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Mitigating Search and Transfer Barriers: Network Structural Approach

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Abstract

In this paper, two performance indexes measuring the ability of searching and transferring information within a network are proposed. Based on the performance indexes, the research collaboration network of a large electronics company is optimized. All the optimized networks show higher performance than the original network does. The analysis on the optimized networks suggests that mitigating search and transfer barriers for collaboration at the same time is not entirely trade-off. To conclude, I argue that an organization should reengineer its collaboration network as follow in order to achieve higher collaboration performance: (1) having an intermediary cluster which is highly specialized in bridging two units and (2) polarizing the strengths of ties connecting different units.

Keyword: collaboration barrier, optimization, network analysis, organization

1. Background

Large organization consists of several units inside. Each unit collaborates with each other. However, not all the units are interconnected for collaboration. Some reach out to seek advices rather than give away their knowledge, while others do in the reverse pattern. Some units actively communicate with others, while others are almost isolated in the network. Many researchers have analyzed the characteristics and structure of such collaboration networks. However, there seems less interest in finding an optimal collaboration network and how to reengineer a current network to construct better performing collaboration network.

Accordingly, the followings are three main questions to be answered in this paper. (1) How can the performance of a collaboration network be measured? (2) How can constraints of network rearrangement be quantitatively modeled? (3) How can we optimize a collaboration network and how much is the performance improved by the optimization? After answering these questions, I would discuss managerial implications from the experiment.

For the dataset used for reengineering, a large electronics company's research network was given. The company's research network has 41 units. Units are connected to each other through directional ties. It means that there is a distinction between knowledge giver and seeker. The strength of each tie ranges from 2 to 14. Strength 2 represents the weakest connection and 14 stands for the strongest one. Exhibit 1 visualizes the network.

2. Research Framework

In order to optimize the network, quantitative index for measuring performance is required. Constraints over the optimization are also needed to be able to perform the optimization. Last, detailed optimization algorithms should be clarified.

a. Developing measurements of collaboration performance

There are four types of collaboration barriers: hoarding, not-invented-here problem, search problem and transfer problem.[1] Among the four, motivational barriers such as hoarding and not-invented-here problem are out of scope of this paper. This paper is focused on alleviating non-motivational barriers – search and transfer problems – by reengineering given network. However, search and transfer problems require different sets of solutions in terms of network structure. Having many weak ties is good at solving search problems. On the other hand, strong ties are better for transferring complex knowledge.[2] Therefore, with fixed total strength of ties, improving both search and transfer problem can be basically assumed as a trade-off problem.

Consequently, two types of performance measurements are developed for search and transfer problem, respectively. First, a unit can access to more information if it can reach more number of units. Therefore, I argue that performance of solving search problems (hereinafter SPI, Search Performance Index) can be measured as the average number of neighbors each unit has. In addition, neighbors' neighbors can be helpful. However, it should be less significantly counted for the aggregate performance index. I decided to designate the strength of ties divided by 14 (the maximum of strength) as the depreciating factor, because the stronger the tie is, the more probable neighbors can introduce their own neighbors.

On the other hand, the performance of solving transfer problems (hereinafter TPI, Transfer Performance Index) is related to the strength of ties rather than the connectivity. Total strengths around a unit are first summed. Then, strengths around the neighbors are totaled and depreciated by the strength of the tie between the original unit and the neighbor. As a result, the following formulas summarize the two measurements. They will be used as a goal function for optimizing a collaboration network.

[1] Morten Hansen, Collaboration: How Leaders Avoid the Traps, Create Unity and Reap Big Results, Harvard Business School Press
[2] Morten Hansen, The Search-Transfer Problem: The Role of Weak Ties in Sharing Knowledge across Organization Subunits, Administrative Science Quarterly, 44 (1999): 82-111

$$\mathrm{SPI} = \sum_i (n_i + \sum_j n_j s_{ij})$$

$$\mathrm{TPI} = \sum_i (\sum_j (s_{ij} + \sum_k s_{ij} s_{jk}))$$

$$\left(\begin{array}{c} i : \text{a unit} \\ j : i\text{'s neighbors} \\ k : i\text{'s neighbors' neighbors} \\ n_i : \#\text{ of neighbors of unit } i \\ s_{ij} : \text{Strength between } i \text{ and } j \end{array} \right)$$

Exhibit 2 illustrates the example of SPI and TPI calculations.

b. Constraints of network reengineering

If there is no constraints, optimization has no practical meaning. That is, having all units connected each other through the strongest ties is meaningless. In this paper, two constraints are placed to situate the environment of limited resources.

First constraint is the total sum of strengths of given network. In the real world, the stronger the tie between two units is, the more efforts two units have to input. In other words, strength can be regarded as resource for collaboration. Therefore, it is reasonable to fix the total sum of strengths.

