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A MODEL OF INFORMATION LOGISTICS: FINDING THE OPTIMAL INFORMATION FLOW AND IT CONFIGURATION IN INFORMATION NETWORKS

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Abstract

In this paper we present a model for optimizing information flow and the configuration of nodes in information networks. As an integral part of supply chain management, information logistics has become essential for the coordination of flows of goods and services and so inter-organizational co-operation. However, to date little work has been carried out to show how supplier relationships and/or networks can improve information flow and infrastructures to reduce cost and achieve competitive advantage. We present a method of modeling the flow of information in a supplier network in digital form and show how to find the optimal flow and node configuration for a given number of transactions.

Keywords: Network infrastructure; supply chain management; information intermediaries; electronic marketplaces; information flow optimization;

Introduction

The synchronization of operations involved in supply chain processes across multiple firms is much more difficult than it is within a single firm (Oliver and Webber 1992). The principal reason for this is the information sharing required to perform supply chain operations. Timely information sharing among all of the entities in the supply chain can increase efficiency across the entire network. Therefore efficient information logistics becomes essential. The concept of information logistics focuses on the functions of planning, control and coordination of intra- and inter-organizational information flows (Klein 1993) and all information processing activities related to physical goods logistics. As well as the allocation, supply and distribution of information, this includes the implementation of information systems, interfaces and standards (Szyperski and Klein 1993). The optimization of information flows in an information network is meant to improve the coordination of supply chain processes and transactions in and between firms. As with supply chain management the goals of information logistics are enhanced performance and customer service as a result of better access to distributed information; better monitoring and coordination of activities; closer inter-company relationships and the development of inter-company cooperation.

A supplier network can typically have more than one recipient for one item of information. In the automotive industry for example, original equipment manufactures (OEMs) often send identical delivery schedules to a huge number of suppliers and logistics services providers involved in a specific process to enable just-in-time processing. The same type of information is typically submitted many times in the supplier network.

In the case of tangible goods needed by three requestors, the identical amount of goods needs to be provided by the supplier. In the case of digital information, only one item of information is necessary because reproduction is possible.

In this paper we are focusing on the unique properties of information in digital form. We are therefore not using a transshipment problem (see Neumann and Morlock 1993) or multicommodity flow problem (see McBride and Mamer 2001) formulation of the problem. Instead we assume that the information can be reproduced at vertices in the network and needs to be requested from the supplier only once to reach multiple recipients.

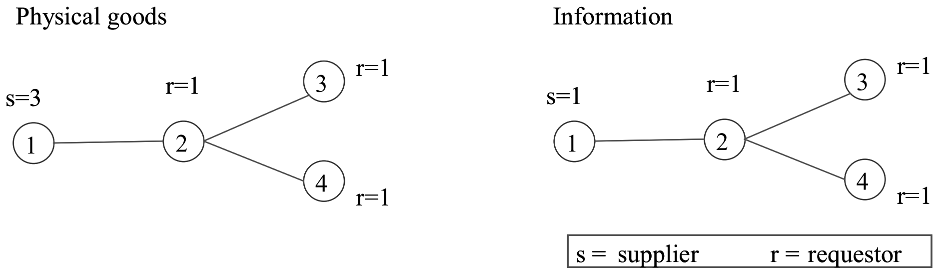

Figure 1. Differences in Distributing Tangible Goods and Information

Model of Information Logistics

As stated before, our model takes the special properties of digital information into account. We assume the following statements to be true for information in digital form:

- Reproduction is possible without loss of quality.
- Cost of reproduction is small.

Further, we are regarding a case in which there are many recipients for one item of information, as is the case in supply chains (see Swaminathan 1995). We make the following assumptions about the communication network:

- Capacity for information flow along the edges is unlimited.
- Capacity for processing on the nodes of the information network is unlimited.

In networks such as telecommunication networks, per unit prices usually fall with increased volume. This means that, keeping the communication price along one line constant, increasing volume offers the opportunity for increased profits. Assuming that the chosen IT architecture at the nodes scales well, adding extra processing capacity can be done merely by adding another server.

