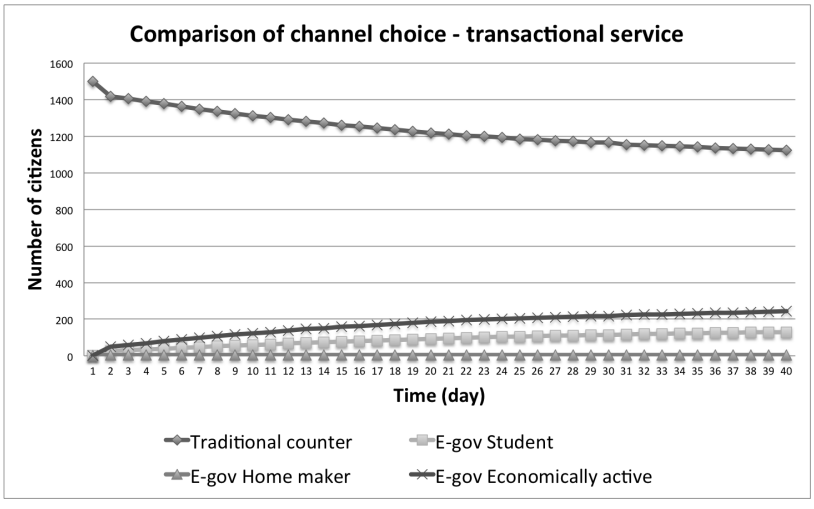
In Fig. 4-4, the base case in scenario 1 is compared to the case with awareness rate considered. For simplicity only the take up rate of E-government is represented in this figure. It is interesting to see that the increased awareness rate does not necessarily improve the take up rate of E-government but rather the opposite case. It could be explained as even more citizens are aware of the transactional service provided by E-government, the involved complexity, especially the neccessity of E_{cert} for transactional service hinders them to take up the service further. As a result, the take up rate of E-government is not increased proportional to the increased awareness rate as expected. In this sense, public propaganda for E-government transactional service might not be very effective to increase



(a) Sex

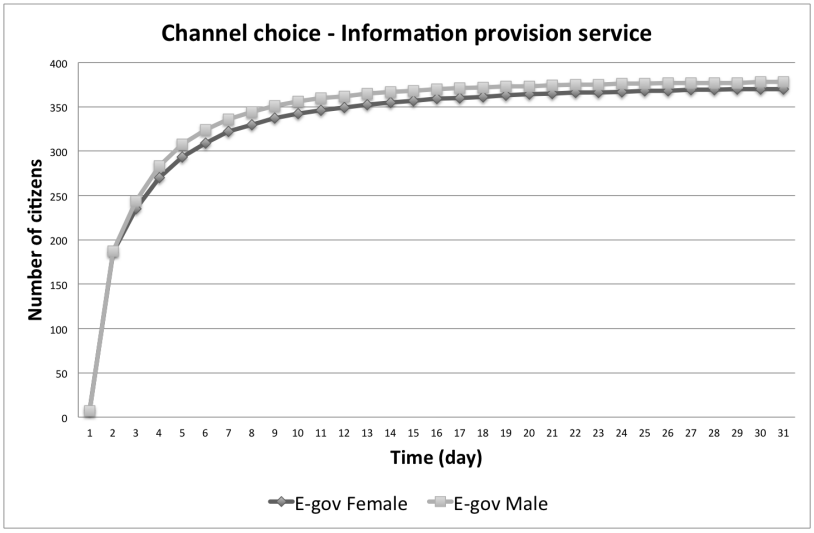


(b) Education

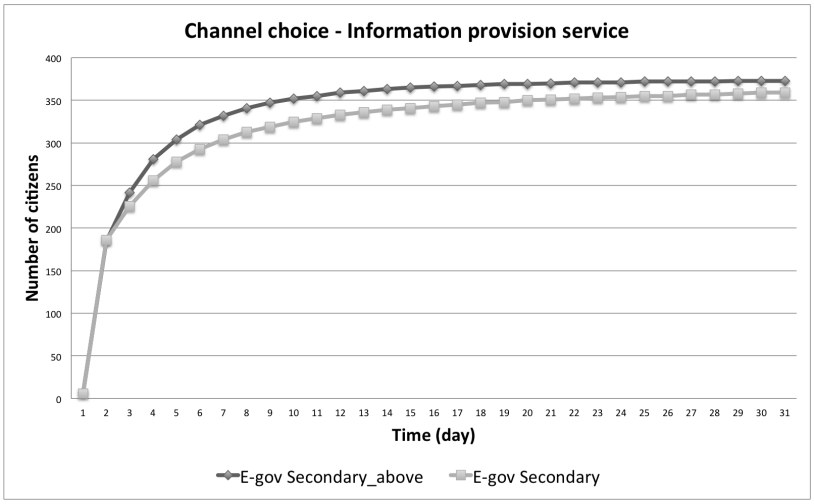


(c) Economic status

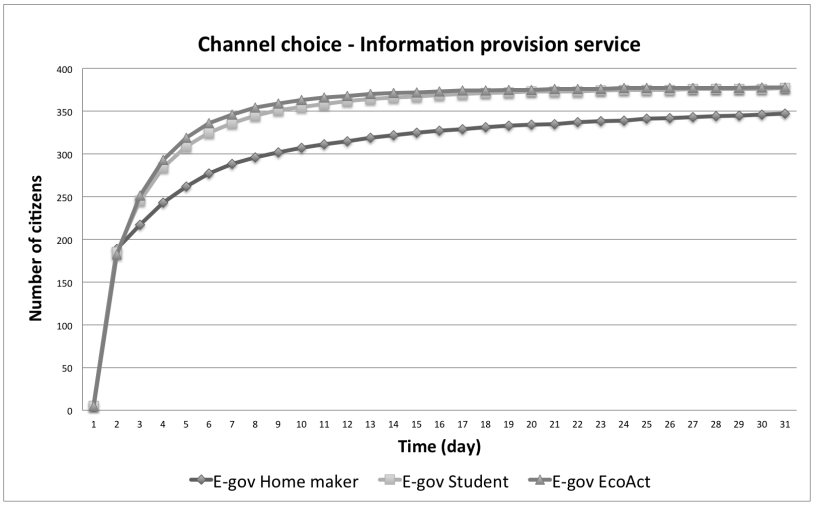
Figure 4-2: Channel choice of different social groups for transactional service



(a) Sex



(b) Education



(c) Economic status

Figure 4-3: Channel choice of different social groups for information provision service

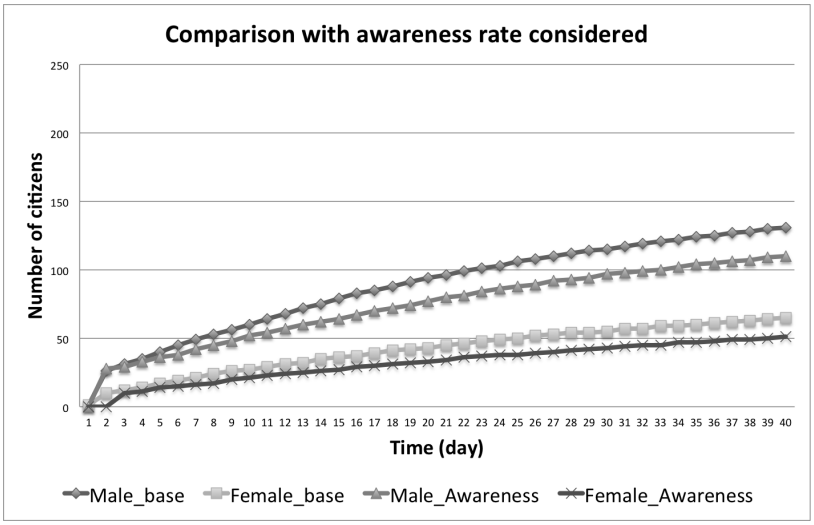
the adoption rate.

Scenario 3

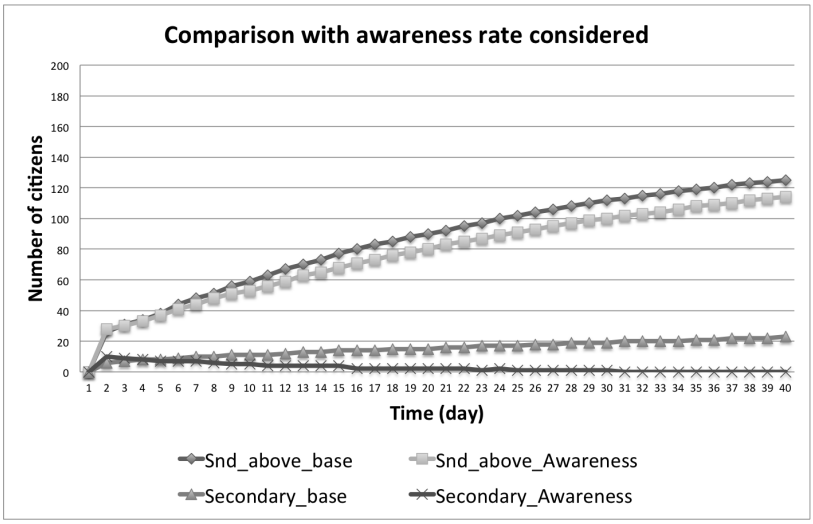
This scenario aims to evaluate the effectiveness of providing more technical support. In this scenario, for E-government transactional service, citizens' willingness rate to request technical support P_{ts} will be increased from 10% to 20% evenly for all kinds of technical support. In addition the effort of acquiring E-certificate E_{cert} will be decreased by $1/3$. The legend "Male-base" in Fig. 4-5 represents the base case while "Male-TS" represents the case with higher rate of technical support requested by male. Other social groups are represented in the same way.

From Fig. 4-5 we could see that for transactional service, with increased technical support the usage of E-government is increased accordingly, though the increased rate is different across various social groups. For social groups who are favoured by E-government, i.e. with smaller value of $Pref_E = 0.45$, such as male, students and citizens with secondary-above education, the increased rate is larger (around 16%) than the one of social groups who not favoured by E-government, i.e. with larger value of $Pref_E = 0.6$, such as Home maker (around 5%). In other words, with the above setting the technical support is more effective for the group of citizens who prefer E-government from the very beginning. In this sense this scenario indicates the possibility of digital divide in utilizing E-government service, even with more technical support provided in a broad sense.

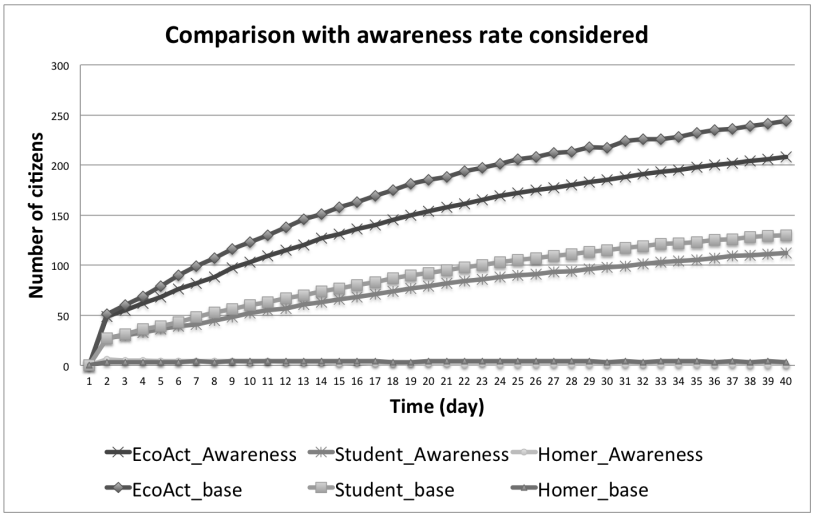
In summary, under the parameter setting presented above, compared with the policy of increasing awareness such as public propaganda, increasing technical support is more effective to help improve E-government transactional service's take up rate. However this strategy is prone to benefit more to social groups with higher usage rate of E-government already. New policies targeting social groups with lower usage rate of E-government should be developed in future.



