MODELING AND APPLICATION OF THE BEST MATCHING PROTOCOL

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"Knowledge through information; Wisdom through collaboration"

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NOMENCLATURE

Terminology

All i, j = 1, 2, …, 8
Ai: Physical Parts Ai
Bj: Physical Parts Bj
δ(Ai): dimension that part Ai needs to be matched with
δ(Bj): dimension that part Bj can match with
β(Ai): Best fit of Ai = min (|δ (B1)- δ (Ai)|/ δ (Ai), | δ (B2)- δ (Ai)|/ δ (Ai), … , |δ (Bn)- δ (Ai)|/ δ (Ai))
$\text{Min} \sum_{i=1}^{m} \beta(Ai, Bj)$): Best overall match
β(Ai, Bj): Best Fit Index for Part Ai when fitted with Part Bj
φ (Ai): Random Fit Index for Part Ai. This is a measure of how well the match is without the use of the Best Matching Protocol. In this research, it is used to compare with β(Ai)
φ (Ai, Bj): Random Fit Index for Part Ai when fitted with Part Bj
P_s: Supplier and Consumer floor price
P_b: Buyer's ceiling price
PCj: Production Cost by Supplier j
VCj: Vulnerability Cost (penalty cost when supplier j cannot fulfill a customer order in time)
CCj: Communication Cost that customer needs to pay to communicate with Supplier j. It includes (1) the communication overhead per data transmission, and (2) the transmission frequency over the optimization period. (Nof, Ceroni, Matsui, 1999)
LCj: Logistics Cost incurred for ordering and receiving supplies from Supplier j
$\Omega_{M,G}$: Best Matching Protocol for geometrical matches, $\Omega_{M,G}$ = {Ai, Bj, M_P, T_B}
M_P: Matching Process
T_B: Tie-Breaking Rules
$\Omega_{M,NG}$: Best Matching Protocol for Non-geometrical matches, $\Omega_{M,NG}$ = {Si, C, M_P, T_B}
Si: Supplier i
C: Customer who wants to match a Supplier to his/her needs
Gi: Gain, $(P_B - P_{Si})/P_B$
Gk: The Gain the customer achieve by choosing Supplier k
ψ: Double-match Index, ψ = Gk* (1/β(Ai, Bj))

Modeling and Application of the Best-Matching Protocol

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Abstract

In this research, the Best-Matching Protocol is developed and tested. This research explains and investigates the importance of having an efficient way of sharing and using information collected from a distributed system. Previous work on protocol development, business process modeling, and statistical control serve as the fundamentals to this research. The focus of this research on a protocol which allows best matches to be made among geometrical specifications (e.g., physical parts) as well as non-geometrical specifications (e.g., members in a supply network).

The scope of this research is to develop a methodology to model, quantify, and analyze the impact of a matching protocol in distributed systems in order to establish the best matches. Two scenarios are used to test the protocol: 1) in a manufacturing system, 2) in a supply-network. Four different statistical distributions are considered for the distribution of physical parts in first scenario. The distributions are Normal, Lognormal, Uniform and Exponential. A double-match is developed for the second scenario where the results of matches in the first scenario are used. Results of matches using the Best-Matching protocol developed in this research are compared to results of matches using a random match. Statistical analyses are performed to test the difference between various types of matches. The differences are presented in both numerical and graphical forms.

The experimental results show that the Best-Matching Protocol provides much better matches than random matches. This is consistent throughout all four statistical distributions that are tested in this research. When applied to a supply-network, the Best-Matching

Protocol serves as a mean for a customer to select (or match) its needs to a supplier who provides the best combination of price and quality of product offered.

1. Introduction

Businesses have become more and more complex in terms of their applications as well as technology within and among them. In order to deal with increased business demand for efficient information flow, human and application integration have been attempted. Such strategy has delivered partially integrated enterprise, which leaves the overall value chain substantially un-integrated and unmanaged. Earlier workflow systems models also lack sufficient detail to make these models executable, hence limiting their benefit to IT. Firms realized that in order to cope with inefficiencies, the focus of integration must be end-to-end business process but not technical integration of applications and data. Business processes will also include processes across organizational boundaries. Because of the close relationship between business partners, when one action occurs, others will be triggered automatically throughout the value chain. As a result, each individual partner must interact cooperatively to ensure best performance throughout the chain (Anussornnitisarn, 2003). The Business Process Management System (BPMS), which is a business process approach to integration, must deliver a rich integration toolset that supports both internal EAI (Electronic Application Integration) and external B2B (Business to Business) interactions, as well as leverage today's limited purpose middleware. It must complement this toolset with a framework that can rapidly and securely deliver emerging visions for collaborative cross-business and cross-business unit processes.