We distinguish between different types of information. Each type of information has a factor by which the cost of a "base unit" of information has to be multiplied to determine the cost of one unit of this particular information along an edge.

In our model, the number of information flows is known. There are no unexpected peaks which could lead to the necessity of adding extra capacity at a higher price. Hence, we have no flow restriction along the edges of our information network and no capacity restrictions at the vertices.

Moreover we can compute the flow cost for different amounts of flows for each item of information. This is trivial, since we only need to multiply the cost by the number of flows. It is nevertheless useful since increasing amounts of flow may justify investment in a different IT architecture, as we will see in the example section of the paper.

A flow describes a relationship of supplier and requestors of an item of information. Because most industrial supply chains are determined by outline agreements we assume that the network nodes, information types and supplier-requestor relations are known. In our model information has an attribute determining the factor by which the cost of submitting a "base unit" of information along an edge must be multiplied to compute the submission cost for this information. Suppose the cost for submission of a base unit along edge (1;2) is 10. We want to compute the cost for information of type "order" with a factor of 0.8. Hence the cost of submission of an order along edge (1;2) is 8.

The weight of the minimum-spanning-tree multiplied by the individual factor for each information and the amount of flow gives us the flow cost for a particular information flow. Recall that we assumed that the information for multiple recipients needs to be requested from the supplier only once and will be reproduced at the vertices of the network. This implies that the cost along the edges need only be computed from the requester to the successor in the path to the supplier and not as the sum of the complete path from each requester to the supplier.

In our network there are a set of standards that can be installed at the vertices. We refer to the installed combination of standards at a vertex as the configuration of this vertex. The configuration of the vertices of both ends of an edge has an impact on the communication cost along this edge (see Figure 2). The problem is to find the best configuration at the vertices of a network to minimize the sum of the configuration investment at the vertices and the variable cost of information flows. How can we chose the best combination of standards at each node on the network and the minimum overall communication cost?
We divide the problem into two parts:

1. The first part of the problem is to find the minimum flow cost for each item of information between supplier and requesters of this information in a given network. Summing the costs of the individual information, we get the information flow cost in a given network, with a given combination of standards used at the nodes of the information network. Different nodes can utilize different combinations of standards, or a single standard or no standard at all.

2. The second part is to find the optimal combination of standards for each node in the network that will minimize the sum of the overall flow- and configuration cost.

With a solution for problem 1, we can search for a solution for problem 2, by evaluating the cost of the current network configuration.

More formally, for a given graph (for definitions see e. g. West 2001), a set of vertices and edges $G(V,E)$ the cost we wish to minimize can be described as the sum of the fixed cost of installing standards on each vertex of the network and the flow cost per unit for each information flow times the quantity of the flow.

For each information flow k there is a set v_k of a set of nodes v_{ki} that can be part of the information flow. The set v_k contains the union of the set of supplier and requestors nodes for an information flow with each element of the power set of the intermediaries.

A simple example will clarify this. Suppose that node 1 is the supplier of an item of information that node 2, 3 and 4 request. In this network, there are intermediaries (like Covisint or SupplyOn in the automotive industry at the time of writing), e.g. node 5 and 6. Hence set of supplier and requestor nodes for this information flow consists of the nodes {1, 2, 3, 4} and the set of intermediaries consists of the nodes{5, 6}. The power set of {5, 6} is {}, {5}, {5,6}, {6}. Hence the set v_k in this example contains the following elements:

{(1,2,3,4); (1,2,3,4,5); (1,2,3,4,5,6), (1,2,3,4,6)}.

After determining the elements of v_k we compute the minimum-spanning-tree of each induced subgraph of *G* formed by each element of v_k .

The minimum of the alternative minimum-spanning-trees multiplied with the individual factor for the information gives us the minimum per unit flow cost for one item of information $c_k := \min MST(v_k)$. The product of the number of transactions x_k multiplied by the per unit cost of the flow yields the flow cost for this information good, $x_k c_k$, in a given network configuration.