Second constraint is the total number of connections in the given network. Not only the strength of ties but also the number of connections maintained within a network represent resources an organization can utilize. As mentioned above, it is meaningless to have an implication such as “increase the number of links by 300% in order to better collaborate.”

c. Algorithms for finding better collaboration network

Resources are fixed so far. However, building a network with given resources – total sum of strengths and total number of ties – from the scratch is pointless. This paper particularly aims to optimize an existing network of an electronics company. Therefore, optimization results should relate to the given network, so two approaches to find better collaboration network are devised.

First approach is link-based optimization. This algorithm rearranges connections, while preserving the strength of each link. It picks an edge first, and it simulates the cases of moving the edge to somewhere else. After comparing all possible moves, it finally decides where the edge should be in order to achieve the maximum of a given goal function. This process is iterated over all edges in the given network. This whole process is a large iteration. If the goal function is not increased by 10% after every large loop, the optimization stops. This algorithm stands for the situation a company can manage whether a connection between units exists or not. The following formulates this process.

```
Iterate if the goal function is not increased by 10%:
    Iterate over all edges within the network:
        (1) Pick an edge
        (2) Move it so that the highest increase of the goal function can be achieved
```

Second algorithm is strength-based optimization. This method redistributes strengths within a network, preserving the connectivity of the network. It selects a pair of edges instead of an edge at the beginning. Then, it calculates which combination of strengths of the two edges most increases the goal function. This process is looped over the entire pairs of edges. This whole process is a large iteration like the link-based algorithm. If the goal function is not increased by 10%, the optimization is finalized. This approach symbolizes the context that a company is able to encourage or discourage each unit to enhance the existing connections. The following conceptualizes this algorithm.

```
Iterate if the goal function is not increased by 10%:
    Iterate over all pairs of edges within the network:
        (1) Pick a pair of edges
        (2) Find the distribution of strengths which most increases the goal function
```

Consequently, the research framework of this paper is summarized in Table 1. Optimized network #1 will be generated by setting SPI as the goal function of optimization and using link-based algorithm. Optimized network #2, #3 and #4 are also generated according to the table.

Algorithm / Goal Function	Link-based approach	Strength-based approach
SPI	Optimized Network #1 (ON#1)	Optimized Network #3 (ON#3)
TPI	Optimized Network #2 (ON#2)	Optimized Network #4 (ON#4)

Table 1. Research framework and output plans

3. Experiment Results and Analysis

a. Performance index of the original network

Based on developed indexes, performance of the original network data was measured. The values will be a point of reference to the performance indexes of optimized networks. Network data is presented as a matrix in Exhibit 3 (a).

$$\mathrm{SPI}_{\mathrm{original}} = 964.5$$
$$\mathrm{TPI}_{\mathrm{original}} = 527.3$$

b. Link-based algorithm optimization results[3]

The common attribute of the two results is high centrality. Almost all units can reach three units which can reach every unit. The three units which play a role of central nodes in the new graphs are the ones belonging to one of clusters in the original network. Exhibit 4 visualizes the highly centralized network structure. The different thing between the two is the distribution of strong ties. In the graph optimized

[3] Network data generated by link-based algorithm are presented in Exhibit 3 (b) and (c). Exhibit 3 (b) is optimization result by setting SPI as the goal function and the goal function of Exhibit 3 (c) is TPI, respectively.

based on SPI, strong ties are pointing from central nodes to peripheral ones. On the other hand, there is no inclination of strong ties in the network optimized based on TPI.

c. Strength-based algorithm optimization results[4]

Two results using strength-based optimization quite resemble each other. Two features to note are polarization of strength and monopolization of strong ties. As the given network was optimized, most ties became either 14, the strongest, or 2, the weakest. Besides, most 14-strength ties belong to a few units, which implies that a few units having many strong ties are better for achieving higher SPI and TPI than many units having a few strong ties.

Compared to the link-based algorithm, strength-based optimization increases the total SPI and TPI. However, it significantly decreases SPI and TPI of some individual units, while the link-based algorithm increases individual units' indexes as well as collective index. (Exhibit 5, 6)

d. Performance improvements

In general, optimization achieved increased search performance (SPI) by 9.3% - 268%. For transfer performance, the increase is from 24.0% to 185.1%. (Exhibit 7)

In detail, all optimized networks show higher performance in transfer than the original network, even if they are optimized based on SPI, and vice versa. It implies that SPI and TPI are not in a perfect trade-off relationship. Rather, both indexes can be improved simultaneously. In terms of optimization method, the link-based algorithm achieves better performance than the strength-based algorithm.