(a) Sex

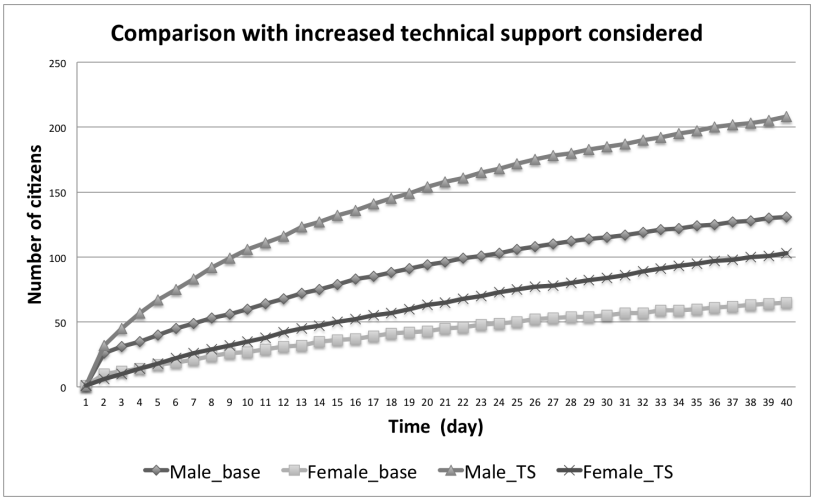


(b) Education

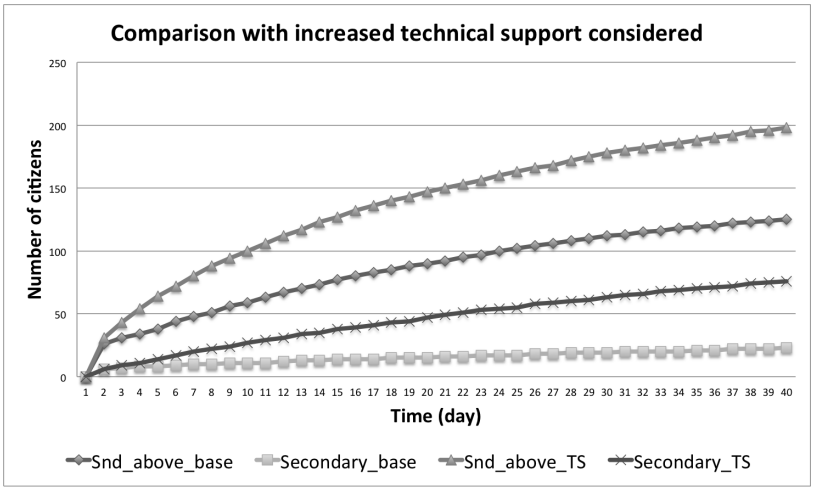


(c) Economic status

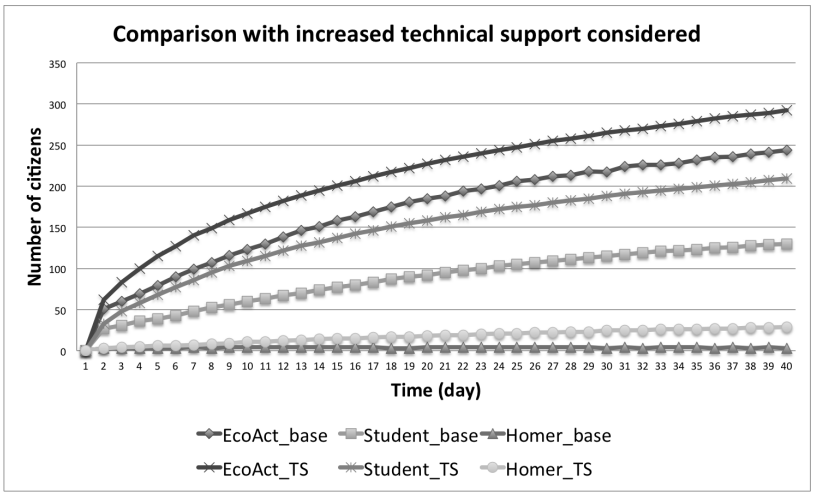
Figure 4-4: Channel choice with awareness rate for transactional service



(a) Sex



(b) Education



(c) Economic status

Figure 4-5: Channel choice with increased technical support for transactional service

4.2.6 Summary

In this section, we propose a new way, agent-based simulation, to understand the channel choice of citizens from different social groups when they want to take up certain type of governmental services. From the three scenarios, firstly we have a better understanding of the basic situation of E-government adoption across different social groups for a particular kind of service, and then predict the take up rate of E government service with policies of increasing awareness rate and providing more technical support. It is interesting to see that increased awareness of E-government transactional service doesn't help improve its take up rate obviously, while increased technical support does. In addition, for different social groups the effectiveness of technical support varies. For social groups who have chosen E-government for transactional service frequently, the increased technical support is more effective, which implies that other policies should be considered in order to improve the E-government adoption rate of social groups who haven't utilized it frequently yet. This work could serve as the first attempt to capture citizens' channel choice of public services by applying agent-based simulation, and future models could be constructed based on it to understand the underlying dynamics better and to examine the effectiveness of potential policies. One advantage of applying agent-based simulation rather than other methodologies is that interactions among citizens, such as social learning, could be integrated to this base model easily for further investigation. On the other side, the parameter setting of agents is not based on empirical data, thus the simulation results are restricted to the parameter setting in this work only.

In Section 4.3, we will integrate community-based learning mechanisms into the citizen's decision making process. Generally speaking, we allow citizens to learn from others within the same community and the environment. Relevant policies will be evaluated in terms of cost-effectiveness.

4.3 Citizens' channel choice with learning

In this section, community-based learning mechanisms will be integrated to Section 4.2's basic channel selection model, and more supporting policies are proposed and evaluated.

4.3.1 Social learning dynamics

Deguchi [19] proposed a social learning dynamics that analyses the learning process from a social learning perspective, rather than assuming agents with traditional utility-maximization rational decision making. In addition, he introduced the concept of indirect control which is a regulation posed by a central authority as the macro functional agent. In such a system, there is no universal laws assumed, but a set of decision-making rules and alternatives instead. Agents will choose an alternative based on their rules, the micro and macro state of the agent society. In addition, the indirect control is manipulated by the macro functional agent through experimenting structural parameters in order to get a better social outcome. Mutual-commitment among agents could also be treated as a kind of indirect control. In the following, we will review its extended model of educational effect and governmental support based on which we construct our community-based learning model.

In this model, there are two underlying alternatives, "A" (a desirable choice) and "B" (a conventional choice). "ASup" and "BSup" are supporting alternatives of the two choices respectively as positive sanction, and "AKnow" and "BKnow" are beliefs of which "A" and/or "B" is correct as meta commitment. a, b, d, and e represent basic payoff of interaction, negative sanction, bandwagon effects, and positive support by the correct knowledge respectively (for further details of the modelling and average payoff table, please refer to [19, pp. 36-39]). Based on this model, two propositions are proposed as follows,

Proposition 1. Assume there is no supportive commitment for attitude "A",

1. If $a < b$, then the existing conventional alternative "B" continues.

2. If $a > 0$, then the desirable alternative "A" is maintained.

Proposition 2. Let PaKnow = 1, then $e > d$ is the condition of spreading supportive commitment of alternative "A" no matter what is the value of "Pa".

4.3.2 General model assumptions

Besides the assumptions mentioned in Section 4.2.2, in this section there are additional assumptions embedded in our agent-based model as follows,

- In this section, we only consider the general public services that involve complex procedures, such as on-line tax filing services. This kind of services requires more time and effort to complete, especially when provided via E-government.
- In this section, citizens are categorized into two general social groups, one is favoured by E-government and the other is not, such as elderly people or people with less education. Different social groups may value time and effort differently which might further influence their selection behaviour. We call the social group that is favoured by E-government as the *ordinary group*, and the other one as the *preferential group*.
- Instead of social network, we assume that citizens are closely associated with each other within communities. They will be influenced by the information prevailing in the community, and learn from citizens who have adopted E-government within the same community. Each community only consists of 5 to 10 citizens, and it could be family, friends or colleagues.

4.3.3 Formal modelling of agents

In this work, we define three types of agents, which are Service provider agent, Community agent and Citizen agent. In the following we will explain the agents in details. The Service provider agent is defined as the same in Section 4.2.3. The only trivial difference is that in this section we only consider transactional service that requires more effort to complete.

Table 4.3: Value of T_s and E_s

T_s/E_s	Public service
Traditional counter	$High/Low$
E-government	$Low/High$

Community agent

We let community be the unit within which citizens are closely associated. Each community could consist either one kind of citizens or mixed kind. Citizens will obtain information of E-government or learn how to use it from the community in which he/she currently reside. Community set is defined as $Community = \{1,2,\ldots,k\}$, where k is the number of communities. For each of the community $i \in \{1,\ldots,k\}$, a set of variables is defined as shown in Table 4.4.

Table 4.4: Explanation of Community agent variables

H_i	A set of citizens who are currently involved in community $i \in \{1,\ldots,k\}$
$K_i \in \Re^+$	Correct knowledge of E-government spread in community i
$N_i \in \mathbb{N}$	Number of citizens currently involved in community i
$NE_i \in \mathbb{N}$	Number of E-government adopters in community i
$NT_i \in \mathbb{N}$	Number of Non-E-government adopters in community i

Citizen agent

A citizen is an active agent who might take up public service through different channels as he/she needs. Citizen set is defined as $Citizen = \{C_1, C_2, \ldots, C_n\}$, where n is the number of citizens. Each citizen is abstracted as $C_i =< Util_{S_1}, Util_{S_2},$
$Pref_T, Pref_E, T_c, E_c, L_{exp}, P_E >$. Detailed explanation of the variables is given in Table 4.5. Total time T_c includes the time to complete the process plus the time of technical support received, while total effort E_c includes the effort to complete the service process, while

Table 4.5: Explanation of Citizen agent variables

$Util_{S_1} \in \Re^+$	Evaluated utility of traditional counter service at each iteration
$Util_{S_2} \in \Re^+$	Evaluated utility of E-government service at each iteration
$T_c, E_c \in \Re^+$	Total time and effort consumed to complete the service respectively
$Pref_T, Pref_E \in \Re^+$	How citizens weight time and effort respectively, while we require $Pref_T + Pref_E = 1$
L_{exp}	A binary list of using history of E-government. 1 as success, 0 otherwise
P_E	Probability of choosing E-government at each iteration

received technical support would help decrease the effort. Besides, the weight $Pref_T$ and $Pref_E$ should be different for citizens coming from different groups. The larger the value, the more citizens emphasize the attribute. For instance, a citizen who thinks time is more important than effort will be with a larger value $Pref_T$ compared with $Pref_E$. Here we assume $Pref_E$ for *ordinary group* is smaller than the one for *preferential group*, while $Pref_T$ is set in the opposite way.

4.3.4 Adaptive learning of citizens

At each iteration, the channel selection behaviour of each citizen is illustrated in Fig. 4-6. The blue square represents optional activity based on policy implemented, which will be introduced in Section 4.3.5. Based on previous experience or communities' learning environment, each citizen will choose either traditional counter or E-government to take up the services. Through the process, he/she will update the time and effort consumed during the process and calculate the utility value by the end of each iteration. At each discrete time unit $t \in T = \{1,2,\ldots,N\}$, the utility value of channel S_i is updated as $Util_{S_i}(t) = Pref_T * T_c(t,S_i) + Pref_E * E_c(t,S_i) + \varepsilon, i \in \{1,2\}$, where ε is a random noise uniformly distributed between 0 and 1. Detailed explanation of the equations will be discussed in the

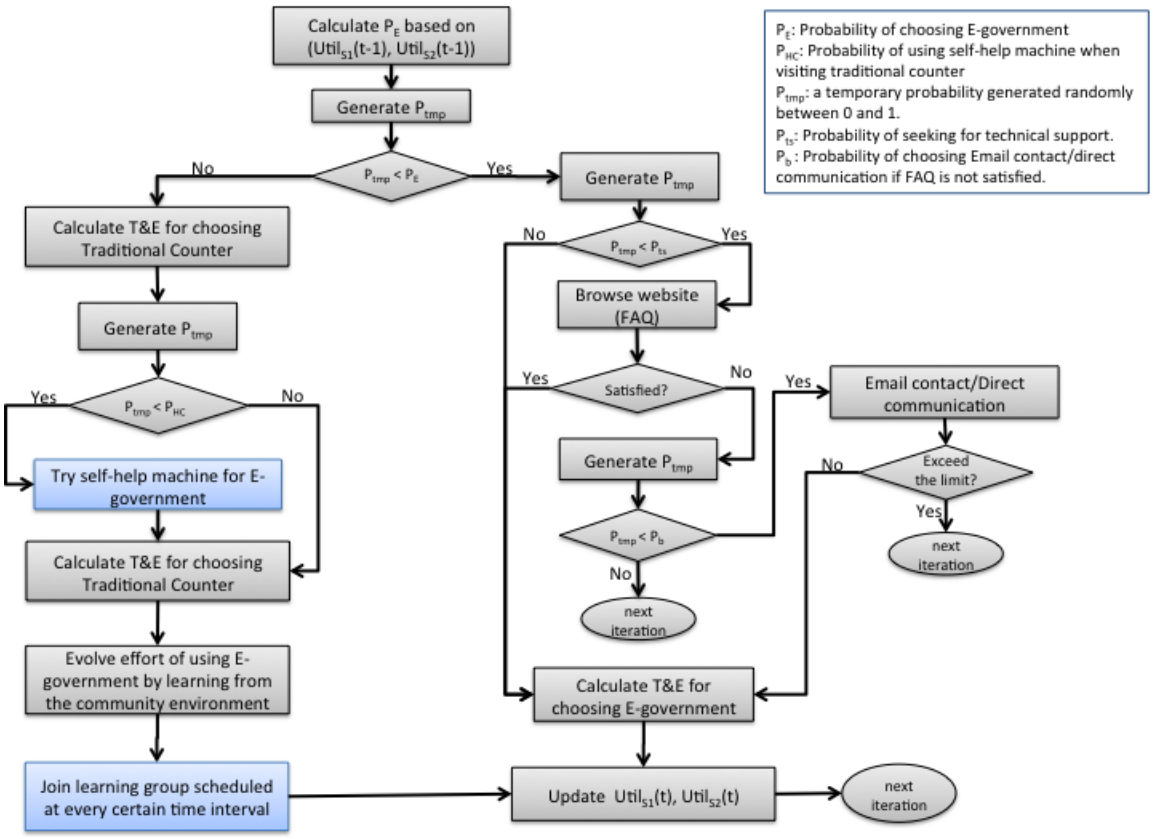


Figure 4-6: Selection behaviour of citizens at each iteration

following subsections.

For traditional counter, we assume that citizens do not need any technical support since they can communicate with the office staff directly during the process. Therefore the time and effort consumed at time t by choosing traditional counter S_1 equal to the time and effort defined in Service provider agent, as $T_c(t,S_1) = T_s$ and $E_c(t,S_1) = E_s$.

