Exploring Quantitative Evaluation Criteria for Service and Potentials of New Service in Transportation: Analyzing Transport Networks of Railway, Subway, and Waterbus

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Abstract: This paper explores *quantitative evaluation criteria* for service and *potentials* of new service from the transportation viewpoint. For this purpose, we analyze transport networks of railway, subway, and waterbus, and have revealed the following implications: (1) *efficiency* criterion proposed by Latora [7, 8] and *centrality* criterion in the complex network literature can be applied as quantitative evaluation criteria for service in a transportation domain; and (2) new services are highly embedded among networks, *i.e.*, the analyses of the combined networks have the great potential for finding new services that cannot be found by analyzing a single network.
Keywords: service science, evaluation criteria, transportation, complex network

1 Introduction

Service science, management and Engineering (SSME) [4, 5] is a new research field that stresses an importance of addressing *service* from the viewpoint of *science* in order to clarify effects of services based on experience and intuition. This approach has the great potential of utilizing or bringing out the hidden experience and vague intuition in human. In spite of this potential, however,

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the following significant problems have not yet solved in SSME: (1) it is generally difficult to evaluate effects of service precisely, *i.e.*, services is hard to be measured quantitatively; (2) it is also difficult to find new services which are useful and have a high value in a market.

To tackle these problems, this paper aims at exploring quantitative evaluation criteria for service and proposing an approach to find new services. As the first step towards our goal, this paper starts by narrowing arguments down to the transportation domain such as railway, subway, and waterbus, and analyze characteristics of the network from the viewpoint of a *complex network* [1, 11, 12]. We focus on transport networks because transportation is indispensable service in our life.

This paper is organized as follows. The next section starts by explaining major measures in a complex network literature, and Section 3 describes the outline of the transport network analysis. The quantitative evaluation criteria for service and an approach to find new services are discussed in Section 4. Finally, our conclusions are given in Section 5.

2 Measures

Measures characterizing networks are divided into two types, *weighted* or *un-weighted* networks. According to Sienkiewicz, the former network is the physical infrastructure network in Euclidean space, while the latter network is the unipartite network [10]. In these two network types, many measures were proposed to evaluate networks. Some of measures are described below.

2.1 Measure in weighted network: Efficiency

The measure called *efficiency* [7, 8] was proposed to consider the physical distance for weighted networks, which is defined as the following equations.

$$E(\mathbf{G}) = \sum_{i \neq j \in \mathbf{G}} \varepsilon_{ij} \tag{1}$$

$$\varepsilon_{ij} = \frac{1}{d_{ij}} \tag{2}$$

In these equations, $\mathbf{G}$ is a network, ε_{ij} is the efficiency that is inversely proportional to the d_{ij} representing the geographical distance along the shortest path between vertex i and j (if there is no path to connect vertex i and j, d_{ij} is infinity). Global efficiency, E_{glob}, and local efficiency, E_{loc}, are obtained from Eqs. (3)(4) respectively with above E.

$$E_{glob} = \frac{E(\Gamma)}{E(\Gamma_{id})} \tag{3}$$

$$E_{loc} = \frac{1}{N} \sum_{i \in \Gamma} \frac{E(\Gamma(\nu_i))}{E(\Gamma_{id}(\nu_i))} \tag{4}$$

In these equations, Γ and $\Gamma(\nu_i)$ denotes the whole network with N vertices and a sub-graph composed of neighbor vertices of vertex i, respectively. Subscript *id* means idealized network comprised of complete graph among all vertices belonging. Thus, d_{ij} of any ideal network becomes direct distance in Euclidean space. It is clear by definition that global or local efficiency ranges from 0 to 1. The efficiency becomes 1 when all pairs of vertices are connected by the straight links in the Euclidean space.