Within the context of the modern-day integration of business processes, dimensional integration among parts is also posing a problem to assembly and manufacturing processes.

This research focuses on the two areas of integration, namely, dimensional integration, and business partners integration. To achieve such a purpose, a protocol, called the Matching Protocol, is developed. However, whether applied to dimensional matching or partners matching, efficient information sharing is critical.

Large industrial systems are often distributed geographically. While it has great advantages such as increasing technical specialty, there are drawbacks to such distributed facilities. Sub-assembly parts are manufactured without always knowing the counterparts' machined dimension. In order to satisfy customer demand and ensure better quality products, it is critical to verify the dimension of parts. It is preferred to select pairs of "preferred matching" assembly parts at production line to give the finished part a desired optimal functionality and performance.

Manufacturers today face tremendous competition from one another to produce parts of higher quality at lower costs. At the same time, selection of business partners and customers based on various criteria (costs, efficiencies, trust, etc.) have become of increasing importance due to the competition in the industry. In order to select the desired suppliers (or customers), requirements from both ends will have to be matched. However, because of the complicated relationship among these members in the supply network, a proper match may be hard to achieve.

Each business partner has its own business process, which interacts with others in the network. When one action occurs, others will be triggered. As a result, a sound communication and matching system is required to ensure maximum performance and effective collaboration throughout the industry network.

This research has the following objectives:

1. Develop a matching protocol which can be used for dimensional matches as well as matches of industry partners requirements.

2. Develop performance measures for determining the “best match”.

3. Adapt performance measures developed in previous research to different scenarios discussed in this research.

4. Develop an architecture for efficient communication and collaboration among business partners.

The scope of this research is to develop a methodology to model, quantify, and analyze the impact of the presence of a matching protocol, together with the use of communication and coordination protocols over a network.

2. Literature Review

Business Process Modeling techniques can help enable efficient coordination, collaboration and communication of business entities. These techniques are not possible without proper communication protocols which control the way information flow in the network of enterprises. This can only be possible with the help of information systems. Hence information systems serve as the backbone for such cooperation. Two of the most essential values we can expect from the application of information technology to daily business practices are speed and credibility (Park, 2001). Earlier workflow systems models lack sufficient detail, hence limiting the benefits to IT. Besides this, another problem area which has been a barrier to effective collaboration is the lack of a proper interface between enterprises. Each enterprise has its own information system in terms of hardware and software. Without a proper medium to “synchronize” these information systems, efficient collaboration will be hindered. Hence, middleware is developed as another layer of software that covers all these legacy information systems in order to provide communication between them.

In the research by Anussornnitisarn and Nof in 2003, an "active middleware" is developed to focus on collaboration among a network of information systems to support the distributed business processes. This research focuses on developing a collaboration paradigm for distributed information systems, by which four major research objectives can be addressed. These research objectives serve to solve practical problems faced by both researchers and practitioners who are seeking an effective approach for collaboration for distributed information systems.

Development of Active Middleware involves investigating into many aspects of the network. One dominant aspect is to minimize the problems that arise during the process of coordination. In this research, four basic coordination problems (Malone and Crowston, 1994) are investigated. For each problem, a Task Administration Protocol (TAP) is proposed to minimize, if not solve the problem. The Best-Matching Protocol can be also used to solve or minimize some coordination problems. Previous research on the coordination problems and the development of TAP are highly related to the development of the Best-Matching Protocol because they trigger the needs for a protocol such as the Best-Matching Protocol.

With the increase in distributed customers and suppliers, "global market" has grown into a size that demands organizations to collaborate and coordinate efforts in order to serve these customers (Ceroni, et al. 1999). There have been researches on protocols and the technical aspects on such issues. This research paper investigates the coordination cost. The cost might limit the benefits of such coordination. In this paper, a job-shop model was studied. This model consists of two distributed collaborating centers, one for sales and one for production. Two coordination modes are also examined: (1) distributed coordination by the two centers; (2) centralized coordination by a third party. Results and conclusion of the study are provided.

Although implementing coordination networks among members of a supply network is important for distributed organizations to ensure proper transmission of information among one another, the cost for such an implementation should not exceed its benefits. While implementing such network, the question that often arises is what kind of communication network should the organization to best serve its purpose. A very fundamental measure of the benefits is the cost and the returns of such an implementation. This paper aims to answer that question.

A job-shop model was used in this research. This model includes a Sales Center and a Production Center. The coordination profitability is determined by comparing the system performance with (F) and without coordination (F') for the same operational parameters. In the first model that looks into distributed coordination, the optimization process is coordinated by an optimization module at either of the two centers. This model requires the centers to exchange data in parallel with the optimization module. In the second model the optimization model is away from both centers, and hence it is an independent module.