Effort evolvement of E-government adopters

For E-government, utility value will be calculated in the same way, but the value of time and effort consumed will be updated differently. For E-government adopters already, the effort of using E-government will be evolved based on their past experience and technical

support received, thus the value at time t will be updated as follows.

$$T_c(t,S_2) = T_s + \gamma * T_{TS} \tag{4.9}$$

$$E_c(t,S_2) = E_s * P_{EST} - \gamma' * E_{TS} \tag{4.10}$$

γ and γ' are uniformly distributed random number ranging between 0 and 1, and multiplied to adjust the time and effort required by technical support. From time to time, the time consumed to complete the service process T_c will not be changed significantly, but the effort of utilizing E-government service will be evolved. E_c will be evolved based on citizens' previous corresponding experience. The way of updating the evolved effort rate P_{EST} is the same as stated in Section 4.2.3, citizen agent.

Social learning of E-government non-adopters

For citizens who haven't adopted E-government yet, they will learn from the community until their ability of using E-government converges to the same level within the same community, and the effort will be updated accordingly. For instance, E_c of citizen $C_i \in H_l$, while $i \in \{1,\ldots,n\}$ and $l \in \{1,\ldots,k\}$ will be updated as follows,

$$E_c(t,S_2) = E_c(t-1,S_2) * (1 - \beta * (E_c(t-1,S_2) - AVG_E^l(t,S_2)) * ADJ) \tag{4.11}$$

$$AVG_E^l(t,S_2) = \frac{\sum_{\forall C_j \in H_l}^{j \neq i} E_c^j(t-1,S_2)}{N_l(t)} \tag{4.12}$$

$$ADJ = \frac{NE_l(t)}{N_l(t)} + K_l(t,Freq_t) \tag{4.13}$$

$$K_l(t,Freq_t) = K_l(t-1,Freq_t) + K_l(t-1,Freq_t) * (1 - K_l(t-1,Freq_t)) \tag{4.14}$$

AVG_E^l indicates the average effort level of citizens within community l, in other words the average ability of using E-government of citizens within the same community. Here we assume citizens within the same community will not directly interact with each other,

but be influenced by the status of the community indirectly. *ADJ* is a parameter considering the influences of the number of E-government adopters and prevailing E-government knowledge within communities. The knowledge/information of E-government $K_l(t)$ will be updated only when $t \mod Freq_t \equiv 0$ where $Freq_t \in \mathbb{N}$. Otherwise the value will remain as the same.

Probability of choosing channels

At each iteration, the probability of choosing E-government P_E will be updated and the probability of choosing traditional counter is defined as $1 - P_E$. For non-adopters of E-government, this probability will depend on the properties of the community he/she currently resides in. For instance, the probability of choosing E-government for citizen $C_i \in H_l$, where $i \in \{1,\ldots,n\}$ and $l \in \{1,\ldots,k\}$ will be updated as follows,

$$P_E(t) = P_E(t-1) + \alpha * P_E(t-1) * \frac{W_l(t-1) - Util_{S_2}(t-1)}{W_l(t-1)} \tag{4.15}$$

$$W_l(t) = (\sum_{\forall C_j \in H_l}^{j \neq i} Util^j_{S_1}(t-1) + \sum_{\forall C_j \in H_l}^{j \neq i} Util^j_{S_2}(t-1))/N_l(t) \tag{4.16}$$

For citizens who are E-government adopters already, the probability will not be influenced by other members within the same community, but this citizen's own previous experience. As a result, $W(t)$ will be updated simply as $W(t) = P_E * Util_{S_1}(t) + (1 - P_E) * Util_{S_2}(t)$.

The value of α and β are both positive real numbers ranging between 0 and 1, and because of the lack of empirical data, they are set as constant in this work. α is used to adjust the influences of community properties when choosing E-government and β is used to adjust the impact of community-based learning. The above social learning and channel selection algorithm are adopted from Deguchi's social learning dynamics and support commitment model [19].

E-government supporting strategies

Basically we assume there are two general kinds of strategy to increase the E-government adoption rate, one is to promote E-government via public media (spread information/knowledge of E-government) and the other is to educate citizens how to use E-government, such as organizing workshop and setting self-help machine in traditional counter such that every time when citizens visit traditional counter, they could try E-government with certain probability. Each of the strategies is bore with an implementation cost at each iteration, $Ct_i \in \Re^+$ and the frequency of implementation, $Freq_i \in \mathbb{N}$ while $i \in \{1,2,3\}$. We assume the total cost of each strategy $Ct_i * \frac{N}{Freq_i}$ will be the same during the simulation, N is time unit. Different scenarios will be carried out on the basis of different compositions of the strategies. E-government promotion strategy will update the knowledge spread in each community, thus indirectly influence citizens' effort of using E-government, whereas educational strategy will help mitigate citizens' effort of using E-government, in other words, they will decrease the value of E_c in certain degree directly.

4.3.5 Simulation model

In the simulation model, we have 1000 citizens divided into two social groups evenly, one is favoured by E-government and the other is not. In this part, we set the value $(Pref_T, Pref_E)$ for preferential group as $(0.4, 0.6)$ and for ordinary group as $(0.6, 0.4)$. All citizens will be allocated to one of the 100 communities defined randomly at the outset of simulation. We will run 2000 iterations and all the results displayed below are the average value of 10 runs. The frequency $Freq_1$ for organizing learning group will be 50, and $Freq_3$ for public promotion will be 30. Attending learning groups will help citizens mitigate the effort by $1/2$ whilst utilizing self-help desk mitigates the effort by $1/3$. Self-help machine will always be available at traditional counter, thus $Freq_2$ will be 1 and the probability of using it will be 10%. α and β are set as 0.05 and 0.2 as to adjust the influences of community properties and the impact of community-based learning respectively. The initial value of

average effort level and knowledge of each community are fixed at the outset of simulation according to the citizen composition because of the lack of relevant empirical data. The scenario settings are listed in Table 4.6.

Table 4.6: Scenario setting

Scenario	Learning group	Self-help machine	Promotion
0	Yes	No	No
1	Yes	Yes	No
2	No	Yes	No
3	No	No	No
4	Yes	No	Yes
5	Yes	Yes	Yes
6	No	Yes	Yes
7	No	No	Yes

4.3.6 Result analysis and discussion

In this subsection, the simulation results will be analysed under two general scenarios: community scenario and policy scenario.

Community scenarios

In these scenarios, we will simulate how social learning influences the E-government adoption rate in closed community and open community respectively. Here closed community indicates the community that only consists of one kind of citizens, i.e. either *ordinary group* or *preferential group*. In contrast open community indicates the community within which different kinds of citizens are mixed.

Closed community

In Fig. 4-7, we will show the adoption rate of both ordinary group and preferential group under the closed community setting in eight different scenarios.

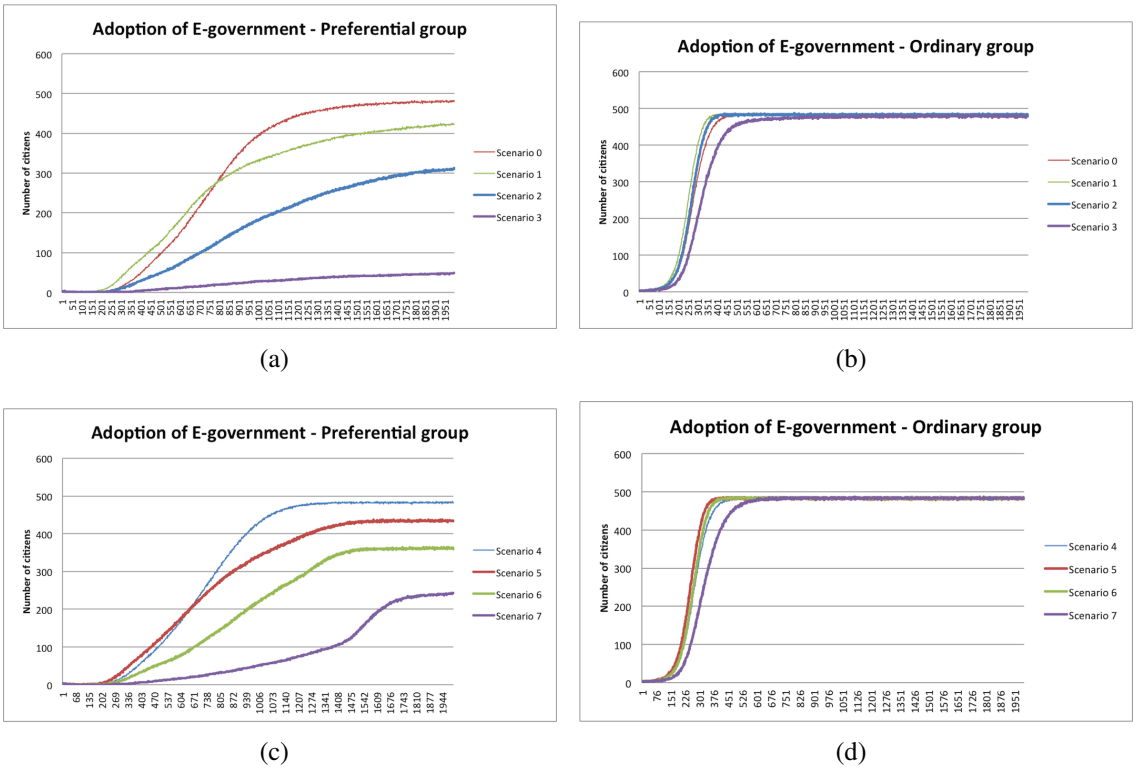


Figure 4-7: Channel choice - Closed community

We could observe that in closed community, without any strategies (Scenario 3), preferential group's adoption rate of E-government is relatively low (Fig. 4-7(a)). While with different strategies, the adoption rate will be improved in various degree over time. Compared with Self-help desk, the learning group will improve the adoption rate more. Comparing Fig. 4-7(a) with (c) in which public promotion is considered, we could observe that the adoption rate will increase more obviously and achieve a better converging point with information spread considered. On the other side, ordinary group's adoption rate will increase steadily in all scenarios with no significant difference among different strategies.

Open community

In Fig. 4-8, we will show the adoption rate of both ordinary group and preferential group under open community setting.

We could observe that in open community, even without any strategy (Fig. 4-8(a), green

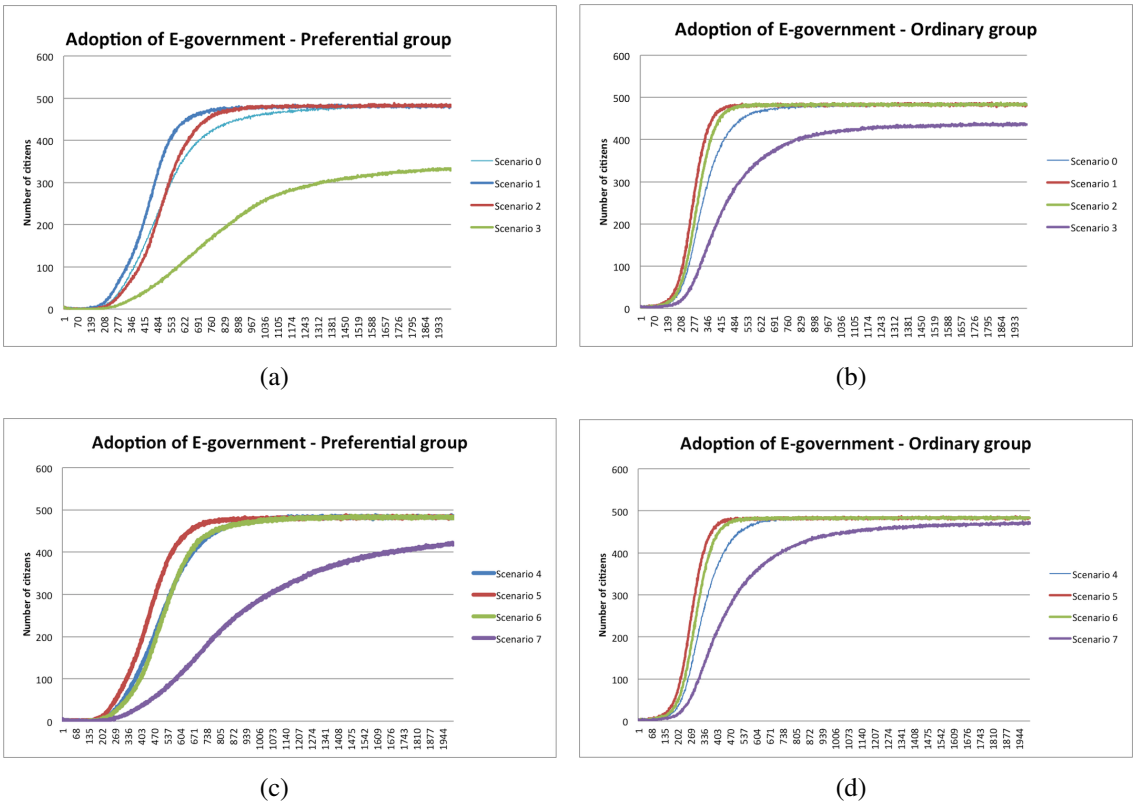


Figure 4-8: Channel choice - Open community

line) the adoption rate of preferential group will increase steadily to certain degree through the learning from ordinary groups within the same community. With public propaganda considered as shown in Fig. 4-8(c), the increase of adoption rate for preferential group will be more obvious. For ordinary group, without any strategy considered the adoption rate will increase slower compared with the case of closed community, which may indicate that even ordinary group needs an environment for E-government learning and adoption.

Policy scenarios

The cost-effectiveness of policies will be evaluated in terms of different social group's adoption rate of E-government per cost invested at each time unit. In other words we will consider the cost of each strategy and their resulting adoption rate for each social group. Due to lack of empirical data, we will set the total cost of three strategies equally in the

simulation.