2.2 Measure in un-weighted network: Centrality

Among several measures of *centrality* [2, 3, 6], *eigenvector centrality* is a measure of an importance of a vertex in a network in terms of topology. This definition becomes eigenvector equation as is shown in Eq.(5) and the vector $\mathbf{x}$ is called as eigenvector centrality. The λ and $\mathbf{x}$ in Eq.(5) stand for the maximum eigenvalue and corresponding eigenvector of an adjacent matrix, $\mathbf{A}$, respectively. Applying the eigenvector centrality to the adjacent matrix, the rank of centrality of stations can be obtained. Since the un-weighted network is comprised of complete graph based on the lines, the rank evaluates an importance of stations from the viewpoint of topology of train or bus lines.

$$\mathbf{x} = \frac{1}{\lambda} \mathbf{A} \mathbf{x} \tag{5}$$

3 Analysis

3.1 Overview

Our previous research [9] analyzed five transport networks, *i.e.*, one railway, three subways, and one hypothetical waterbus line in terms of complex network using the measures described in the previous section. This analysis was typically performed around Tokyo Metropolitan, because Tokyo is the most populated area in Japan. For subway, in particular, we analyzed not only the subway network in Tokyo but also those in Osaka and Nagoya, both of them are major cities in Japan.

Furthermore, the location of stations and links in the railway and subways were based on the real date, while those of waterbus is hypothetical due to the fact that its network does not exist now. We, however, consider the waterbus because it provides an efficient transport network from the viewpoint of modal shift or reducing the commuter rushes. To show such effects, several projects are under way [13], which employs the combination of the river system and ships as a substitute of road network suffered from chronic traffic congestion.

3.2 Evaluation criteria

As evaluation criteria, we employed the measures described in Section 2, *i.e.*, (1) global and local efficiencies from the weighted network viewpoint; and (2) eigenvector centrality from the un-weighted network viewpoint. The detailed meaning of these criteria are summarized as follows. Note that geographical distance between two stations is employed as the weight in the network for the efficiently criterion[1].

- **Global efficiency** measures the path length of any pair of stations in the network by comparing that in the ideal network in which any pair of stations is connected by straight line in the Euclidean space. This measure evaluates the network from the viewpoint of the *shortest path length*.
- **Local efficiency** measures the number of alternative paths of any pair of stations in the network by comparing that in the ideal network. This measure evaluates the network from the viewpoint of *redundancy of paths*.
- **Eigenvector centrality** measures the numbers of connected stations, which includes not only directly connected stations but also near stations (*e.g,*, stations which are closed to connected stations).

Finally, efficiency is calculated by the Warshall-Floyd shortest path algorithm applying adjacent matrix, while the eigenvector centrality is calculated by Jacobi method.

4 Discussion

4.1 Efficiency

4.1.1 Unit network analysis

Our previous research [9] calculated the efficiency as shown in Table 1. In this table, N, E_{glob}, E_{loc}, RW, SW, and WB indicate the number of stations,

[1] The trip time can be considered another important factor as weight. However, the transferring time from one line to another line is not the same according to the type of train, such as express train or local train. From this fact, our previous research employed the geographical distance not trip time.

the global efficiency, the local efficiency, railway, subway, and waterbus, respectively. In addition to five transport networks and one combined network of JR and subway in Tokyo, results for the subway in Boston obtained from literatures [7, 8] is also described in the table. Combination network above means the transport networks of JR and subway in Tokyo, those of which are combined at the stations. There are 37 stations that JR railway and subway in Tokyo have in common.

From Table 1, the global efficiency, E_{glob}, indicates the large efficiency around 0.7, which means that the public transport networks in real world is about 30% less efficient than the ideal network. The local efficiencies, E_{loc}, on the other hand, are extremely small except for waterbus network. Specifically, the local efficiencies of subway in Osaka and Nagoya are 0, which means that triangle comprised of three adjacent stations does not exist at all, *i.e.*, the networks of subway in Osaka and Nagoya does not have redundant paths. When such triangle exists, passengers can circumvent the station or the link with another path in triangle even if one of three stations or links composing a triangle is damaged. Thus, the triangle in the transport network leads to a redundancy. In comparison with these small E_{loc}, that in waterbus network is relatively large, which indicates that waterbus network has a high redundancy.

It should be noted here that a high redundancy has the great potentials of providing passengers *many services*, *e.g.*, passengers can select alternative paths in terms of minimizing time or costs. Alternative paths also contributes to providing business chances in transfer areas, *e.g.*, shops or stores in transfer areas. However, these services are based on high global efficiency because the network with the low global efficiency does not have many direct routes which prevent passengers from selecting such network. From this viewpoint, the following implications are revealed: (1) both high global and local efficiencies are required to increase business chances; and (2) the waterbus network that has high global and local efficiencies has the potentials of providing business chances in comparison with other public transport networks.