4. Discussion and Conclusion

a. Implication

Above all, search and transfer problems could be alleviated at the same time with fixed resources. To do that, an overarching central unit or cluster should be established. That is, a unit highly specialized in

[4] Exhibit 3 (d): Optimized network based on SPI using strength-based algorithm
Exhibit 3 (e): Optimized network based on TPI using strength-based algorighm

information intermediary job is helpful for solving both search and transfer problems. When selecting units for the central intermediary position, an organization management team should look at the clusters already existing in the current network. For search problems particularly, most units just need to maintain a strong relationship towards one of central units. It means that individual peripheral units should not hesitate to ask one of central units about information it is searching for. Meanwhile, the central units should be aware of what is going on within the organization, so that it can redirect inquiries to the appropriate unit. The central units do not have to hold deep knowledge on every issue. It just needs to know who knows what.

Strength of the relationship between units is another issue. The implication is that strong relationship should be stronger and weak one has to be weaker. That is, the effort spent on maintaining relationship should be focused. Strength can be interpreted in many ways in the real world. If strength represents frequency of contact in an organization, the organization should boost frequent relationship to make it more frequent. Monopolization of strong relationship by a few units is also important. To make the units capable of holding many strong ties, an organization may have to supply more human power to the units.

b. Conclusion

The goal of this paper was to investigate how to overcome search and transfer collaboration barriers in a systematic way. Network structural approach was taken here. To achieve the goal, measurements of search and transfer performance were developed first. Based on these indexes, a real company's research network was optimized. By generalizing the analysis of the optimization results, I conclude that the following items are helpful for lowering search and transfer problems in the context of collaboration.

1) Have a central unit or cluster bridging different two units.
2) Focus on currently strong relationship rather than try to make weak relationship strong.

5. Limitation and Future Work

a. Limitation

First of all, the fundamental assumption of this paper is that organization headquarters can alter or at least affect the links between units. Reengineering the collaboration network charges an organization with costs such as confusion, conflict over information gate-keeping power among units and risk from increased vulnerability. If the cost overwhelms the estimate of benefit, the organization would not rearrange its collaboration network.

Another limitation is that there are many other factors affecting the real world collaboration performance. For example, one factor is the type of knowledge each unit is holding. If the links between units naturally emerged because of the type of knowledge itself, it would be much harder to reconfigure the network artificially.

Lastly, the proposed networks are not global optima, rather they are local optima. The current algorithms are searches for an optimum in an incremental way. They never bear any little decrease of the goal function at any moment. To find a global optimum or at least better local optimum, fundamental algorithm should be revised. Besides, the proposed results are path-dependently optimized. The optimization processes were performed in a certain order. If the order had been different, the detailed results could have been different, too. However, the overall structure of optimized networks would not be different. Therefore, connectivity and big picture of the results rather than specific unit numbers should be focused.

b. Future work

First of all, applying this approach to other datasets is desirable to see if the current result is organization-specific. Also, in this paper, only two constraints limiting total number of links and total sum of strength in the given whole network are in place. I hope to introduce new constraints in the future. Limiting the number of links per unit and total strength per unit would make the results more realistic.

Exhibit 1. Network graph of the dataset[5]

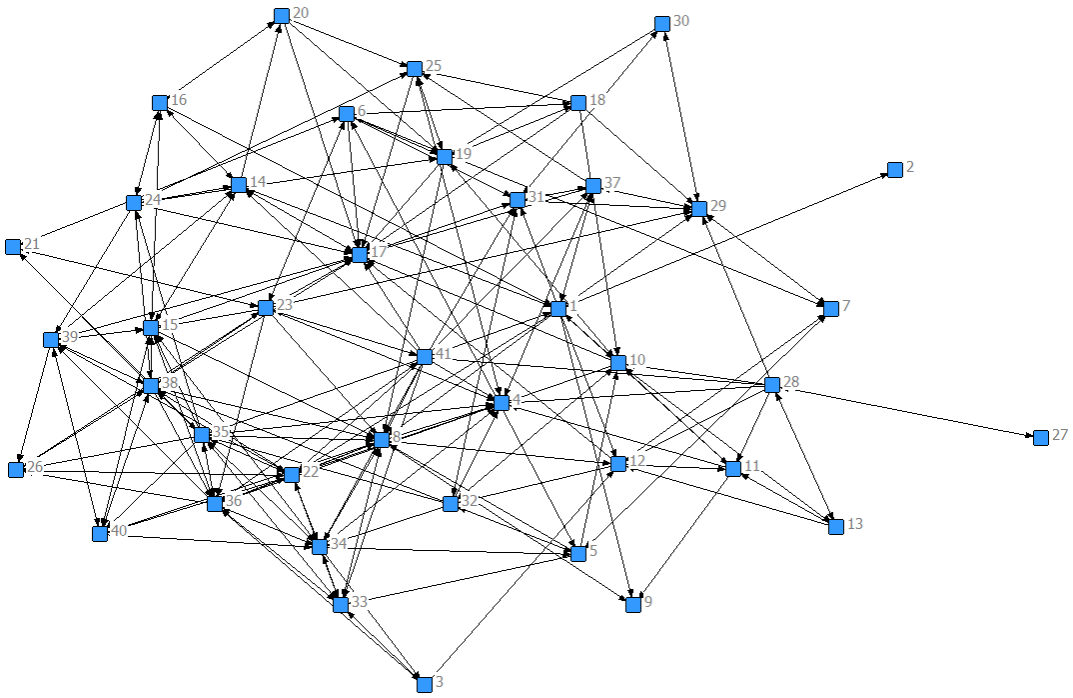
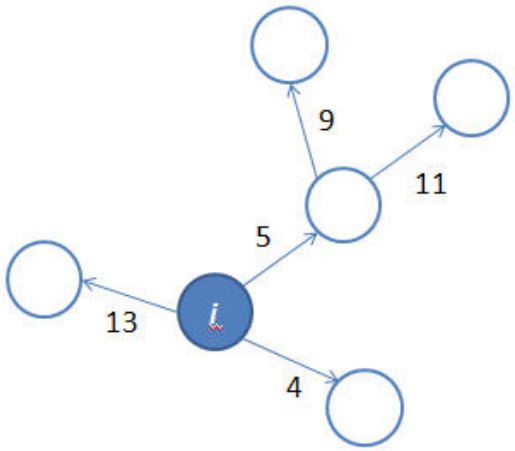