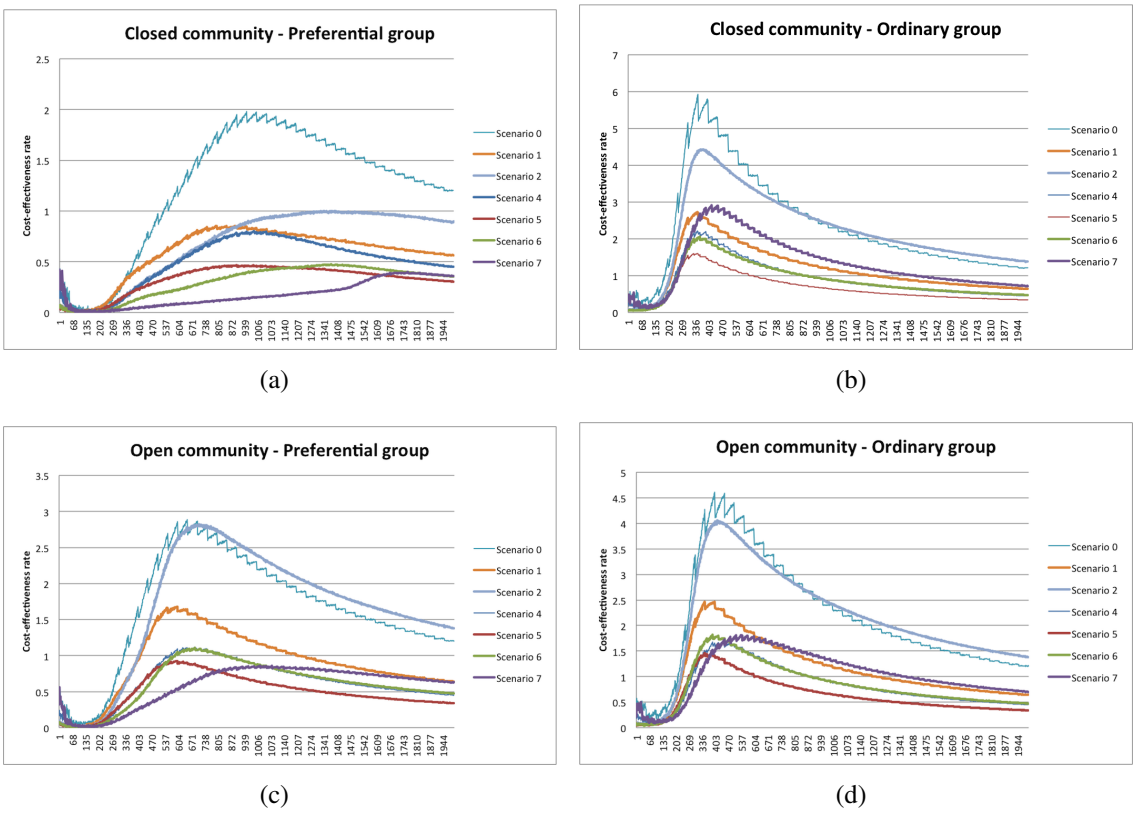


Figure 4-9: Cost-effectiveness of strategies

From Fig. 4-9, we could observe that for preferential group in closed community, the most cost-effective strategy is Scenario 0 that implements learning group only. In contrast for preferential group in open community, the cost-effectiveness of strategy that implements learning group and the one sets Self-help machine are relatively the same. For ordinary group, we could observe a similar result to the one for preferential group that the most cost-effective strategy is organizing learning group only. Without considering the public propaganda, implementing both other strategies is the least cost-effective one in the long term for both preferential group and ordinary group, which may indicate resources waste in both cases. In general, although public propaganda improves the adoption rate in all cases, the cost-effectiveness is relatively low when implementation cost is considered. At the outset, all strategies will experience a slump, which makes sense that strategies need time

to become effective. When the adoption rate of E-government increases slowly with time going, the effectiveness of all strategies will decline. For ordinary group, the effectiveness of strategies will change swiftly compared with the one for preferential group.

In general, open community in which ordinary group and preferential group could communicate with each other is a better environment for E-government adoption, especially for preferential group. Besides, learning group is a much more cost-effective strategy for both ordinary group and preferential group.

4.3.7 Verification and Validation

For verification, we run the simulation for 10 and 20 times respectively and calculate the average. The result shows that there is no significant difference between the two cases, which indicates that 10 times' run is enough to get a relatively accurate average of the result. For agent-based models, the validation of the model could be conducted by guaranteeing consistency with empirical data in the real world, conventional models in literature and stylized facts [23]. In this work, we do not intend to reproduce any specific social phenomenon, rather we aim to examine the underlying learning mechanisms and the resulted adoption behaviours. Therefore, we validate our model according to the propositions proposed in Deguchi's analytical social learning dynamic and support commitment model in macro-level [19].

In Deguchi's model, players will choose either A option that is desirable or B option that is currently prevailing, and indirect control as supporting commitment and educational effect are also considered. In our work, E-government could be considered as the A option while traditional counter is as B option, inverse of utility value $Inv(Util_{S1/S2})$ of choosing E-government and traditional counter can be treated as the corresponding payoff a and b (notations defined as in Section 4.3.1). The improvement of effort towards choosing E-government could be treated as supporting E-government. When the effort of using E-government is mitigated to certain level that the corresponding utility is smaller, then citizens will choose E-government. Mutual commitment could be treated as learning within

communities, whilst centralized commitment as the supporting strategies such as learning programs and public propaganda, both of which are kind of indirect control manipulated by the government. In other words, public promotion is a kind of educational effect to spread correct knowledge of E-government. The improvement of effort $E_c(t,S_2)$ is defined as a function of community's average effort, proportion of E-government adopters and the right knowledge, as $F_1(AVG_E^l(t,S_2),ADJ(t))$ (see details in Equation 4.11), similar to the supporting commitment defined in Deguchi's work as $G_1(Pa,PaKnow)$. The change of probability of choosing E-government $P_E(t)$ is defined as a function of the average payoff and the total payoff within the community, as $F_2(Util_{S2}(t-1),W_l(t-1))$ (see details in Equation 4.15). Without any supporting policy, if the utility value of choosing E-government is smaller, i.e. $a > b$, the probability of choosing E-government will converge to almost 100% after certain time unit and keep stable (*Ordinary group* case in Fig. 4-7(b)), while if it is the opposite case, i.e. $a < b$, then the probability of choosing E-government will remain relatively low (*Preferential group* case in Fig. 4-7(a)). This result matches with the *Proposition 1* (see Section 4.3.1 for details). The inverse of average effort of a community is treated as the bandwagon effects d, whilst the inverse value of effort mitigated by supporting strategies is treated as the positive support e. When the supporting strategies, such as learning programs is carried out, the effort of using E-government will be mitigated to certain level such that citizens will prefer E-government (as in Fig. 4-8). On the other hand, when the average effort of community is too large that there is no supporting strategy to help improve the effort, then the original common choice, i.e. traditional counter, will be dominant (Closed community case in Fig. 4-7). In Fig. 6-4, Fig. 6-5, and Fig. 6-6 which depict the micro-level community properties, the relation between community property and impact of supporting strategy is demonstrated more clearly. This result matches with the *Proposition 2* (see Section 4.3.1 for details).

4.3.8 Summary

In this section, community-based social learning are considered in this model, both in closed community and open community. Based on this model, different strategies which aim at improving E-government adoption rate, such as public propaganda and organizing learning programs are examined in terms of adoption rate and cost-effectiveness. From the result we could observe that in open community, adoption rate of E-government for citizens from preferential group is better compared with the one in closed community. Organizing learning group could be a better strategy compared with others, especially the one organized particularly for preferential groups in closed community. In open community, the cost-effectiveness of strategies are less distinguishable from each other. With our best knowledge, this is the first work to understand the channel choice of public services with community-based social learning considered, by using agent based simulation. Although the parameters in this work are fixed due to being lack of empirical data, it could still provide some insight for the policy makers.

4.4 Concluding remarks

In this chapter, we capture the citizen-side characteristics and adaptive behaviours, and build agent-based models to explore different citizens' channel selection behaviours, community-based learning mechanisms and based on which various supporting policies are proposed and evaluated. In future works, the value of parameters in this model could be calibrated to fit a particular situation and thus the model could be validated with empirical data collected from the real world.

Chapter 5

Resource allocation

This chapter aims to capture the government-side resource allocation optimization among different social groups in terms of user support. We formulate this problem as a multi-objective optimization which will be resolved by genetic algorithm. In Section 5.1, the motivation of this chapter and a brief review of multi-objective optimization are presented. Problem formulation and the agent-based simulation with genetic algorithm will be explained in Section 5.2. In Section 5.3, simulation results are presented and analysed. Conclusion and future work are offered in the last section.

5.1 Introduction

In order to encourage more citizens to utilize E-government services, there are many strategies deployed such as improving IT awareness and making E-government services more appealing. User support such as FAQ and service hotline that aim to help citizens use E-government in a much smoother way is also one of this kind. However from our previous work [12], we could observe that for different social groups, the effectiveness of user support varies. For social groups who have already utilized E-government frequently, the increased user support is more effective, which implies that particular strategies should be carried out in order to improve the E-government adoption rate of social groups who

haven't utilize it frequently yet. On the other side, if we only pay special attention on the social groups who are not favoured by E-government such as elderly people and allocate more resources to them, it is very possible that in turn other social groups will not be satisfied since the resources is limited. Therefore in terms of user support, how to allocate the limited resources in an optimized way such that all the social groups are satisfied is a challenging and meaningful research problem. In this section we aim to minimize the utility of all social groups simultaneously and to achieve a Pareto optimal [74] allocation of the resources among different social groups (Here we assume that smaller utility value indicates higher preference of E-government, thus better adoption rate).

5.1.1 Multi-objective optimization

Simultaneously satisfying all social groups' need in an optimized way with limited resources gives rise to the multiple-objective optimization nature of the above mentioned problem. In this section we formulate this resource allocation problem as a multi-objective optimization problem that aims to minimize the objectives of different social groups who may favour E-government service in different degree.

To our best knowledge there is no extant empirical work on citizen-centred E-government user support resources allocation problem formulated as multi-objective optimization and carried out by agent-based simulation with evolutionary algorithm. To solve the multi-objective problem, there are several approaches in literature. The most famous one is weighted approach [97] in which the objectives are combined with different weights into one single objective and thereafter be optimized. The disadvantage of this approach is that the appropriate weight selection is very complex and a comprehensive Pareto set is hard to achieve [35]. Another popular method is ε-constraint method in which a target constraint is set such that one objective is optimized while others are minimized to be less than this value [13]. The drawback of this method is that a proper selection of the constraint is difficult. On the other hand genetic algorithm (GA) is becoming a common and well suited solution for multi-objective optimization problem. In literature there are many multi-objective GA

algorithms proposed with their unique advantage and drawback [55]. In this work we adopt NSGA-II (Fast Elitist Non-dominated Sorting Genetic Algorithm) [18] since it is efficient and has been well tested. Comprehensive survey and comparison on multi-objective GA could be found in many works [55, 15, 60] and thus not discussed in this work.

5.2 Problem formulation

There is a set of assumptions embedded in this studying as follows,

- The resources in terms of user support is limited. For Email contact and direct communication, only a limited number of citizens could be served at each time unit.
- For simplicity we assume citizens are categorized into two social groups only in this work, one is favoured by E-government and the other is not. The social group not favoured by E-government (such as elderly people) is treated as preferential group indicating that potentially they should receive more user support. Each citizen belongs to only one social group.
- At the initial iteration, all citizens will be served randomly or according to certain probability. In the following iterations the resources distribution between two social groups will be evolved based on GA in order to achieve Pareto optimality.

5.2.1 Formal modelling of agents

We apply agent-based simulation (ABS) [33] and multi-objective genetic algorithm [18] to find appropriate resource allocation such that satisfying the user support requests issued by different social groups in an optimized way.

In this work citizens are abstracted as rational agent who may take up governmental service through E-government based on the utility evaluated in terms of time and effort. The rationale behind this abstraction is that the governmental services normally can be evaluated by three major aspects: easier service, faster service and better service [36].

Easier service refers to the citizens' effort to complete the service. Faster service refers to the time that citizens may need until obtaining the service result. Better service refers to the user support received during the service provision process. User support is as well defined by the time required to complete the support and the effort saved by receiving user support. In this work, different social groups may value time and effort differently which may influence their utility evaluation of the E-government service. The activity of a citizen at each iteration is illustrated in the following diagram (Fig. 5-1).