Table 1 Global and local efficiencies in five transport networks

Mode*)	N	E_{glob}	E_{loc}
JR(RW)	371	0.78	0.033
Tokyo(SW)	211	0.70	0.024
Osaka(SW)	100	0.72	0
Nagoya(SW)	82	0.80	0
Boston(SW)[7][11]	124	0.63	0.030
JR(RW)+Tokyo(SW)	544	0.75	0.030
Tokyo(WB)	24	0.77	0.20

*) RW:Railway, SW:Subway, WB:Waterbus

4.1.2 Combined network analysis

Previous section shows the high potential of the waterbus network, but what should be noticed here is that the business chances provided by this potential depends on the number of passengers. Considering the fact that the numbers of passengers in railway and subway is quite larger than that in waterbus, the waterbus network is hard to provide *big* business chances. From this fact, this section considers the network that combines the railway and/or subway networks with the waterbus network.

Our previous research [9] assumed that the waterbus stations can be identical with railway or subway stations when the distance between them is less than 500m. There were identical waterbus stations with stations of three in JR, six in subway in Tokyo, and seven in JR and subway combined network. Calculated measures on all combinations with the waterbus network are summarized in Table 2. This table indicates that the global efficiency, E_{glob}, is not affected by the combination with the waterbus network, while the local efficiency, E_{loc}, in the subway network and the combined network of JR and subway increases, even though the number of waterbus stations is very small. For example, E_{loc} in the subway network is 0.024 and it becomes 0.031 when the waterbus network connects.

This results revealed that an combination of the waterbus network with other transport ones has the potential of increasing business chances because the waterbus network contributes to increasing E_{loc} with keeping a high E_{glob}.

4.2 Centrality

4.2.1 Network analysis without waterbus

Table 3 shows the top 10 stations of a *centrality* in the combined network of JR and subway in Tokyo. In this table, k and x represent *degree* (*i.e.*, the number of links connected to a station) and *centrality* of each station, respectively. Although the positive correlation is observed between degree

Table 2 Global and local efficiencies with or without combining waterbus network

Mode	N	Without WB		With WB	
		E_{glob}	E_{loc}	E_{glob}	E_{loc}
JR	371	0.78	0.033	0.78	0.033
SW	211	0.70	0.024	0.70	0.031
JR+SW	544	0.75	0.030	0.75	0.033

and centrality, it does not need that the station with the higher degree has the higher rank in terms of centrality. Since the stations, such as Higashi-Nakano or Ryogoku, are not major stations (according to the census data, the ranks of these stations in the number of users are lower than 100), people living in and around Tokyo may feel peculiar about the rank in Table 3. The reason is that stations in the high rank have lines connecting to a number of another lines like Sobu and Oedo lines where the numbers of transfer stations of the two lines are the second and third highest values among the lines. Thus, passengers at stations with a high centrality can reach to most stations without changing trains.

Table 3 Eigenvector centrality in the top 10 stations

Rank	Station Name	x	k
1	Shinjuku	0.200	164
2	Tokyo	0.171	167
3	Akihabara	0.161	120
4	Yoyogi	0.158	97
5	Iidabashi	0.148	126
6	Shimbashi	0.127	116
7	Ueno	0.120	126
8	Higashi-Nakano	0.115	71
9	Ryogoku	0.115	71
10	Kanda	0.115	85

From this analysis, a high centrality has the great potentials of increasing business chances because passengers do not want to increase transfer times but want to select stations that can reach to most stations without changing trains. This suggests that all stations in Table 3 have the potentials of providing business chances. However, stations except for Higashi-Nakano or Ryogoku have been already full growth, which means that it is difficult to find other business chances in such stations. In comparison with these stations, Higashi-Nakano or Ryogoku stations are important for business chances. From this viewpoint, the following implications are revealed: (1) the high centrality is required to increase business chances; and (2) stations that has the high centrality but not major or full growth (such as Higashi-Nakano or Ryogoku) have the potentials of providing business chances.

4.2.2 Network analysis with waterbus

For the same reason discussed in Section 4.1.2, this section also consider the network that combines the railway and/or subway networks with the waterbus network. Table 4 summarizes the centrality of stations to which the waterbus connects. The centrality of some stations improves by several dozen percent and the rank of the stations becomes higher drastically. For example, the centrality of Honjoazumabashi station in the subway network increases by 45% and its rank improves from 175 to 86 owing to the waterbus network.