Coordination cost is determined by evaluating:

(1) the communication overhead per data transmission. This overhead is evaluated based on the message passing protocol for transmitting data from a sender to one or more receptors. The parameters of this model are: exchange rate of messages from/to the communication channel, transmission startup time, data packing/unpacking time from/to the channel and the number of senders/receptors.

(2) The transmission frequency over the optimization period. This frequency is evaluated by decomposing the data requirements into a series of transmissions and computations per iteration of such decomposition.

The coordination cost can be formulated as:

Coordination cost rate = (communication time*wc + HEC)*(number of iterations/mean periodic time)

Where wc: communication time to communication cost conversion factor

HEC: hardware equivalent cost

The research by Ceroni, et al., in 1999 is highly relevant to this research because the definitions of the cost functions in the two research are identical. The definition of Communication Cost (CC) by Ceroni, et al., is used in this research as part of the double-match.

With recent advances information technology, the research and practice of information sharing is having a significant impact on many aspects of supply chains. However, it is not clear how and what information should be shared or used, and how to quantify the benefits of information sharing. Real-time information sharing is investigated in this research which leads to a dramatic quality improvement for an assembly process.

This research by Chiam and Nof in 2004 investigates the type of information that should be shared and used, and how to use such information. Benefits of such information sharing are shown by the quantity defined as the Best Fit Index as well as the Cost of information sharing.

As businesses grow, manufacturing becomes more and more distributed geographically. Information gathered at individual manufacturing stations should be shared among authorized stations in order to best make use of the captured information from these individual stations. This research by Kang in 1994 develops protocols to make such information sharing possible. The information to be shared among the stations are inspection information which will be integrated to match parts together based on their dimensions and tolerances. Test cases were developed and results collected.

This research also aimed to achieve information integration through developing protocols and provide a framework for which such integration is possible. The information integration architecture consists of three main modules, i.e., Inspection Station Module, Information Integration Module, and Assembly Simulator Module. Figure 2.1 summarizes the sequence of information transfer from one module to another.