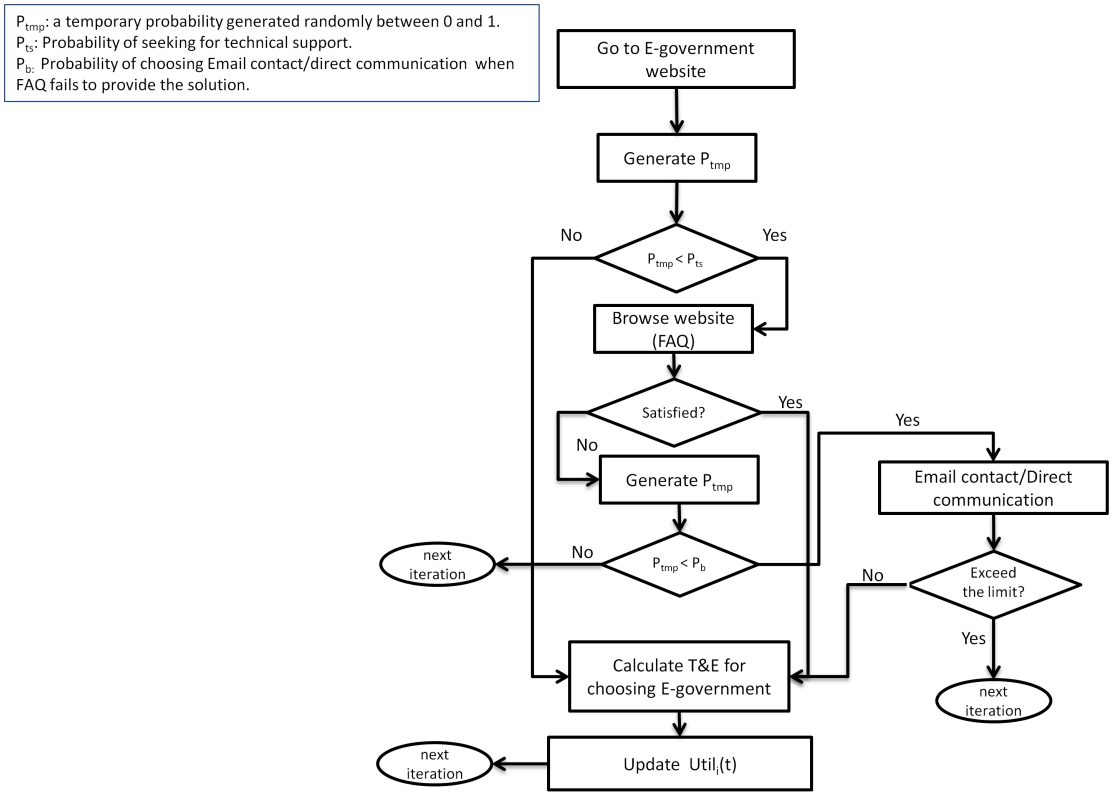


Figure 5-1: Behaviour of citizen agent

Citizen set is defined as $Citizen = \{C_1, C_2, \ldots, C_n\}$, where n is the number of citizens. Each citizen agent is abstracted as $C_i =< Util, Pref_T, Pref_E, T_c, E_c, L_{exp} >$. For E-government service agent, it will be defined as $< T_s, E_s >$. In addition user support will be provided as well. Three kinds of user support are identified, which are Help web-

site (such as FAQ provided on website), Email contact and direct communication (such as face to face communication or phone call). Each type of user support TS is defined as $< T_{TS}, E_{TS}, Cap_{TS} >$. Detailed explanation of the variables are presented in the following Table 5.1. For the preference $Pref_T$ and $Pref_E$, the value will be different for citizens coming from different social groups. The larger the value, the more citizens emphasize the attribute. For instance, a citizen who thinks time is more important than effort will be with a larger value $Pref_T$ compared with $Pref_E$.

Table 5.1: Explanation of agent variables

$Util \in \Re^+$	Evaluated utility of E-government service at each iteration
$T_c, E_c \in \Re^+$	Total time and effort consumed to complete the service respectively
$Pref_T, Pref_E \in \Re^+$	How citizens weight time and effort respectively, while we require $Pref_T + Pref_E = 1$
L_{exp}	A list of using history of E-government. 1 as success, 0 otherwise
$T_s, E_s \in \Re^+$	Time and effort designed to complete the service respectively
$T_{TS}, E_{TS} \in \Re^+$	Time consumed by requiring user support and effort saved by receiving user support
$Cap_{TS} \in \mathbb{Z}$	The capacity per time unit enabled by the service provider, i.e. the number of requests could be handled within certain time
x_i	Whether citizen i gets help from user support. 1 indicates yes, while 0 otherwise

The utility value $Util$ of citizen i at time t will be updated at each iteration as follows,

$$Util_i(t) = Pref_T * T_c(t) + Pref_E * E_c(t) + \varepsilon \tag{5.1}$$

$$T_c(t) = T_s + \frac{Num_c(t)}{Cap_{TS}} * T_{TS} * x_i \tag{5.2}$$

$$E_c(t) = E_s * P_{EST} - \frac{Num_c(t)}{Cap_{TS}} * E_{TS} * x_i \tag{5.3}$$

$\frac{Num_c(t)}{Cap_{TS}}$ is multiplied to adjust the time and effort required by user support according to the current situation. $Num_c(t)$ is the number of citizens at time t receiving the user support. For Help website and Email contact, the value of this ratio is assigned by 1. For direct communication this value is calculated based on the simulation process. ε is a random noise valued between 0 and 1. $k = \{1,2\}$ denotes the set of preferential group, P_k is the set of citizens in group k, where $P_k \subset C$. The value of x_i denotes whether citizen i gets help from Email contact or direct communication. From time to time, the time required to complete the service process T_c will not be changed significantly, but the effort of utilizing E-government service will be evolved. E_c will be evolved depending on whether the previous w tries of E-government are successful or not. We let Num indicate the number of tries, NoW indicate the number of success of last w tries, and NoS represent the total number of successful tries, while w, $Num, NoW, NoS \in \mathbb{Z}$, and $P_{EST} \in \Re$. The way of updating the evolved effort rate P_{EST} is the same as stated in Section 4.2.3, citizen agent.

The multi-objective optimization problem is formulated in the following,

$$minF_1(x) = min \sum_{i \in P_1} Util_i(t) \tag{5.4}$$

$$minF_2(x) = min \sum_{i \in P_2} Util_i(t) \tag{5.5}$$

we aim to minimize the total utility of both social groups simultaneously. $\sum_{i \in P_k} Util_i(t)$ represents the total utility of citizens belongs to group P_k at time t, $k = \{1,2\}$. Here we assume P_1 represents the ordinary social group while P_2 represents the preferential one. In addition, in the simulation the total utility of both groups is proportioned to the same scale, i.e. total utility of same number of citizens.

5.2.2 Multi-objective genetic algorithm approach

In this subsection the design of the multi-objective genetic algorithm will be explained briefly.

Chromosomal representation. The length of the chromosome will be the number of available user support (including Email contact and direct communication service) slot at each time unit, i.e. the number of citizens could be served at each time unit. Suppose each unit in the chromosome records the group to which citizens who are receiving the user support belong. In other words the chromosome is a list of integers with value 1 or 2. At each iteration the proportion of 1 and 2 will be calculated and indicate that social group P_1 and P_2 could be served by the user support with this probability.

Fitness function. In this work the fitness function $f_{it}(x)$ at iteration t of objective i will be the same as objective function $F_i(x)$ as defined in above subsection, in other words the purpose is to minimize the total utility of both social groups simultaneously to achieve a Pareto optimal resources allocation.

Pareto Optimality. The Pareto optimality could be defined in the following way [55]. We have a set of decisions $X = \{x_1, x_2, ..., x_n\}$ that minimizes a set of objective functions $F(X) = \{f_1(x), ..., f_m(x)\}$, while $m = 2$ in our case. A feasible solution X is said to dominate another feasible solution Y if and only if, $f_i(X) <= f_i(Y)$ for $i = 1, \ldots, m$ and $f_j(X) < f_j(Y)$ for at least one objective function j. We aim to find a solution which is not dominated by any other solutions, in other words, a Pareto efficient solution.

5.3 Simulation result analysis and discussion

The implementation of our work is based on an open source Java-based framework, jMetal which aims at "the development, experimentation, and study of metaheuristics for solving multi-objective optimization problems" [22]. We assume there are 1000 citizens divided into two social groups. For GA the population in this work is set to 100 and will be evaluated for 3000 times. In the following figures, x-axis represents the utility value of ordinary social group while y-axis represents the utility value of preferential social group.

5.3.1 Scenarios

Four composition of the preferential social group in the total population, 20%, 30%, 40% and 50% will be evaluated respectively. In addition different initial resources allocation will be evaluated as well. The corresponding Pareto efficiency solution set obtained by GA evaluation is showed in the following figures.

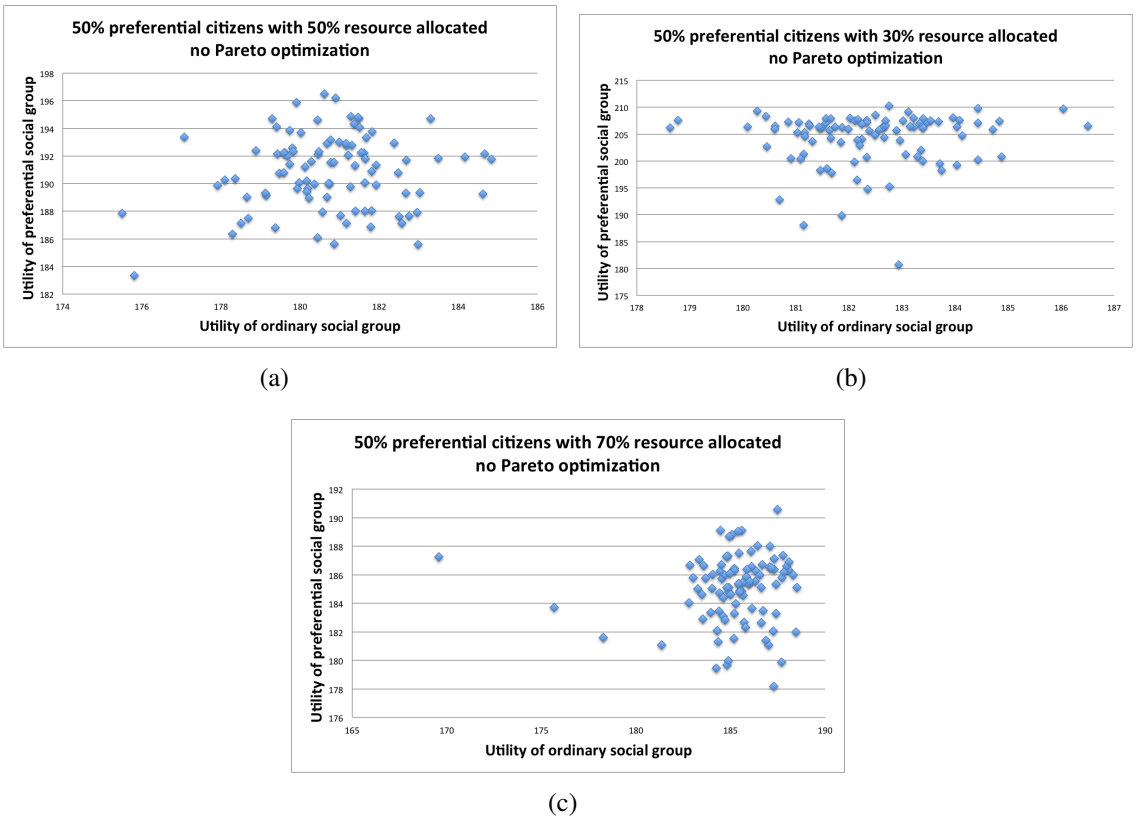


Figure 5-2: Utility ratio of 50% preferential citizens with different portion of resources allocated

Scenario 1

In this scenario (Fig. 5-2), utility distribution between the two social groups without Pareto optimization evaluation are presented. We could see that if we allocate the resources randomly (Fig. 5-2(a)) to the two groups, the total utility of both groups is randomly distributed. If we ignore the need of preferential group and allocate less resources to it (Fig. 5-

2(b)), it is obvious that the utility of preferential group is high which may indicate less citizens in this group will choose E-government. When the preferential social group is with more resources allocated (Fig. 5-2(c)), although the utility of preferential group is decreased, the utility of the other group will be relatively high which may indicate that this group could not be satisfied by the service.

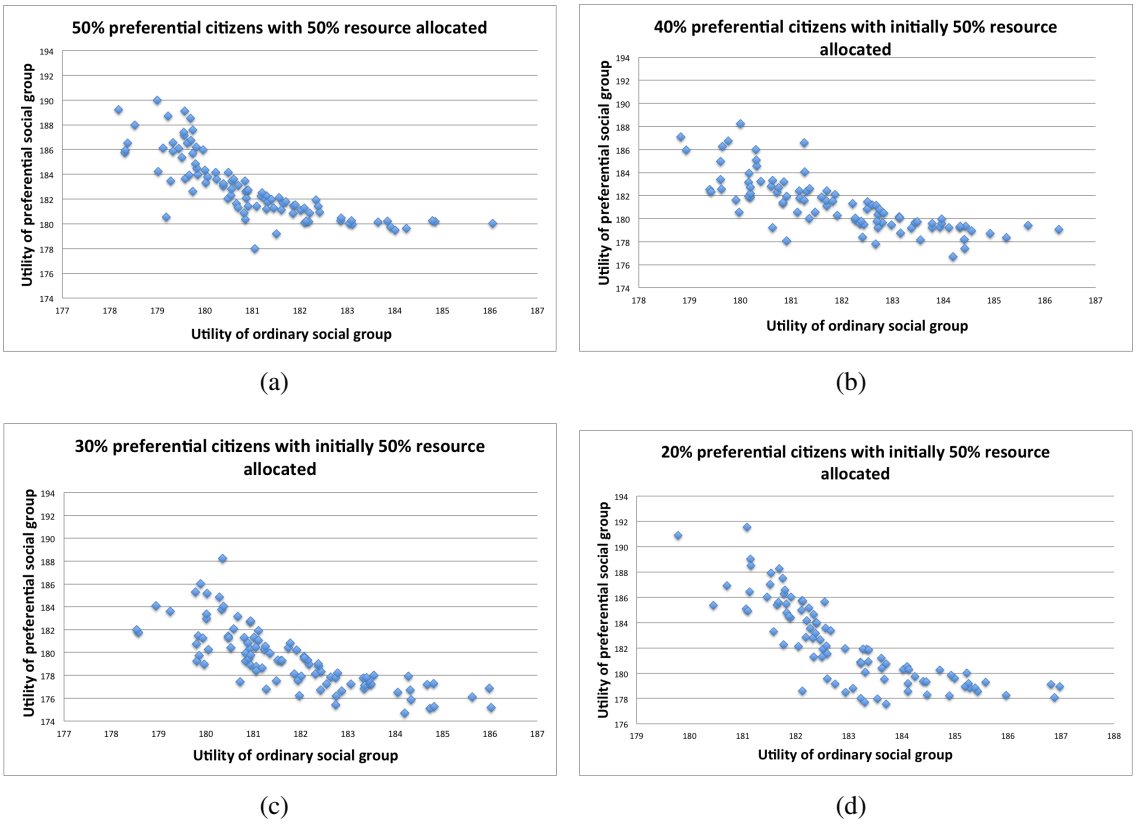


Figure 5-3: Utility ratio of different proportion of preferential citizens initially with 50% resources allocated

Scenario 2

In this scenario (Fig. 5-3), different proportion of preferential group in total population with initially 50% resource allocated will be evaluated. Generally we could observe that if we allocate the same amount of resource to the preferential social group with different population size, the smaller the size, the better result we could yield. However it is inter-

esting to see that if 20% (Fig. 5-3(d)) of the total population belonging to the preferential group, the utility of the other social group is higher compared to other cases. Probably this could indicate the existence of resource waste that abundant resource has been reserved for preferential group while other social group could not get enough support.