Exhibit 2. Examples of calculating SPI and TPI



# of direct neighbors

Depreciating factor

# of neighbor's neighbors

$$SPI_i = 3 + \frac{5}{14} \times 2$$

$$TPI_i = \left(\frac{13}{14} + \frac{4}{14} + \frac{5}{14}\right) + \frac{5}{14} \times \left(\frac{9}{14} + \frac{11}{14}\right)$$

Sum of strengths around itself

Sum of strengths around its neighbor

[5] The graph is generated by the computer program, UCINet.

Exhibit 3 (a). Original Network

Unit #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
1	.	14	.	.	.	.	.	5	5	8	2	2	.	.	.	.	.	.	.	.	.	3	.	.	.	.	.	.	2	.	4	.	.	.	.	.	9	.	.	.	.
2	14	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
3	.	.	.	.	.	.	.	.	.	.	.	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	4	.	.	.	.	.	.	.	.
4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	13	.	.	.	.
5	.	.	.	.	.	14	14	2	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	10	6	8	.	.	.	.	.	.	.
6	.	.	.	.	14	.	14	.	.	.	.	.	.	.	.	.	2	2	2	.	9	.	4	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.
7	.	.	.	.	14	14	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.
8	.	.	.	2	.	.	.	.	8	.	.	3	.	.	.	.	.	.	.	.	.	4	.	.	.	.	.	.	.	.	.	.	14	8	.	11	.	.	.	.	.
9	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
10	8	.	.	.	.	.	.	.	.	.	10	.	10	.	.	.	7	.	10	.	.	9	.	.	.	.	.	.	.	.	.	10	.	.	.	.	.	.	.	.	.
11	.	.	.	4	.	.	.	.	4	8	.	14	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
12	.	.	.	.	.	.	5	.	.	.	8	.	.	.	.	.	7	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.
13	.	.	.	.	.	.	.	.	.	6	4	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	10	.	.	.	.	.	.	.	.	.	.	.	.	.
14	3	.	.	.	.	.	.	.	.	.	.	.	.	.	14	14	14	.	.	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
15	.	.	.	.	.	.	.	7	.	.	.	.	.	14	.	14	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	11	.	7	.	.	.	8	.
16	6	.	.	.	.	.	.	.	.	.	.	.	.	14	14	.	.	.	.	2	.	.	.	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
17	.	.	.	.	.	.	.	.	.	.	.	.	.	7	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.
18	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	3	.	14	.	.	.	.	.	3	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.
19	.	.	.	.	.	.	.	2	.	6	.	.	.	.	.	.	12	11	.	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
20	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	9	.	9	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
21	.	.	.	.	.	10	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
22	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	9	9	9	.	5	5	5	.
23	.	.	.	2	.	9	.	2	.	.	.	.	.	.	2	.	5	.	.	.	7	.	.	.	.	3	.	.	2	.	.	.	.	.	.	2	.	9	.	.	3
24	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	2	5	.	2	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	2	12	.	.
25	.	.	.	5	.	.	.	.	.	.	.	.	.	.	.	.	5	.	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
26	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	.	.	.	.
27	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	14	.	.	.	.	.	.	.	.	.	.	.	.	.
28	.	.	.	6	.	.	.	.	.	2	2	7	8	.	.	.	.	.	.	.	.	.	.	.	.	.	14	.	2	.	.	.	.	.	.	.	.	.	.	.	9
29	.	.	.	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	14	14	.	.	.	.	.	5	.	.	.	.
30	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	.	.	14	.	14	.	.	.	.	.	.	.	.	.	.
31	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	14	14	.	8	.	.	.	.	11	.	.	.	.
32	.	.	.	9	10	.	.	.	.	10	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	13	.	.	9	9	.	.	13	.	.	.
33	.	.	.	.	.	.	.	14	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	14	14	14	.	.	.	.	.	.
34	.	.	3	4	9	.	.	5	.	.	.	.	.	.	6	.	.	.	.	.	.	12	.	.	.	.	.	.	.	.	.	.	8	.	14	14	.	.	.	.	.	.
35	.	.	.	7	.	.	.	2	.	.	.	.	.	.	2	.	.	.	.	.	2	9	.	2	.	4	.	.	.	.	.	.	12	14	.	14	.	6	.	2	.
36	.	.	7	8	.	.	.	12	.	.	.	.	.	.	.	.	.	.	.	.	.	11	.	.	.	2	.	.	.	.	.	.	14	14	14	.	.	.	2	.	12
37	5	.	.	12	.	.	.	.	.	.	.	.	.	.	.	.	6	.	.	.	.	.	.	.	2	.	.	.	7	.	10	.	.	.	.	.	.	.	.	.	.
38	.	.	.	.	.	.	.	3	.	.	.	.	.	.	2	.	3	.	.	.	2	12	6	.	.	7	.	.	.	.	.	.	.	.	10	7	.	.	14	14	.
39	.	.	.	.	.	.	.	.	.	.	.	.	.	5	7	.	6	.	.	.	.	6	.	.	.	3	.	.	.	.	.	.	.	.	.	.	.	14	.	14	.
40	.	.	.	.	.	.	.	5	.	.	.	.	.	.	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	11	.	.	.	14	14	.	.
41	2	.	.	2	.	.	.	5	.	.	.	.	.	6	.	.	2	.	.	.	.	2	2	.	.	.	.	.	.	.	2	.	2	5	5	2	2	.	.	.	.