The sum of the flow costs for each information flow, $\sum_{k=1}^{n} x_k c_k$ is the variable costs for a given configuration.

The variable costs plus the costs of installing the configuration $conf$ which is one combination out of the set of available standards $stset$ at the vertices of the graph yields the total cost we wish to minimize. This requires an estimation of the number of transactions we believe will take place in a given period, ideally the lifespan of the supplier network.

We can describe the objective function as follows, where $conf(v)$ denotes the fixed costs for installing a chosen configuration for vertex v, m is the number of vertices in the graph, and n is the number of information flows in the network.

Minimize $\sum_{v=1}^{m} conf(v) + \sum_{k=1}^{n} x_k c_k$ satisfying: $x_k \geq 0$

A Search Strategy for Obtaining an Optimal Solution

Finding an optimal solution for part one of our problem, we distinguish three cases. For every case, we compute the minimum flow costs for each item of information. The minimum of the minimum flow costs for each item of information defines the flow of that information.

Problem 1: Finding the Optimal Flow of Information in a Given Network

Case 1: Only Supplier and Requester Nodes in the Network, No Intermediaries
First, we determine the set of nodes involved in each information flow, that is the supplier and requesters of each item of information. Next, we compute the minimum-spanning-tree with the given set of edges for this information flow. In the given network, the minimum-spanning-tree denotes the optimal flow of information. Its value is the flow costs, since information need not flow on a path from the supplier to every requester. It can be copied and sent from one requester to another once it has been received from the supplier. We continue the computation for every item of information.

Case 2: Supplier and Requesters Nodes in the Network, and a Single Intermediary
First, we determine the set of nodes involved in each information flow by adding the intermediary to the list of nodes for each set found in case 1. We continue by determining the flow cost for each information flow, forcing each flow to make use of the intermediary by computing the minimum-spanning-tree connecting all nodes in the set.

Case 3: Supplier and Requesters Nodes in the Network, and More than One Intermediary
In this third case with multiple intermediaries we evaluate the flow costs for the union of the nodes involved in the information flow with every element of the power set of intermediaries.

After completing the computation of flow costs for each item of information in every possible case, the minimum information flow cost of a given network configuration is computed by summing the minimum flow costs found for each information flow. The minimum-spanning-tree associated with the minimum flow cost for each supplier-requester relationship determines the information flow. It is possible that using an intermediary is optimal for one item of information but not for another. Thus being able to use intermediaries does not necessarily lead to the utilization of an intermediary.

Problem 2: Finding the Optimal Configuration for Each Node in the Network

Knowing the minimum flow cost and the associated flows of information in a given configuration, we can search for the optimal configuration by changing the configuration of a node and computing the associated flow cost of the new configuration. Of all possible communication lines between two nodes, the one with the minimum cost determines the communication cost along the edge connecting these two nodes (see Figure 2). Hence, after changing the configuration of a network we recalculate the weight of the edges in the graph.

We can find an optimal solution for problem 2 using a branch and bound algorithm. We start with a network without any standards and compute the flow cost. We then expand every possible configuration for one node in the network. The cost of the set-up of the new configuration is added to the flow cost of this configuration to determine the total cost of the configuration. The set-up costs are calculated as the cost for the current configuration of the network given the initial configuration. We can also start the branch and bound with a given configuration of the network and change the configuration of nodes from there on. A lower bound is easily computed by simply regarding the set-up costs, assuming the flow costs to be zero.