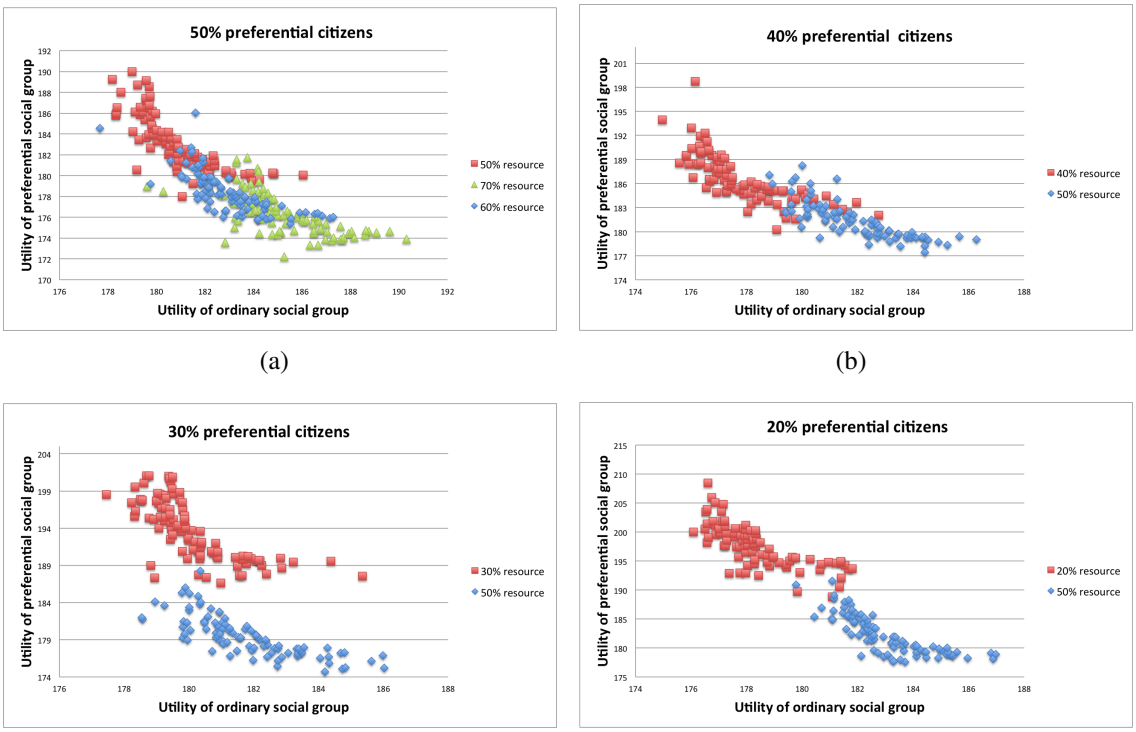


Figure 5-4: Utility ratio of different proportion of preferential citizens initially with different proportion of resource allocated

Scenario 3

In this scenario (Fig. 5-4), different percentage of preferential group in total population with initially proportional resources allocated will be evaluated. In other words in this scenario the resources initially is allocated proportional to the population of preferential group (red dots in Fig. 5-4). For Fig. 5-4(a), 50% preferential citizens will be allocated $50\%, 60\%, 70\%$ resources respectively. Compared with random resources allocation (blue dots in Fig. 5-4), We could observe that the performance of preferential group is degrading

that indicates proportional allocation might not be effective and more resource should be allocated for it. We could observe that increased resources allocated is more effective for the 30% preferential citizens case (Fig. 5-4(c)) than 40% case (Fig. 5-4(b)). Furthermore for the 20% case (Fig. 5-4(d)), although the utility of preferential group improves, the utility of the ordinary one increases in a very obvious way compared to other cases, which again shows that when the population of preferential social group is small, we should find a balanced resource allocation point such that on one side the preferential group gets enough support while on the other side no resources is wasted.

In all scenarios, a set of approximate Pareto efficient solutions is presented and it is quite robust across different cases in terms of the Pareto front shape. Generally speaking the most preferred solution could be found at the turning point of the curve which may help decision makers have some insights on how to allocate the user support to different social groups in an optimized way, thus achieving a balance among them. For each of the dots presented in above diagrams, we could acquire the resource allocation between two social groups. The resource distribution has a slight trend towards favouring preferential social groups, but not for the 20% preferential group case which indicates the special situation that when the preferential group is minority.

5.4 Concluding remarks

In this chapter, we propose a new way, multi-objective optimization, to formulate the E-government user support allocation problem among social groups with diverse preference of E-government. By applying agent-based simulation and genetic algorithm, we yield a set of Pareto efficiency solutions that could minimize the utility of both social groups thus satisfying their needs simultaneously. By simulating different scenarios with different preferential group population and initially allocated resource, we could provide some insight on the resources allocation problem to policy makers. However the parameters' value used in this work is not based on empirical data but estimated one, and the results' interpretation

is restricted to the parameter setting in this work only. Future work could be carried out based on empirical data collected from the reality. This section could serve as a first attempt to optimize the E-government user support resources allocation, and the model could be further expanded to see how it influences the number of citizens choosing E-government rather than other channels. In addition citizens are categorized into two social groups only in this work, thus in future work it could be divided into multiple social groups with respect to the problem setting, and the implementation will not be changed too much.

Chapter 6

Simulation result analysis

In this chapter, we are going to analyse the simulation results generated in Chapter 4 in a more comprehensive manner from both macro-level and micro-level perspectives. In the following, they will be represented separately.

6.1 Macro-level analysis and implications

Ohori and Takahashi [68] introduced an analytical method to agent-based simulation, named "scenario analysis". This analytical method differs from previous methods by which average results of simulation runs are presented, rather it describes the result of each run without modification. The advantage of this method is the consideration of divergent situations, design policies and possible changes, which could support the decision-making process.

From the macro-level point of view, we focus on the E-government adoption rate of preferential social groups who are the primary target social group of E-government supporting strategies. By changing the community composition, the availability and implementation frequency of supporting strategies, we will examine the corresponding E-government adoption rate. The specific value of variables in each scenario is represented in the following Table 6.1, Table 6.2 and Table 6.3. In all the following figures, the result of 10

simulation runs are plotted and the average values are connected by lines.

Table 6.1: Scenarios without any strategy

Time unit	Community property	Preferential population	Scenario
500	Open community	30%	1
		40%	2
		60%	3
		70%	4
		80%	5
1000	Open community	30%	6
		40%	7
		60%	8
		70%	9
		80%	10
1500	Open community	30%	11
		40%	12
		60%	13
		70%	14
		80%	15
2000	Open community	30%	16
		40%	17
		60%	18
		70%	19
		80%	20

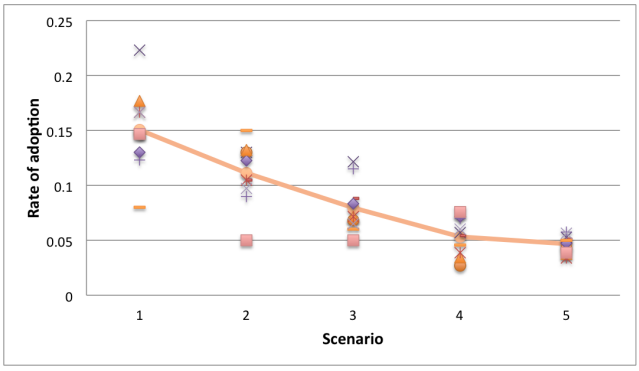
In Fig. 6-1, scenario 1 to 20 aim to investigate the influence of population composition - ratio of ordinary social groups and preferential social groups - on the final adoption rate of E-government for preferential social groups at iteration 500, 1000, 1500 and 2000 respectively. The community is open community within which both ordinary social groups and preferential social groups are mixed. There is no E-government supporting strategy carried out. From scenario 16 to 20, which represent the final adoption rate for preferential groups at iteration 2000, we could see that if initially the population of preferential groups only accounts for a smaller proportion (30% and 40% in scenario 16 and 17), then the corresponding adoption rate will be relatively high (93% and 90%) and converge to a particular value. Intuitively it makes sense that when the majority within a community has adopted

a new service and been equipped with the ability to use it, then the rest of the population might have a higher possibility to learn from them and adopt the new service. In contrast, when the majority within the community are "laggards" [73] and not skilled to use the new services, then the influence of a relatively small number of adopters will be limited, as shown in scenario 19 and 20. Another indication from Fig. 6-1 (comparing scenario 1 and 5 with scenario 17 and 20 respectively) is that the influence of ordinary social group upon preferential social groups will affect the adoption rate for the latter more slowly when preferential social groups are the majority within a community.

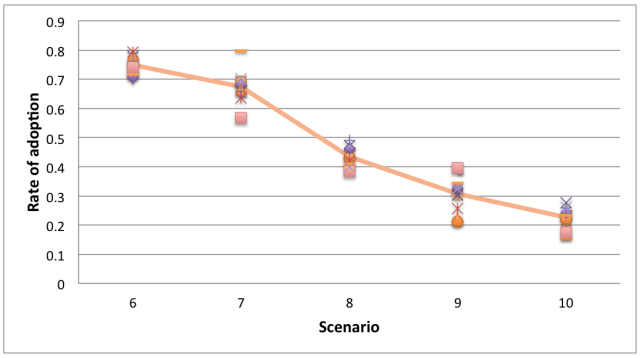
Table 6.2: Scenarios with information promotion

Time unit	Community property	Preferential population	Scenario
500	Closed community	30%	21
		40%	22
		60%	23
		70%	24
		80%	25
1000	Closed community	30%	26
		40%	27
		60%	28
		70%	29
		80%	30
1500	Closed community	30%	31
		40%	32
		60%	33
		70%	34
		80%	35
2000	Closed community	30%	36
		40%	37
		60%	38
		70%	39
		80%	40

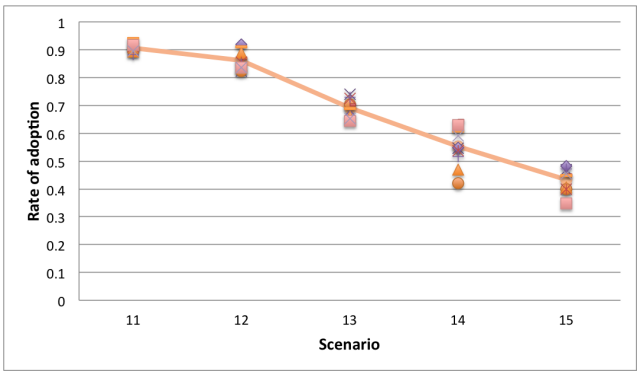
In Fig. 6-2, scenario 21 to 40 aim to investigate the influence of information promotion in different cases of which the composition of closed community is different (30%, 40%, 60%, 70% and 80% of preferential group respectively). Closed community indicates the



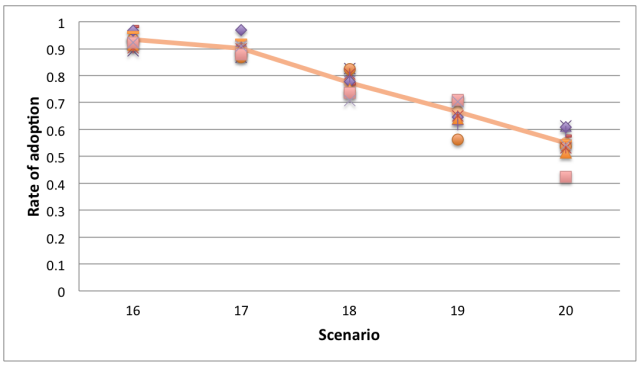
(a) 500 time units



(b) 1000 time units



(c) 1500 time units



(d) 2000 time units

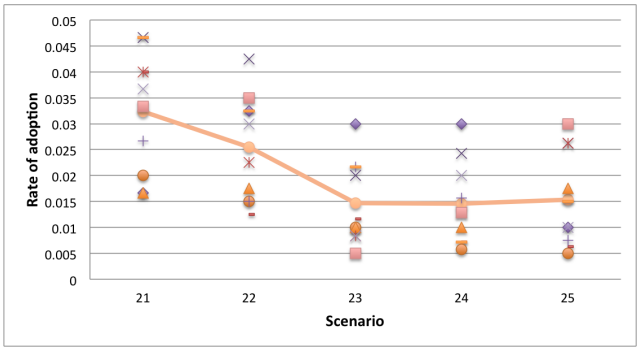
Figure 6-1: Landscapes of adoption rate - Influence of community composition

case that there is only type of social group in each community. When the total population of preferential social groups is small, it represents the case that the size of community with only preferential social groups is relatively small. From Fig. 6-2 we could see that the influence upon the adoption rate will be relatively the same (adoption rate between 30% and 35%) at the final iteration. In contrast, at early stages (iteration 500 and 1000), in the case that the size of preferential social groups is relatively small, the adoption rate of E-government will be better (scenario 21) than the opposite case (scenario 23, 24 and 25).