Table 4 Eigenvector centrality with or without combining waterbus network

	JR		JR+WB		x
Station Name	x	Rank	x	Rank	Increase
Etchujima	0.035	158	0.038	156	7%
Ryogoku	0.085	51	0.086	39	1%
Asakusa	0.011	227	0.013	218	25%

	SW		SW+WB		x
Station Name	x	Rank	x	Rank	Increase
Ryogoku	0.134	31	0.137	16	2%
Asakusa	0.041	79	0.051	54	22%
Hamacho	0.024	162	0.029	88	24%
Honjoazumabashi	0.020	175	0.030	86	45%
Morishita	0.149	11	0.151	8	1%
Higashi-ojima	0.024	166	0.029	87	25%

	JR+SW		JR+SW+WB		x
Station Name	x	Rank	x	Rank	Increase
Etchujima	0.025	203	0.031	191	25%
Ryogoku	0.115	9	0.118	8	3%
Asakusa	0.041	140	0.047	131	14%
Hamacho	0.016	353	0.021	253	28%
Honjoazumabashi	0.015	370	0.020	260	36%
Morishita	0.065	78	0.068	74	5%
Higashi-ojima	0.016	357	0.021	252	28%

This results revealed that an combination of the waterbus network with other transport ones has the potential of increasing business chances because the waterbus network contributes to increasing the centrality of stations to which the waterbus line connects.

4.3 Quantitative evaluation criteria and new services

From the above analyses, the following implications have revealed:

- **Quantitative evaluation criteria:** The global and local efficiencies and centrality can be applied as quantitative evaluation criteria for service in a transportation domain. Specifically, the analyses suggests that both high global and local efficiencies and high centrality contribute to increasing business chances. This is because (1) the high global and local efficiencies provide not only mostly direct routes that promote passengers to select them but also alternative paths that can be selected by passengers in terms of minimizing time or costs; and (2) high centrality clarifies the stations that enable passengers to reach to most stations without changing trains. From the analyses, the waterbus network that has high global and local efficiencies has appeal for business from the efficiency viewpoint, while stations that has the high centrality but not major or full growth (such as Higashi-Nakano or Ryogoku) also have appeal for business from the centrality viewpoint.

- **An exploration of new services:** New services are highly embedded among networks, *i.e.*, the combined networks have the great potential for finding new services that cannot be found by analyzing a single network. Specifically, an combination of the waterbus network with other transport ones has the potential of increasing business chances because the waterbus network contributes to not only increasing E_{loc} with keeping a high E_{glob} but also increasing the centrality of stations to which the waterbus line connects. This is an approach to explore new services. Although an advertisement of the connection between waterbus and other transportation or a development of more smooth connection are indispensable to acquire business chances, new services can be introduced in the process of combining the waterbus network with other transport ones.

5 Conclusions

This paper explored *quantitative evaluation criteria* for service and *potentials* of new service from the transportation viewpoint. For this purpose, we analyzed transport networks of railway, subway, and waterbus, and have revealed the following implications: (1) *efficiency* criterion proposed by Latora [7, 8] and *centrality* criterion in the complex network literature can be applied as quantitative evaluation criteria for service in a transportation domain. Specifically, both high global and local efficiencies and high centrality contribute to increasing business chances; and (2) new services are highly embedded among networks, *i.e.*, the analyses of the combined networks have the great potential for finding new services that cannot be found in the single network. In our analyses, an combination of the waterbus network with other transport ones has the potential of increasing business chances.

However, these results have only been obtained from one domain, a transportation domain. Therefore, further careful qualifications and justifications, including the analysis of the results of other domains, are needed to generalize our results. Such important directions must be pursued in the near future in addition to the following future research: (1) an exploration of new quantitative evaluation criteria for service science not by employing measures that have been proposed so far; (2) an investigation of both efficiency and centrality introducing the flow in the network, *i.e.*, the number of passengers; (3) an investigation of effects of different hypothetical waterbus networks clarifying differences of features between railways and waterbus; and (4) an exploration of conditions of the networks that increase the global and local efficiencies and centrality.

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