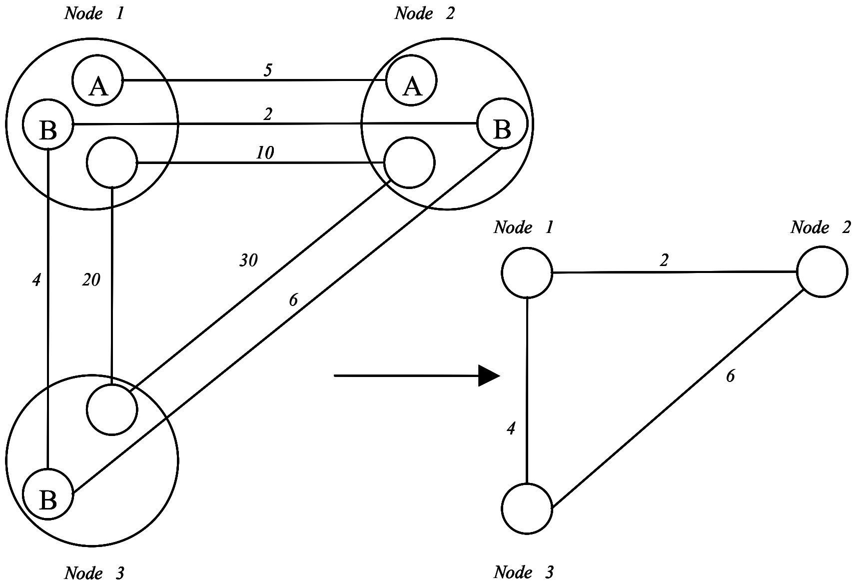

Figure 2. Communication Cost per Unit Between Different Network Nodes

The minimum communication cost between node 1 and 2 is 2 and between node 1 and 3 is 4. In both cases standard B is used in both nodes. Using standard B reduces the cost of one base unit of information to 20%, using standard A reduces the cost to 50%. The minimum communication cost per unit between node 2 and 3 is 7. Again standard B is utilized. The minimum communication costs determine the edge weight.

Examples for Problem 1

The supplier-requester relationship can be described as follows: Node 2 offers information I_1 (e. g. a delivery schedule) needed by the nodes 1 and 4 to process physical goods processes. Node 1 offers information I_2 which is requested from the nodes 2, 3 and 4.

Example 1: Network with Information Suppliers and Information Requesters

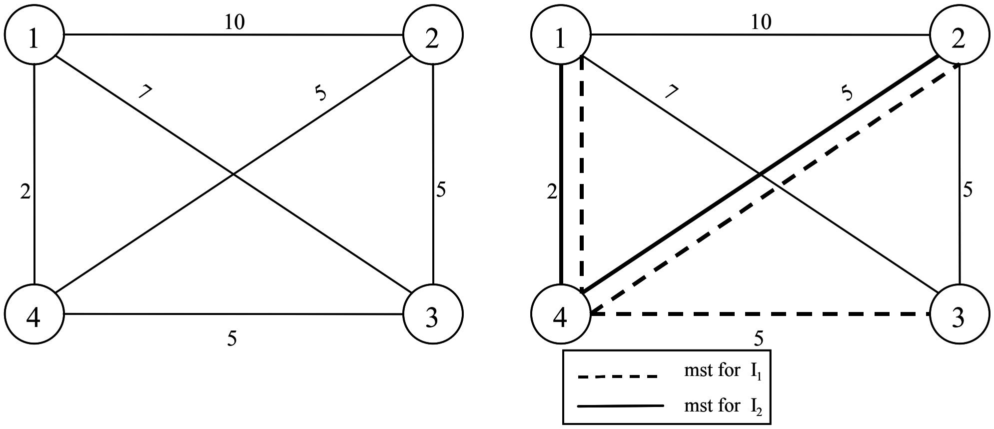

Figure 3. Network and Minimum-Spanning-Tree for Example 1

The minimum communication cost for one base information unit result from the edges 1,4=2 and 4,2=5. In total they are 7. To determine the cost for information I_1*, we need to multiply with the factor for information* I_1*. The minimum-spanning-tree for* I_2 *consists of the edges 1:4 =2; 4:2=5 and 4:3 =5. The communication costs for one base information unit are 12.*