Exhibit 3 (b). Goal function: SPI / Algorithm: Link-based

Unit #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	14	2	.	.	13	.	.	.
2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	14	8	.	.	12	.	.	.
3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	10	2	.	.	14	.	.	.
4	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	14	14	.	.	14	.	.	.
5	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	14	9	.	.	14	.	.	.
6	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	14	8	.	.	12	.	.	.
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35	3	10	6	7	5	5	2	2	2	3	2	5	3	2	2	2	3	2	3	3	2	5	6	2	2	4	2	4	.	6	2	2	.	14	.	14	7	6	5	2	7
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Exhibit 3 (c). Goal function: TPI / Algorithm: Link-based

Unit #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	7	4	.	.	.	.	.
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35	6	4	2	7	3	13	2	2	2	3	14	6	14	10	2	2	9	14	6	2	5	9	2	2	2	5	3	2	12	3	3	2	12	14	.	14	14	6	14	2	10
36	5	7	7	8	14	5	14	12	4	6	10	3	8	2	10	8	9	9	2	3	7	11	14	7	6	2	10	14	2	10	14	2	14	14	14	.	3	8	2	2	12
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Exhibit 3 (d). Goal function: SPI / Algorithm: Strength-based

Unit #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
1	.	2	.	.	.	.	.	14	2	14	2	2	.	.	.	.	.	.	.	.	.	14	.	.	.	.	.	.	2	.	2	.	.	.	.	.	3	.	.	.	.
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36	.	.	2	2	.	.	.	14	.	.	.	.	.	.	.	.	.	.	.	.	.	14	.	.	.	2	.	.	.	.	.	.	2	14	14	.	.	.	14	.	14
37	14	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	2	.	.	.	2	.	2	.	.	.	.	.	.	.	.	.	.
38	.	.	.	.	.	.	.	13	.	.	.	.	.	.	5	.	2	.	.	.	2	13	14	.	.	2	.	.	.	.	.	.	.	14	14	.	.	14	2	.
39	.	.	.	.	.	.	.	.	.	.	.	.	.	2	14	.	2	.	.	.	.	14	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	14	.	2	.
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41	14	.	.	2	.	.	.	6	.	.	.	.	.	2	.	.	2	.	.	.	.	6	14	.	.	.	.	.	.	.	2	.	2	14	14	14	2	.	.	.	.

