Modeling and Simulation of Urban Socio-Technical Systems for Human-Centered Resilience Assessment

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Abstract
Since most of the industrialized countries nowadays rely mainly on service industry, the assessment of the resilience of such systems against disaster is an important issue for safety and security of today’s industrialized society. On the other hand, the service industry heavily depends on physical lifeline systems and is also highly dependent on demand from daily life in and around the urban area. For the purpose of the assessment of service systems, it is necessary to consider such aspects as well as the multi-interdependency lying behind urban socio-technical systems. In this paper, we present the modeling of urban socio-technical systems and show some simulation results based on this model.

Keywords –service systems resilience, multiple interdependency, human-centered assessment

1 Introduction
Service systems resilience is a crucial topic for safety and security today because most of the developed countries rely mainly on service industry. Service systems are built on lifeline systems and also depend on the demand from daily life. For the assessment of the service systems resilience, therefore, it is necessary to consider multiple interdependencies behind such urban socio-technical systems. This paper presents the modeling of the urban socio-technical systems as system of systems and to present simulation of recovery process from disaster damage and the assessment of its resilience based on the result.

2 Modeling of Urban Socio-Technical Systems
Our model of urban socio-technical systems consists of three sub-systems: lifeline infrastructures, service systems, and civic life. A schematic of this model is illustrated in Fig. 1. Six types of inter- and intra-subsystem dependencies can be defined by the combination of each subsystem.

![Fig. 1. Urban Socio-Technical Systems.](image)

2.1 Infra-Infra dependency
Several types of infra-infra dependency have been reported [1,2], however, we identified only two types of direct dependencies among different lifeline systems. Physical dependency is created when two or more components are physically connected or in mutual proximity where damage on one component can cause another physical damage on the other components. Functional dependency occurs when one lifeline system depends on the other to function. For most of life systems, electricity and information are required for functioning.

2.2 Service-Lifeline Dependency
Service activity and lifeline systems are interdependent each other. We summarized such dependencies as follows. Resource: Some service tasks require resources provided by lifeline systems. Transportation: Transportation of materials and people are necessary to do some tasks. Communication: Intra-organizational communication through telecommunication systems is usually required for service. Waste Disposal: It is periodically necessary to dispose of waste materials and water produced in the service activity. Operation and Monitoring tasks are required to keep lifeline systems functioning, that is, lifeline systems depend on service. Restoration: Restoration is necessary once lifeline systems are damaged.

2.3 Life-Lifeline Dependency
Our daily life is also heavily dependent on lifeline systems. Resource: Many daily life activities require resources from lifelines systems. Transportation: We usually move on foot, by private car, and public transportation. Waste Disposal: Waste of daily life needs to be disposed. Communication: We often communicate through telecommunication systems.

2.4 Service-Service Dependency
Service is usually provided by organizations, thus its structure can be modeled with PCANS model [3]. This dependency can described in terms of the combination of the different model components. Precedence: There is a temporal of service tasks, that is, some tasks are completed before other tasks begin. Commitment: A task requires certain resources that are provided by other tasks or lifeline. Assignment: Each agent such as a company has its own task for providing service products. Networks: Each agent has differential access to each other. Skills: Each agent has different abilities to use some resources to complete some tasks.

2.5 Life-Life Dependency
There are two types of dependency in this category. One is the dependency within a family, that is, how to divide limited resources into different tasks or activities in daily life. The other type is the resource conflict between different families.

2.6 Service-Life Dependency
Service and life is interdependent each other. While we cannot have comfortable daily lives without service, a service company cannot exist without consumers. In addition, we provide labour force to such a service company.
3 Simulation

In the implementation of the model, we need to consider two aspects, that is, system structure and process. We implemented system structure by network model and process by agent-based model. Lifeline networks are implemented as simple networks with nodes and links. The reachability of a node in the graph from any source node determines the availability of the lifeline at that node. Service agents, consumers, and restoration agents move along the road and transportation networks following their purpose. Each consumer agent has preference of service and values some specific service over others, which enable to assess individual resilience against disaster. The general simulation settings are shown in Table 1. The initial status of the network and the deployment of agents are shown in Fig. 2.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Initial Settings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of the network</td>
<td>5×5 lattice</td>
</tr>
<tr>
<td>Number of lifeline systems</td>
<td>12</td>
</tr>
<tr>
<td>Number of Consumer Agents</td>
<td>300 in 70 families with 25 daily activities</td>
</tr>
<tr>
<td>Number of Service Agents</td>
<td>300 with 150 tasks</td>
</tr>
<tr>
<td>Number of Restoration Agents</td>
<td>180 in 9 tasks</td>
</tr>
<tr>
<td>Damages</td>
<td>60% randomly damaged</td>
</tr>
<tr>
<td>Simulation Period</td>
<td>60 steps (days)</td>
</tr>
</tbody>
</table>

3.1 Assessment of Resilience

We adopted Vugrin’s framework for assessing resilience [4] and assess the service systems resilience as the capacity for recovery under the optimized recovery plan in consideration of recovery effort (RE) that is obtained by Genetic Algorithm. In addition, we introduce three different criteria corresponding to the function of each subsystem: rate of restoration from the damage (RR), achievement of service activities (AS), and satisfaction of consumers (SC). The objective function shown in Eq. 1 is used for the optimization.

\[ (\alpha RR + \beta AS + \gamma SC) - \sigma RE \quad \text{Eq.(1)} \]

3.2 Results

We can obtain resilience triangles from simulation results, which enable various resilience analyses, for example, using different assessment criteria and simulation conditions. Fig. 3, for example, shows resilience triangles of the service achievement under different damage quantity. We can see that the area of the triangle becomes smaller as the damage decreases.

Fig. 4 shows the resilience of service achievement and customer satisfaction obtained with different objective functions for the GA, i.e. under different restoration plans. The value of resilience is obtained by calculating the area of corresponding resilience triangle. The graph shows that in both cases, the resilience becomes the lowest when only RR was considered ( \( \beta = \gamma = 0 \)), which suggests that it is useless to restore lifeline systems blindly without considering service activities and customer satisfactions. In other words, human-centred restoration is indispensable for urban socio-technical systems. The result also shows that the best resilience can be obtained when all three criteria are considered equally, which suggests that it is important to balance between speed and effectiveness in the planning of restoration.

4 Conclusion

We present modeling of urban socio-technical systems focusing on multiple dependencies in and among its subsystems for the human-centred resilience assessments. We also present simulation of the recovery process from the damage on lifelines as well as several results of resilience assessment. The analysis results suggest a simple outcome that human-centred restoration planning is important for the effective recovery. The next challenge using this model is to examine the effect of individual differences on service systems resilience.

References