Example 2: Suppliers, Requesters, Marketplace

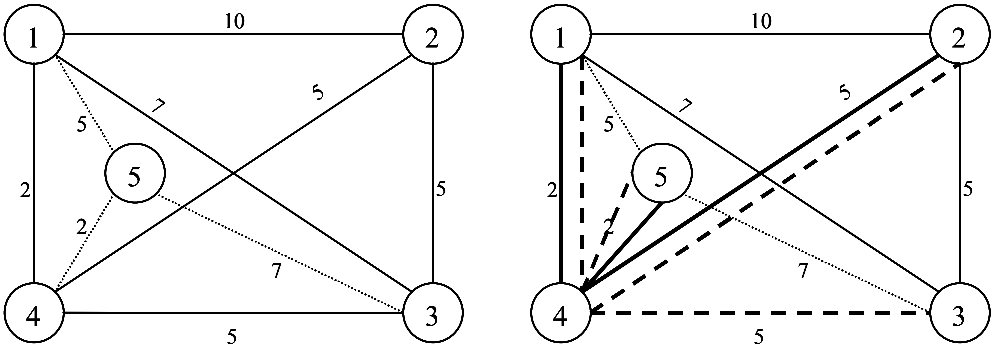

Figure 4. Network and Minimum-Spanning-Tree for Example 2

The minimum-spanning-tree for I_1 *is determined through the edges 1,4=2; 4,2=5 and 4,5=2 with costs of 9 per base information unit. The cost of submission per base information unit for* I_2 *is 14.*

Example 3: Suppliers, Requesters, Another Marketplace

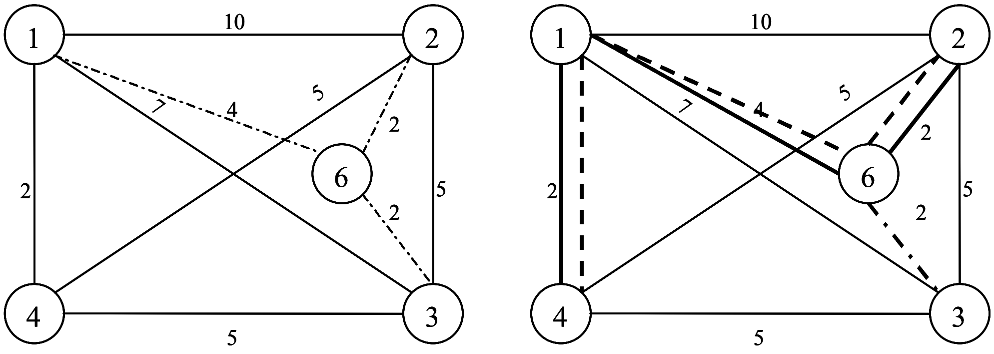

Figure 5. Network and Minimum-Spanning-Tree for Example 3

The minimum-spanning-tree for I_1 *is based on the edges 1,4=2; 4,2=5 and 2,6=2. The cost per base information unit is 8.* I_2 *is submitted using the edges 1,4=2; 1,6=4; 6,2=2 and 6,3=2. The cost per base information unit is 10.*

Example 4: Suppliers, Requesters, Two Marketplaces

Example 4 differs from 2 and 3 because of the existence of more than one marketplace.