Exhibit 3 (e). Goal function: TPI / Algorithm: Strength-based

Unit #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
1	.	2	.	.	.	.	.	14	2	2	2	2	.	.	.	.	.	.	.	.	.	14	.	.	.	.	.	.	2	.	2	.	.	.	.	.	3	.	.	.	.
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23	.	.	.	2	.	2	.	14	.	.	.	.	.	.	14	.	2	.	.	.	2	.	.	.	.	2	.	.	2	.	.	.	.	.	.	14	.	14	.	.	14
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34	.	.	14	14	14	.	.	14	.	.	.	.	.	.	14	.	.	.	.	.	.	14	.	.	.	.	.	.	.	.	.	.	14	.	14	14	.	.	.	.	.	.
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36	.	.	14	14	.	.	.	14	.	.	.	.	.	.	.	.	.	.	.	.	.	14	.	.	.	14	.	.	.	.	.	.	14	14	14	.	.	.	14	.	14
37	2	.	.	2	.	.	.	.	.	.	.	.	.	.	.	.	2	.	.	.	.	.	.	.	2	.	.	.	2	.	2	.	.	.	.	.	.	.	.	.	.
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39	.	.	.	.	.	.	.	.	.	.	.	.	.	2	14	.	2	.	.	.	.	14	.	.	.	2	.	.	.	.	.	.	.	.	.	.	.	14	.	14	.
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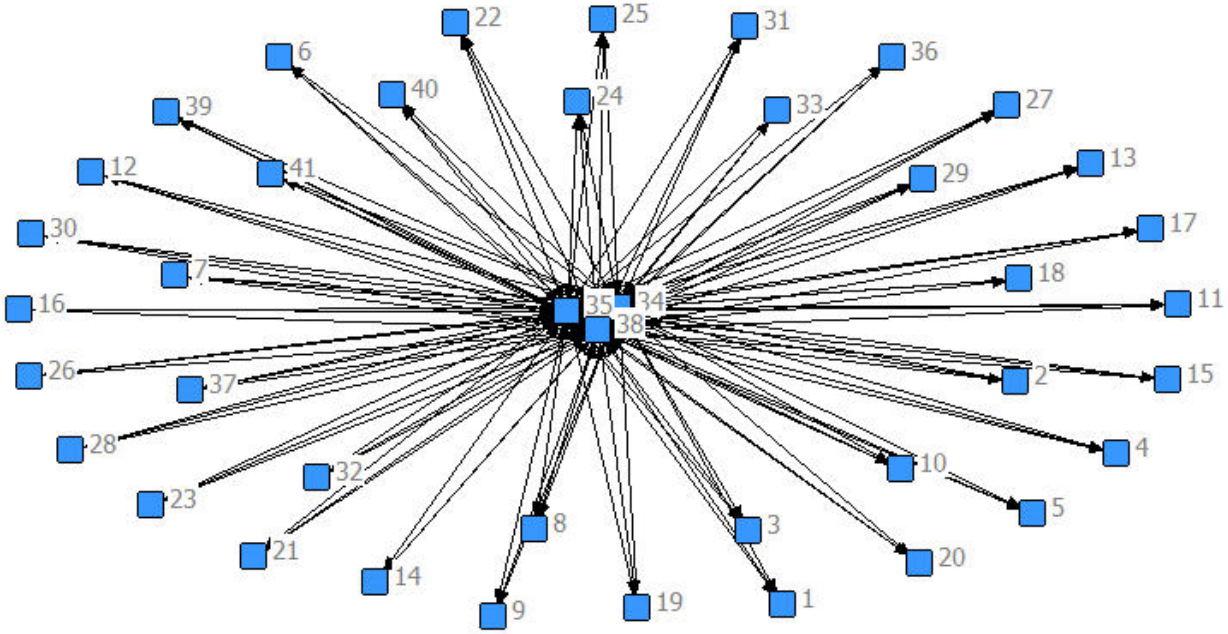
41	2	.	.	2	.	.	.	14	.	.	.	.	.	2	.	.	2	.	.	.	.	14	14	.	.	.	.	.	.	.	2	.	2	14	14	14	2	.	.	.	.

Exhibit 4. Network visualization

(a) Optimized Network #1 (Goal function: SPI, Algorithm: link-based)



(b) Optimized Network #2 (Goal function: TPI, Algorithm: link-based)