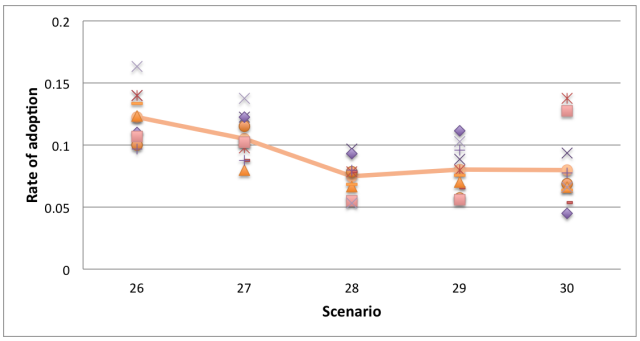
Table 6.3: Scenarios with learning groups

Time unit	Community property	Frequency	Scenario
500	Closed community	Every 20 times	41
		Every 30 times	42
		Every 70 times	43
		Every 100 times	44
1000	Closed community	Every 20 times	45
		Every 30 times	46
		Every 70 times	47
		Every 100 times	48
1500	Closed community	Every 20 times	49
		Every 30 times	50
		Every 70 times	51
		Every 100 times	52
2000	Closed community	Every 20 times	53
		Every 30 times	54
		Every 70 times	55
		Every 100 times	56

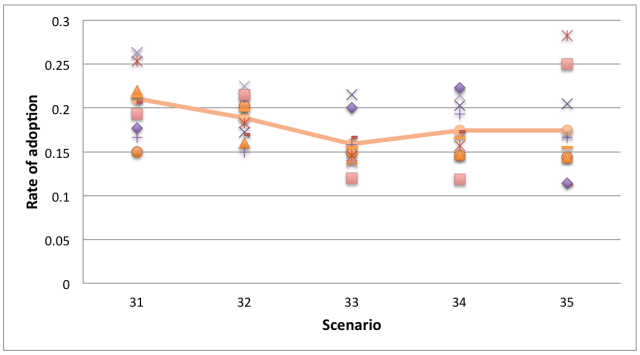
In addition, in Fig. 6-3 scenario 41 to 56 aim to examine the influence of strategy implementation frequency on the adoption rate. Here we assume the community is closed in which only one type of citizens resides, and ordinary social groups and preferential social groups are with equal population. In addition, only learning group strategy will be experimented. The frequency of strategy implementation means the frequency of visiting learning groups from the viewpoint of citizens, or the frequency of organizing learning



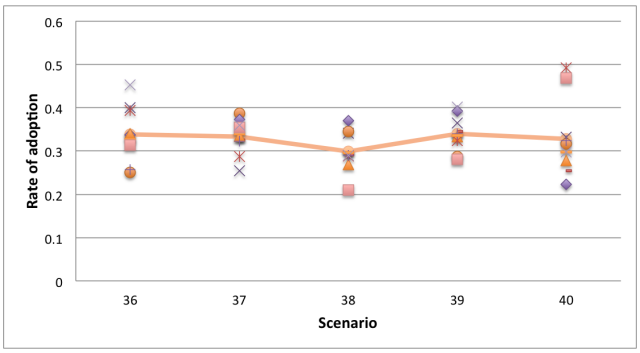
(a) 500 time units



(b) 1000 time units



(c) 1500 time units



(d) 2000 time units

Figure 6-2: Landscapes of adoption rate - Influence of information promotion

groups or workshops from the viewpoint of public sectors. From scenario 41 to 44, we could observe that when the frequency of implementation is high, the strategy will be more effective (scenario 41 with frequency 20 compared to scenario 44 with frequency 100). Consequently, the adoption rate will increase faster and converge to be stable as in scenario 49 and 50 with final adoption rate around 95%. In such cases, the duration of strategy implementation should be considered that after certain periods when the effectiveness of strategy is reaching the saturated point, such strategy should be suspended or ceased.

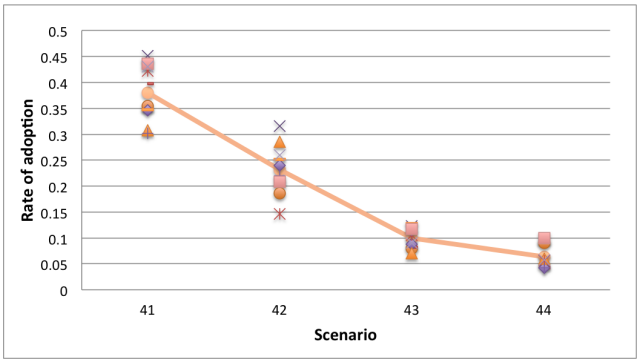
The above "landscape" representation of simulation results provides a way to analyse the result in different scenarios by experimenting various composition of variables. Certainly simulation results could be represented and interpreted in different ways, and the above figures make the influence of different properties on the final adoption in macro-level more clear.

6.2 Micro-level analysis and implications

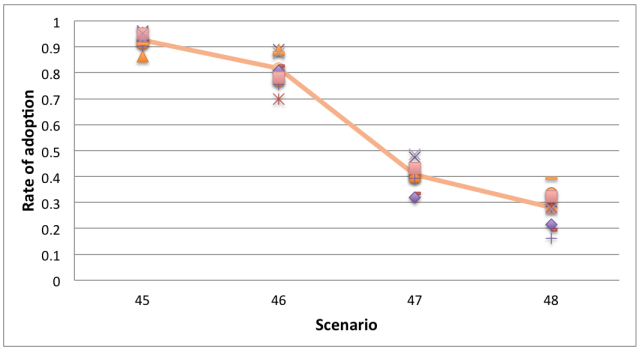
Ohori and Takahashi [68] also introduced a micro-level analysis method called "micro dynamics analysis" which analyses the simulated data from a micro viewpoint. By adopting this analysis method, we aim to examine how the average learning ability of each community changes along with time under different scenarios.

From the macro-level result analysis, we could observe the adoption trend for all citizens/communities in long term under changes with respect to different community properties and strategy implementation scenarios. However, the adoption rate and learning dynamics down to each community are still missing. As we mentioned above, different communities with different population composition hold their own properties that will lead to divergent adoption behaviours. It is meaningful and necessary to investigate into such dynamics and analyse them further in details. In the following, we will analyse the micro-level (community-level) data and treat each community as the unit of case study.

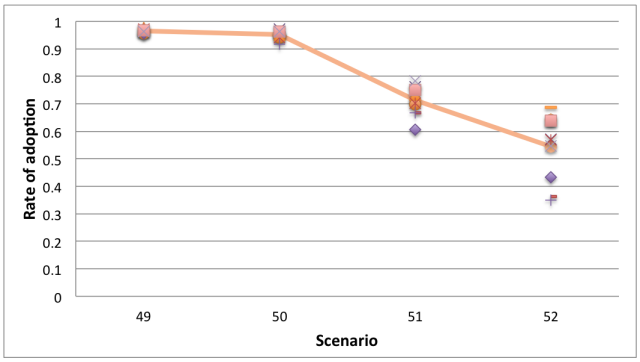
There are several steps to identify special cases (unit of analysis). First, we check the



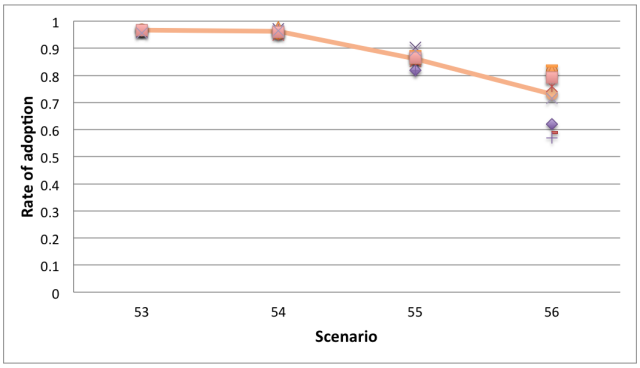
(a) 500 time units



(b) 1000 time units



(c) 1500 time units



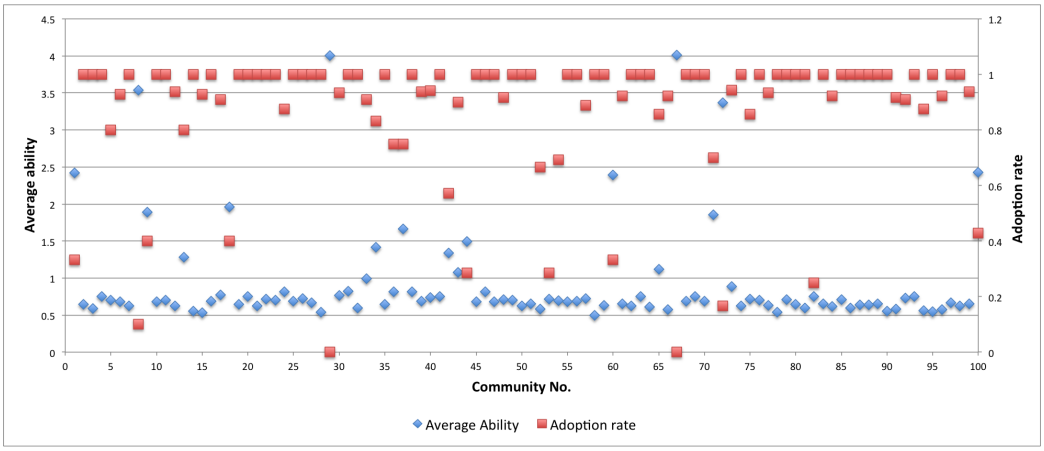
(d) 2000 time units

Figure 6-3: Landscapes of adoption rate - Influence of information promotion

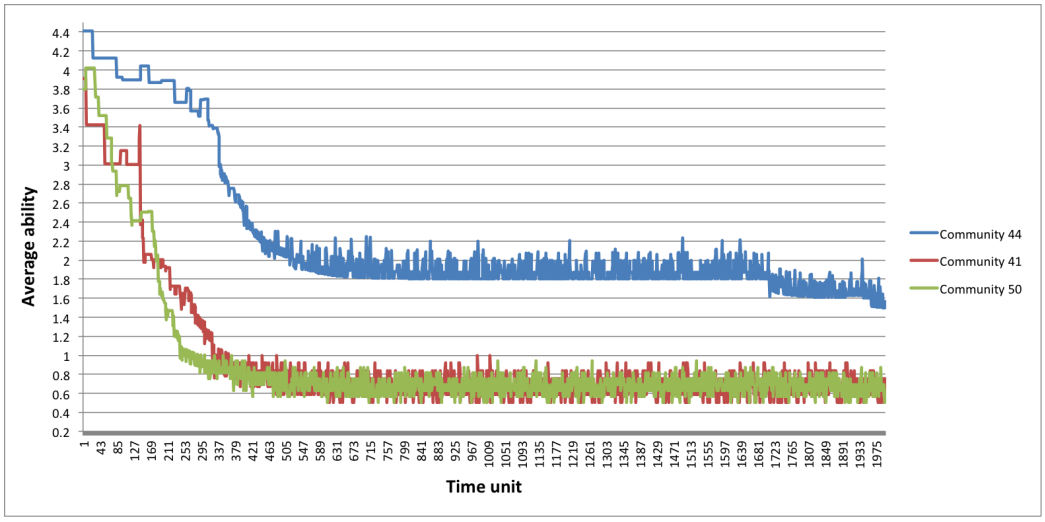
adoption rate for all communities at the final iteration through which we could identify the communities with the lowest adoption rate, as shown in Fig. 6-4(a), Fig. 6-5(a) and Fig. 6-6(a) (x-axis: community number; left y-axis: average ability of using E-government; right y-axis: adoption rate of E-government). Second, we go into the details of those communities identified in the previous step, i.e., community composition and average effort, as shown in Fig. 6-4(b), Fig. 6-5(b) and Fig. 6-6(b) (x-axis: time unit; y-axis: average ability of each community). Then if necessary we could check the record of each citizen within this community, such as whether they are E-government adopters, and what their effort level and the corresponding utility value of E-government are.

In the following Fig. 6-4 we take the scenario of which there are 40% of preferential group in the whole population (open community), and no supporting strategy is carried out. Therefore, the only way through which preferential groups could improve their ability to use E-government is from the environment. Fig. 6-4(a) shows adoption rate of E-government and the average ability of using E-government for all 100 communities at the final iteration (i.e. 2000). We could see that for community (percentage of preferential groups in the community) 1 (50%), 8 (60%), 9 (40%), 18 (40%), 29 (67%), 44 (55%), 53 (85%), 60 (33%), 67 (83%), 72 (50%), 82 (50%), and 100 (25%), the adoption rate is below 50%. Especially in the case when preferential groups dominate the community population (over 50%), the adoption rate will be relatively harder and slower to increase. In addition, we could see that for those communities with lower adoption rate, the average ability of using E-government is relatively low as well. If we take a closer look into the average ability of community 41 (33%), 44 (55%) and 50 (25%) as in Fig 6-4(b), we could see that for communities with more ordinary social groups (community 41 and 50), the average ability will be improved faster than the one with less ordinary social groups (community 44).