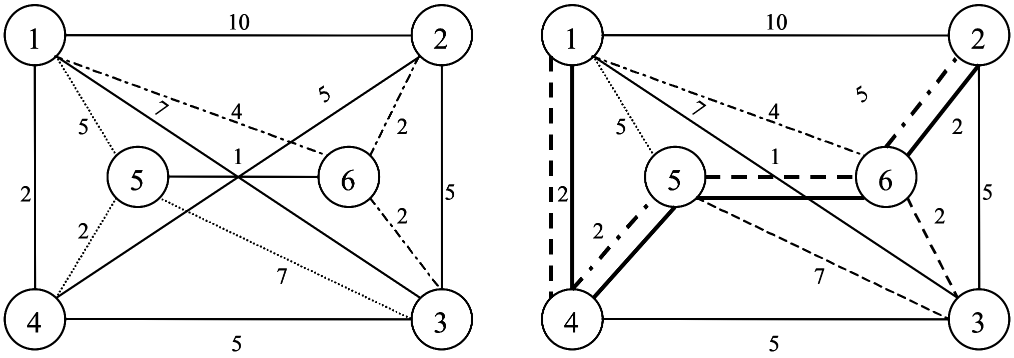

Figure 6. Network and Minimum-Spanning-Tree for Example 4

The minimum-spanning-tree for information I_1 *consists of the edges 1,4=2; 4,5=2; 5,6=1 and 6,2=2. The communication costs per base unit are 7. The minimum-spanning-tree for* I_2 *is based on the edges 1,4=2; 4,5=2; 5,6=1; 6,2=2 and 6,3=2. The communication costs per base information unit are 9.*

Examples for Problem 2

We describe the branch and bound procedure for the following network. The information is supplied by node one and requested by node 2. Node 3 is a marketplace. The variable per base unit communication cost need not be the same for all edges (see Figure 7). At each node there is either standard A installed or no standard, denoted by 0. Node 1 and node 2 can pay membership fees for the intermediary, node 3. If both nodes have paid for the marketplace membership, the marketplace can be utilized as an intermediary. In Table 1 we see the nodes and the factor by which the costs along the edges in Figure 7 have to be multiplied to determine the weight of the edge. The one time investment for installing standard A is given in table 6 as well as the membership fee for the marketplace. Marketplaces in supplier networks, e. g. in the automotive industry, currently charge a fixed membership fee and a fee per transaction as well.

We are using the "big M" notation, making it clear that the marketplace functionality cannot be used unless B, marketplace membership, is available in both the sending and receiving node. If both nodes are a member of the marketplace, they can transmit information utilizing the marketplace at the per base-unit cost described along the edges in Figure 7. If both nodes have standard A installed, the costs along the edges are multiplied by the factor 0.2, hence reduced to 20 % of the costs without a standard in place. If the marketplace has standard A installed, the communication costs between a node with standard A and the marketplace is reduced to 0.1 times the cost along the connecting edge in figure 1.

The communication costs along the edges in Figure 7 denote the flow cost of one base unit of information. Different types of information are modeled as a factor by which the base unit of information is multiplied. In our example for simplicity the information we utilize is determined by multiplying the base unit with factor 1.

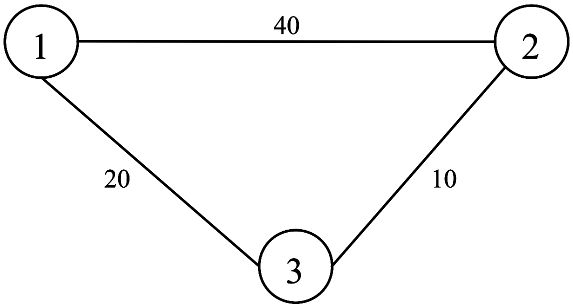

Figure 7. A Three Vertices Network Example

Table 1. Factor by Which the Edge Weight Is Multiplied to Determine the Communication Cost perUnit of One Base Information Unit Depending on the Configuration of the Vertices at Both Ends of the Edge

	0	A	B	AB
0	1	M	M	M
A	M	2	M	2
B	M	M	8	8
AB	M	M	8	1

Table 2. Configuration Costs of Installing Different Communication Standards or Combinations of Standards at the Vertices of the Communication Network

Configuration costs		
Configuration	**Cost**	**Description**
A	100	cost of implementing standard A (e.g. AnsiX12-Interface)
B	20	cost of intermediary services (e.g. membership fee of a marketplace)
AB	120	cost of implementing standard A and using the intermediary.

The installed configuration has an impact on the edge weight connection two vertices (see Figure 2).

In Figure 8 we are determining the optimal network configuration in the case of the flow of one unit of information 1. The optimal solution is to not invest into a standard at the vertices. The total cost of investment and information flow is 40.