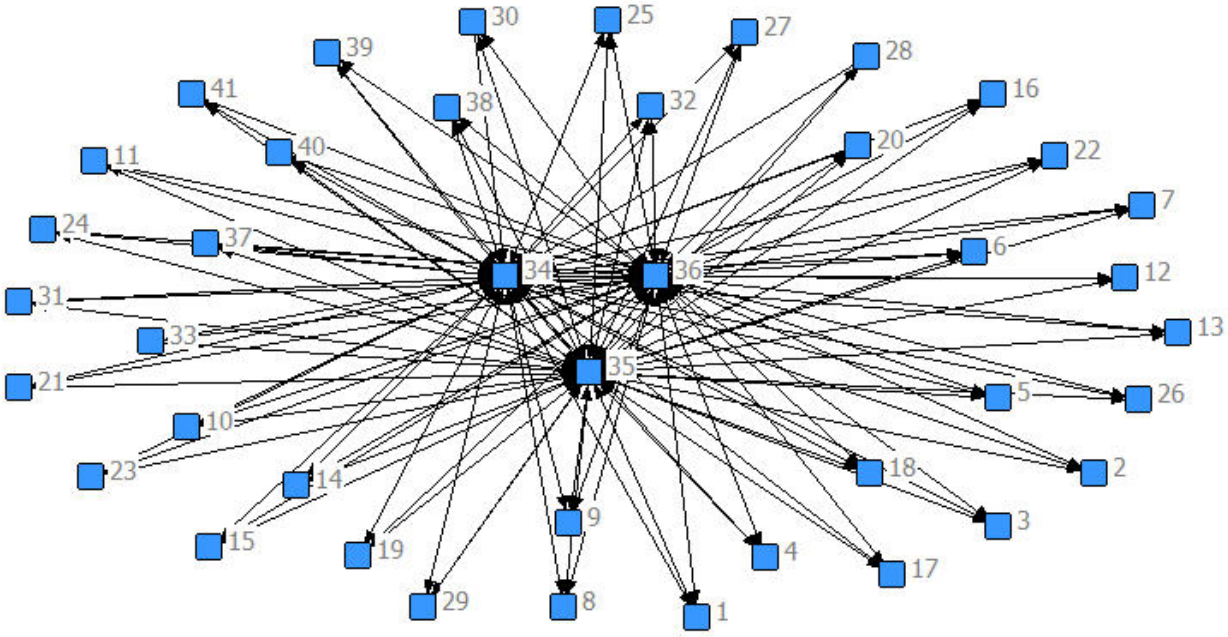


Exhibit 5. Search performance index (SPI) sorted by unit[6]

Unit #	Original	ON #1	ON #2	ON #3	ON #4
1	25.7	85.6	39.4	34.7	28.7
2	11.0	99.0	56.9	11.0	2.4
3	4.6	77.0	52.6	3.1	3.4
4	8.2	121.0	75.1	3.3	3.3
5	31.9	107.4	79.4	40.5	27.1
6	24.7	99.0	80.1	29.0	13.6
7	18.9	57.0	78.4	13.6	5.7
8	27.1	103.9	80.9	34.4	43.0
9	0.0	59.4	39.4	0.0	0.0
10	32.5	92.4	71.2	33.1	18.6
11	12.6	106.7	78.4	11.9	5.9
12	9.9	88.4	51.6	12.3	6.3
13	15.0	77.0	69.1	20.1	7.3
14	22.6	84.9	68.0	23.6	15.0
15	36.0	87.6	74.1	35.4	50.0
16	24.4	73.1	58.7	30.3	15.7
17	5.1	101.0	95.5	3.3	3.3
18	12.9	81.9	63.7	14.0	8.0
19	15.3	82.3	61.9	20.4	14.4
20	9.6	65.0	35.5	6.1	6.1
21	12.4	31.0	73.4	21.0	4.7
22	37.4	67.4	74.1	57.3	65.0
23	32.4	81.7	28.0	67.7	61.9
24	17.9	74.1	56.6	24.9	21.9
25	5.9	79.4	59.4	4.3	4.3
26	12.3	78.9	50.9	19.5	20.0
27	9.0	50.3	68.0	9.0	2.1
28	24.6	61.7	26.9	26.7	21.0
29	13.8	109.9	67.6	6.3	6.3
30	11.7	78.6	39.4	4.9	4.9
31	19.7	106.7	80.9	12.4	6.9
32	45.7	76.0	71.2	53.9	41.9
33	42.0	121.0	118.0	42.0	42.0
34	50.3	126.4	160.0	60.1	67.0
35	49.2	124.5	164.4	69.6	81.9
36	61.1	121.0	176.1	66.4	75.0
37	17.4	109.6	91.6	18.1	9.6
38	51.5	119.7	56.6	68.1	83.0
39	32.6	76.3	93.4	34.0	38.3
40	36.6	73.4	44.9	45.0	46.0
41	33.1	41.0	35.5	74.3	73.7
TOTAL	**964.5**	**3558.1**	**2946.7**	**1165.6**	**1055.0**