Similarly we could also check other scenarios. For example, we could compare the closed community case when supporting strategy learning group is carried out in different frequencies. In Fig. 6-5, we could see that when learning group is carried out less frequently (per 100 time units), the final adoption adoption rate for communities with only preferential



(a) Adoption rate and Average ability



(b) Average ability trend

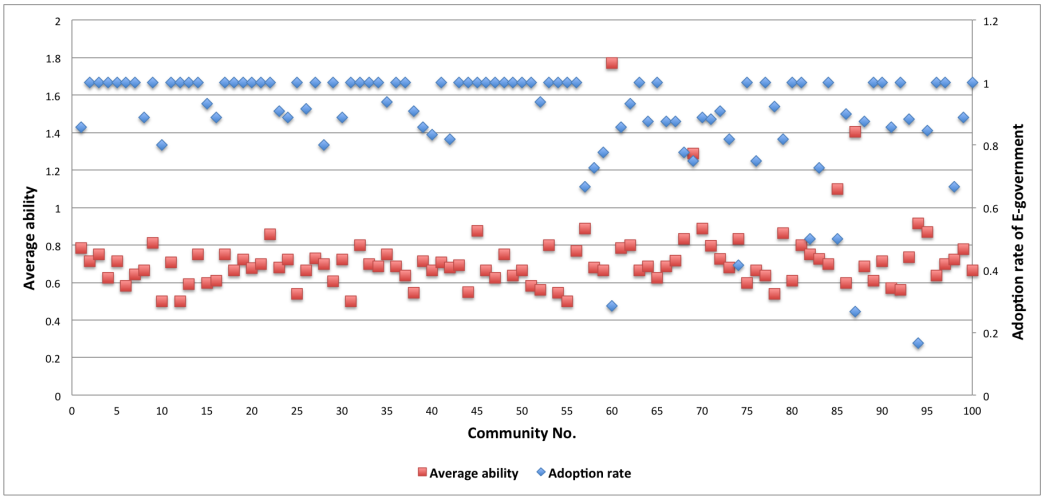
Figure 6-4: Average ability of each community and the corresponding adoption rate: 40% of preferential group

groups (community 51 to 100) will be relatively low and various, whilst the adoption rate of communities with only ordinary groups (community 1 to 50) will be converge to 100% at the final stage, as in Fig. 6-5(a). In Fig. 6-5(b) showing the average ability of different communities, we select one community from pure ordinary group community (community 11) and two communities from pure preferential group ones (community 67 with final adoption rate 88% and 94 with final adoption rate 17%), and we could see that the ability is improved slower for preferential group-only communities (community 94 for instance), which may result a lower adoption rate.

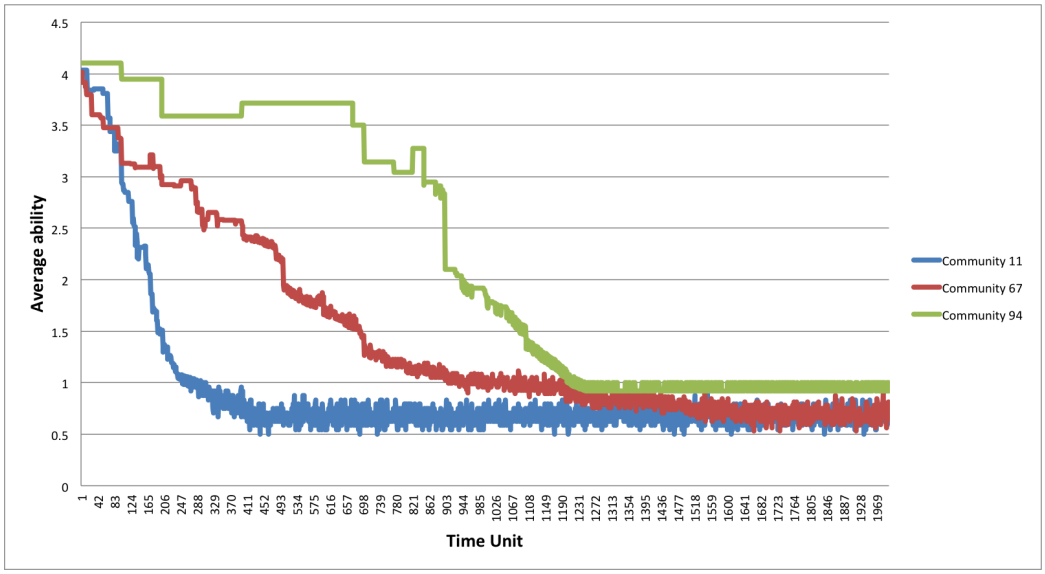
In contrast, in Fig. 6-6 when the strategy is carried out frequently (per 30 time units), the adoption rate for ordinary group and preferential group at final iteration are quite evenly distributed as shown in Fig 6-6(a), and the gap between these two groups is trivial. Furthermore, the average ability between communities with different property, such as community 24 (adoption rate 100%) and 74 (adoption rate 80%), will not be obviously distinguishable, as shown in Fig. 6-6(b).

6.3 Concluding remarks

In this chapter, we represent two ways to analyse agent-based simulated data. Both macro-level phenomenon, such as the adoption rate of E-government, and micro-level properties, such as community composition and properties are examined. In addition, for the macro-level phenomenon, we apply the "landscape" representation to reflect the influence of initial value of parameters on the final adoption behaviour. Besides modelling individual's behaviours and interactions, we could also track the changes of the community properties. The micro-level data analyse is one particular advantage inherited in agent-based simulation by applying which we could look into the details down to individual/community level that provides more profound and dynamic insight for policy makers. In this chapter, we only select several scenarios to analyse, but a full-range and more deeper analysis could be carried out in future.

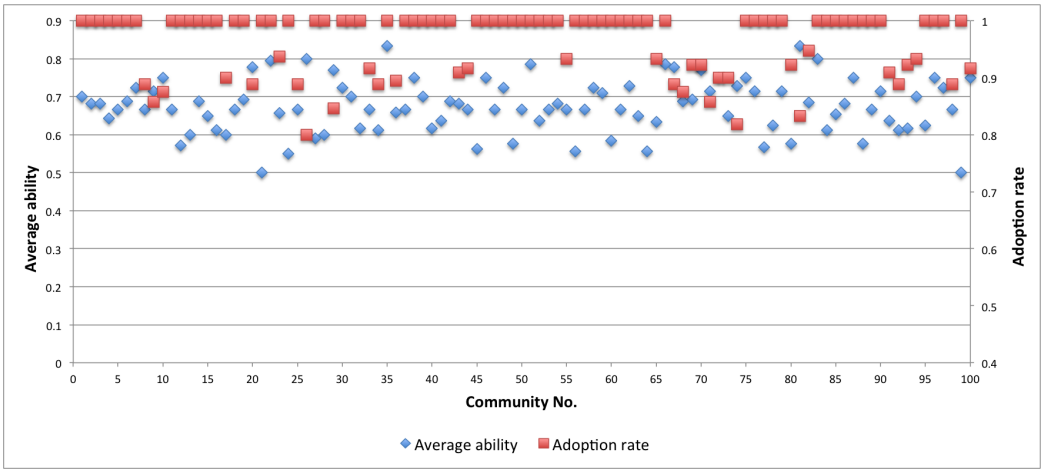


(a) Adoption rate and Average ability

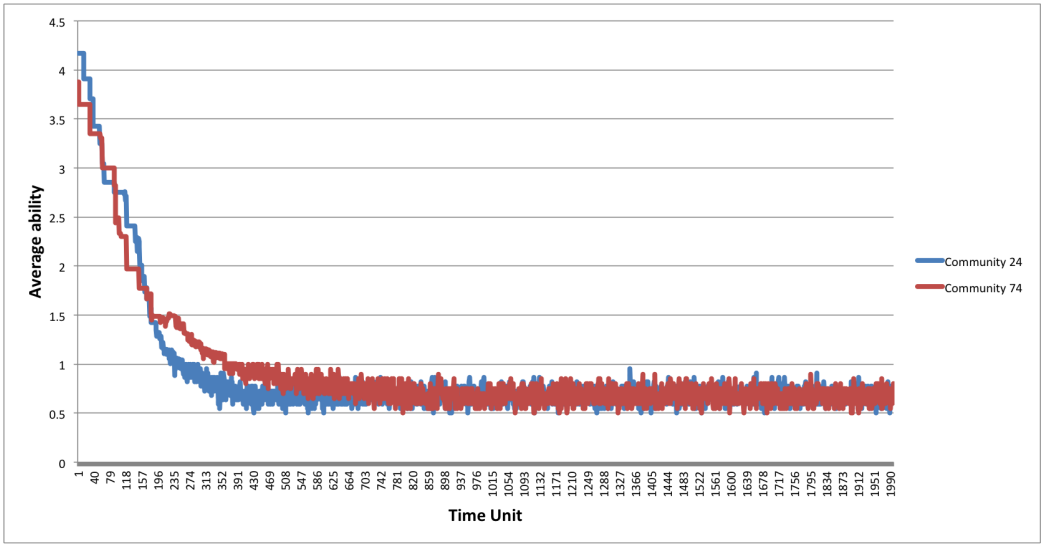


(b) Average ability trend

Figure 6-5: Average ability of each community and the corresponding adoption rate: Frequency 100



(a) Adoption rate and Average ability



(b) Average ability trend

Figure 6-6: Average ability of each community and the corresponding adoption rate: Frequency 30

Chapter 7

Conclusion

In this thesis, started from the introduction of E-government phenomenon and a literature review from both methodological and theoretical aspects of this field, we argue that new perspective and methodology should be applied in E-government research field to capture the divergent characteristics of heterogeneous stakeholders, their adaptive behaviours to the environment and interactions among them as an integrated service system. Through the agent-based modelling of the system, insight and knowledge gained not only from the macro-level perspective but also the micro-level perspective enables new understanding of E-government systems which could aid better service design and policy making. The contributions of this thesis are listed as follows,

1. We built an integrated conceptual framework of E-government to identify the characteristics of heterogeneous stakeholders, their adaptive behaviours, and the interaction mechanisms among them from a service system perspective. Such integration provides a holistic view of the system which could capture the dynamic service provision process and the macro-level phenomenon emerged from the micro-level interactions. It could complement the understanding of such systems by applying agent-based approach which could not be achieved by traditional qualitative and quantitative studies.

2. We applied a new way, agent-based simulation, to understand the channel choice

of citizens from different social groups when they want to take up certain type of governmental services. Based on the model, basic strategies such as increasing the awareness rate of E-government and providing more technical support are evaluated from which we could have some results different from what we've expected. This work could serve as the first attempt to capture citizens' channel choice of public services by applying agent-based simulation in literature.

3. We integrated the community-based social learning into the citizens' channel selection model, both in closed community and open community. Based on this model, different strategies which aim at improving E-government adoption rate, such as public propaganda and organizing learning programs were examined in terms of adoption rate and cost-effectiveness. The simulation results were analysed in both macro-level and micro/meso-level. With our best knowledge, this is the first work to understand the channel choice of public services with community-based social learning considered, by using-agent based simulation. Although the parameters in this work are fixed due to being lack of empirical data, it could still provide some insight for policy makers.

4. We formulated the E-government user support allocation problem among social groups with diverse preference of E-government by a new way, multi-objective optimization. By applying agent-based simulation and genetic algorithm, we yield a set of Pareto efficiency solutions that could minimize the utility of both social groups thus satisfying their needs simultaneously. By simulating different scenarios with different preferential group population and initially allocated resource, we could provide some insight on the resources allocation problem to policy makers. In addition citizens are categorized into two social groups only in this work, thus in future work it could be divided into multiple social groups with respect to the case setting, and the problem setting and implementation will be not changed too much.

5. We analysed the simulated data from both macro-level and micro-level perspectives.

Insight and knowledge not only on the collective adoption behaviours across different social groups, but also the learning dynamics within each community could be gained to facilitate better service and supporting strategy design.

This thesis serves as the first step towards understanding E-government services and designing supporting strategies from the viewpoint of citizens by agent-based approach. By adopting a service system perspective and applying agent-based approach, we could examine citizens' behaviours and dynamic changes of community properties in different scenarios and based on which to propose and evaluate supporting policies. There are still many potential future works left to be explored and carried out to advance our understanding of this field. In the following, some major ones are proposed.

1. Since the simulation results and interpretations are based on pure parameter setting and no empirical data is applied in this work, field study should be conducted in future to collect first-hand empirical data for calibrating the parameters and validating the simulation results.

2. Besides E-government services, new paradigms of public services are emerging, amongst which open-government attracts the attention of both scholars and practitioners. If we say the ultimate purpose of E-government is to prompt efficient services, then open-government goes further in the way to prompt transparent government and actively invites not only citizens but also private sectors to participate in the service delivery process. New paradigms of public-private collaboration on public affairs and new supporting initiatives are needed, while the application of agent-based approach is expected to contribute new knowledge and insight.

3. In this thesis, we only assume a single public administration, thus the hierarchical integration of public services between central and local governments, as well as the vertical integration among different functioning departments are out of the scope of modelling. However, these two aspects are important in E-government service development and should be explored further and deeper in future.

4. Co-evolvement between the public sector and citizens could be another potential research direction. The public sector could be evolved based on the feedback from citizens in terms of evaluation criteria, which will further influence the citizens' evolvement and adaptation.

5. There are some further considerations that could be integrated into this framework, such as spatial concern and community structure. For citizens, spatial concern could be measured as the distance or time and scaled to fit into the current formulation. For service providers, this concern could be formalized as a location facility problem taking into account citizens' reflections, preferences and constraints. Community structure is particularly applicable to explore the service diffusion pattern when the structure of service providers is hierarchical and service receivers are scattered.

6. Each of the major stakeholders involved in this framework could be further generalized as an individual module and integrated as required in later service systems modelling. Especially the system of E-government service process proposed in this work could be generalized and interpreted with constraints into other service domains as isomorphic systems in future works.

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1. Refereed Journal

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4. Reviewed Conference Proceeding

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