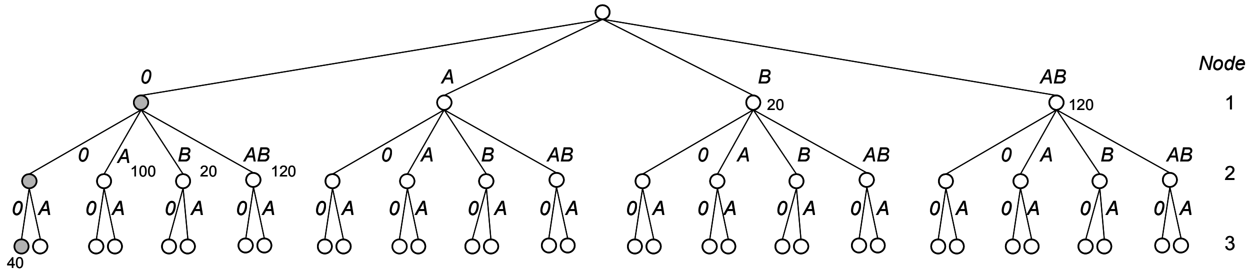

Figure 8. A Decision Tree for One Unit of Information 1

Because node 3 is the marketplace there is no configuration B and AB for node 3.

In Figure 9 we are determining the optimal network configuration in case of the flow of ten units of information 1. The optimal solution here is to invest in standard A at node 1 and node 2. The total cost of investment and information flow is 280.

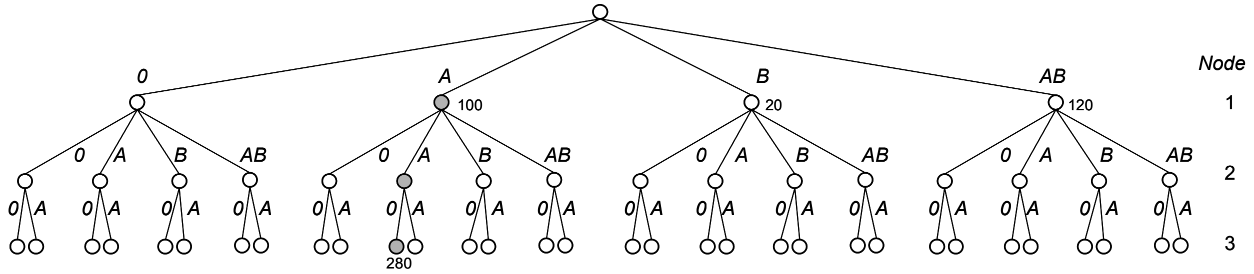

Figure 9. A Decision Tree for Ten Units of Information 1.

Because node 3 is the marketplace there is no configuration B and AB for node 3.

As we can see the optimal configuration of the network varies with the number of information units transmitted in a given period of time. If the number of information units flowing is increased, a different combination of standards might become optimal.

Quality Versus Computation Time

The search strategy described is guaranteed to find the globally optimal solution. It is possible that the time needed to find a globally optimal solution exceeds the available time. If we are willing to give up solution quality for computation time, we can use local search methods (see Aarts and Lenstra 1997). These methods will not necessarily find the optimal solution, but have been capable of finding good approximate solutions in the past. We have not yet categorized the complexity class of the problem. It might be possible to find an efficient algorithm for the problem. It might also be possible that an efficient algorithm for a problem with this complexity class has not been found yet. In the latter case it is feasible to use a branch and bound approach.

Summary

We have presented a model of information logistics and a method that can be applied to find the optimal flow of information and the optimal configuration of nodes in a supplier network with multiple types of information and different supplier-requester relations. We have taken into account the quantity of information flow per period for each type of information. We showed that different configurations of standards and different routes of information can become optimal when changing the number of information units flowing in a given period. Using our model, the decision for the configuration can be supported and estimates of future increases of the number of transactions can be taken into account. We haven shown a way of finding the optimal configuration and the related optimal information flow for a network of multiple information types and multiple supplier-requester relations. Using our model, organizations can determine the flow cost of information for their current configuration and compute possible savings by changing the configuration. Moreover in a strongly interdependent industry like the automotive industry the optimal configuration for every node in the whole industrial network and the corresponding information flow can be computed and compared to the current state and its cost.

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