[6] ON = Optimized Network

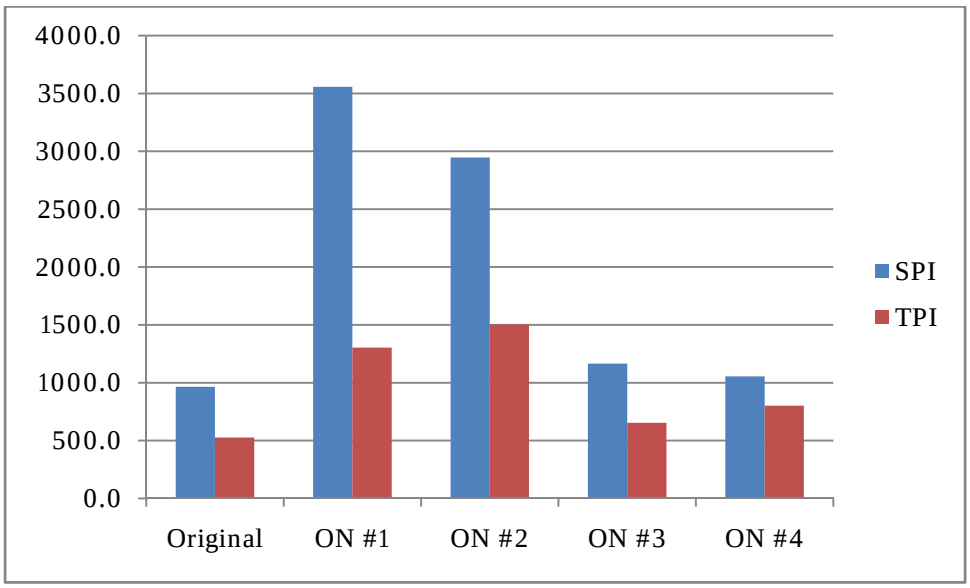
Exhibit 6. Transfer performance index (TPI) sorted by unit[7]

Unit #	Original	ON #1	ON #2	ON #3	ON #4
1	13.3	31.2	19.0	17.7	18.0
2	4.9	35.5	29.2	5.1	0.6
3	2.4	28.3	27.6	1.1	1.3
4	4.1	43.3	37.3	0.6	0.5
5	19.4	38.7	39.1	23.1	20.3
6	12.6	35.5	42.1	15.2	2.9
7	10.3	21.2	41.0	5.7	1.1
8	17.6	37.2	41.5	22.7	37.9
9	0.0	21.3	19.6	0.0	0.0
10	17.6	33.1	34.5	19.1	10.3
11	6.7	37.9	39.3	5.2	1.0
12	5.1	32.4	26.5	7.2	1.3
13	7.3	28.3	33.6	8.6	1.2
14	13.2	30.8	35.8	10.7	9.4
15	22.9	31.3	37.3	21.7	41.4
16	13.7	24.7	31.4	13.6	9.6
17	2.9	36.0	49.4	0.8	0.6
18	5.8	28.6	31.2	5.7	1.4
19	7.1	29.3	30.1	9.9	9.0
20	4.1	22.0	17.6	1.5	1.1
21	5.1	10.0	36.8	11.4	1.3
22	22.0	23.2	37.8	37.3	60.9
23	13.5	29.6	12.9	36.9	48.5
24	7.8	26.5	30.2	12.4	14.3
25	2.3	28.7	28.8	0.9	0.7
26	6.4	28.0	26.3	13.6	20.0
27	4.6	16.6	35.8	3.3	0.4
28	10.0	20.7	12.6	11.5	7.4
29	9.6	39.4	35.7	1.3	0.9
30	8.4	26.5	19.0	1.1	0.8
31	13.4	38.2	42.6	6.7	1.3
32	27.4	26.7	37.8	34.2	34.8
33	25.2	43.3	61.0	27.9	40.4
34	29.3	54.2	85.0	37.9	57.8
35	28.9	53.5	87.1	42.7	74.4
36	31.6	43.3	91.1	40.4	61.5
37	9.5	39.2	46.6	6.2	1.6
38	27.4	57.2	28.2	41.7	70.3
39	19.0	28.5	47.1	20.6	35.0
40	21.5	27.5	21.5	28.3	43.4
41	13.7	16.4	16.8	42.9	57.8
TOTAL	**527.3**	**1304.1**	**1503.4**	**654.0**	**802.3**

[7] ON = Optimized Network

Exhibit 7. Performance improvement by optimization[8]

	Original	ON #1	ON #2	ON #3	ON #4
SPI	964.5	3558.1	2946.7	1165.6	1055.0
TPI	527.3	1304.1	1503.4	654.0	802.3



[8] ON = Optimized Network

References

- Borgatti, S.P., Everett, M.G. and Freeman, L.C. 2002. Ucinet for Windows: Software for Social Network Analysis. Harvard, MA: Analytic Technologies.
- Hansen M., Collaboration: How Leaders Avoid the Traps, Create Unity and Reap Big Results, Harvard Business School Press
- Hansen M., The Search-Transfer Problem: The Role of Weak Ties in Sharing Knowledge across Organization Subunits, Administrative Science Quarterly, 44 (1999): 82-111
- Python network library, "NetworkX", http://networkx.lanl.gov/