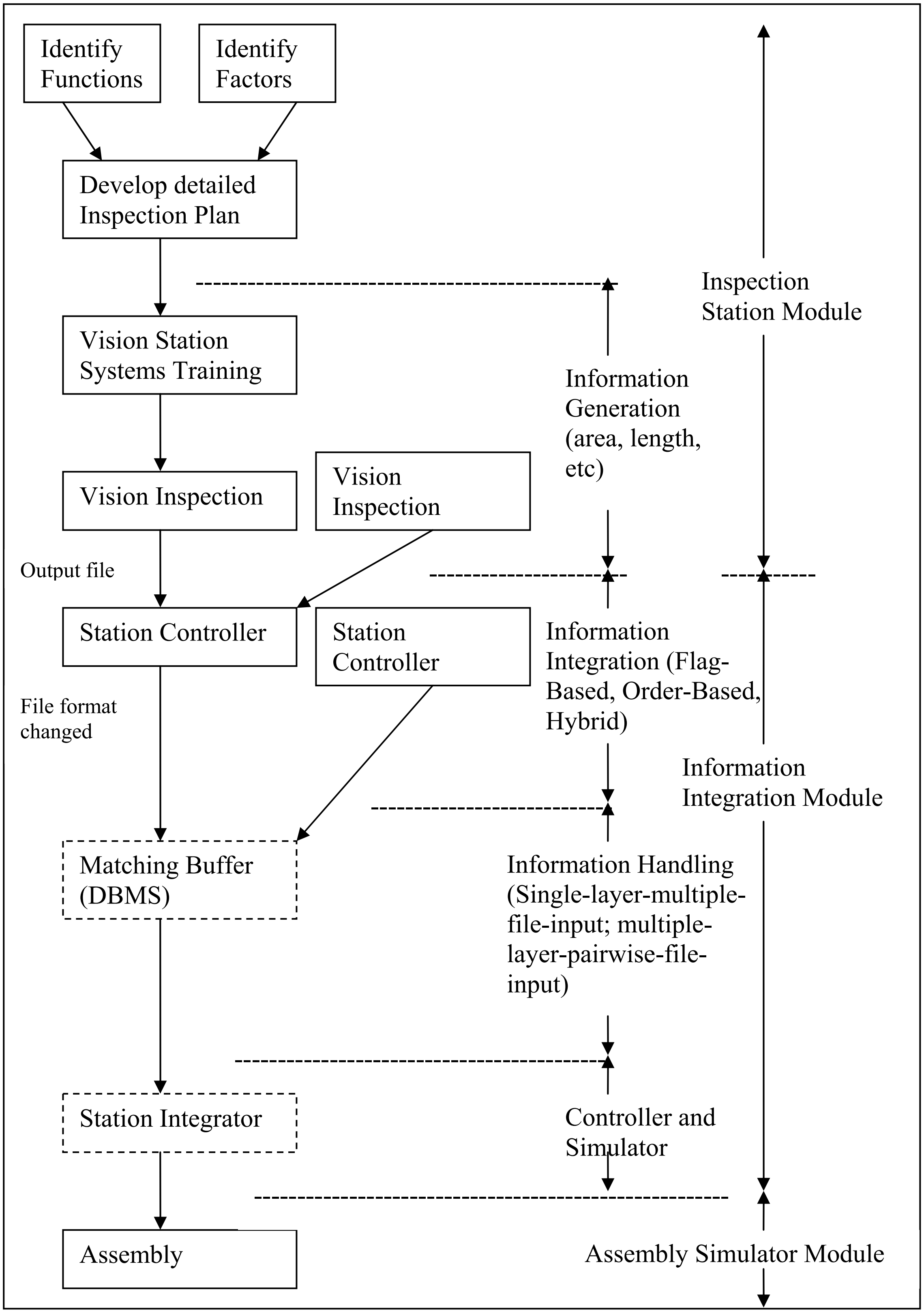

Figure 2.1: Flow of information through the Information Integration Protocols (Kang, 1994).

3. Geometrical and Non-geometrical Matching

The following outlines methodology for use for both geometrical and non-geometrical matching:

3.1 Logic and Design of the Matching Protocol when applied to geometrical match

Assuming a database consisting of dimensions of Part Ai's and a database consisting of dimensions of Part Bj's:

<u>Definition #1</u>: δ is the dimension of the part that needs to be matched.

$\delta(Ai)$ = dimension that part Ai needs to be matched with (e.g., a nut of 5cm diameter)

$\delta(Bi)$ = dimension that part Bi can match with (e.g., a bolt of 5cm diameter)

<u>Definition #2</u>: $\beta(Ai)$ is the Best Fit Index of part Ai.

Best fit of Ai = $\min(|\delta(B1) - \delta(Ai)|/\delta(Ai), |\delta(B2) - \delta(Ai)|/\delta(Ai), \ldots, |\delta(Bn) - \delta(Ai)|/\delta(Ai))$ $= \beta(Ai)$, n, i = 1, 2, …, 8 in this research.

<u>Definition #3</u>: $\beta(Ai, Bj)$ is the Best Fit Index of part Ai when matched to Part Bj.

<u>Definition #4</u>: T_B is the tie-breaking rules. In the case where the same Bj can be matched to multiple Ai's, tie-breaking rules are applied to select the Ai which yields the lowest $\beta(Ai)$.

There are certain cases where we need to apply tie-breaking rules. The following are the tie-breaking rules, T_B, used in this research:

If B1 is the best match for A1 and A2,

Pick the next best match, Bh, for A1 and compute $|\delta(Bh) - \delta(A1)|/\delta(A1) = x$

Pick the next best match, Bk, for A2 and compute $|\delta(Bk) - \delta(A2)|/\delta(A2) = y$

If x < y, match B1 with A2

If x > y, match B1 with A1.

If B1 and B2 are the best matches for A1,

If neither B's matches any other As,

Arbitrarily pick either B1 or B2 to match with A1

If one of the two Bs matches another A,

Pick the B (from B1 and B2) that does not have any other matches to match with A1

If both Bs match with some other Ai

Compute $|\delta(B1) - \delta(Ai)|/\delta(Ai) = c$

Compute $|\delta(B2) - \delta(Ai)|/\delta(Ai) = d$

If c < d, match B2 with A1

If c > d, match B2 with A2.

Best overall match is when we minimize $\sum_{i=1}^{m} \beta(Ai, Bj)$.

<u>Definition #5</u>: $\Omega_{M, G,}$ the Best Matching Protocol for geometrical matches, is defined as:

$\Omega_{M, G} = \{Ai, Bj, M_P, T_B\}$

Where Ai: Physical Parts Ai

Bj: Physical Parts Bj

M_P: Matching process

T_B: Tie-breaking rules

3.2 Matching Protocol when applied to a Supply Network

To apply the Matching Protocol to a supply network, more variables are to be defined. The following shows these variables and various test cases, including cases where supplier's floor price is higher than customer's ceiling price as shown in Figure 3.1a; supplier's floor price is equal to the customer's ceiling price as shown in Figure 3.1b; supplier's floor price is lower than customer's ceiling price as shown in Figure 3.1c:

P_s: Supplier's floor price

P_b: Buyer's ceiling price

Case 1: $P_S > P_B$

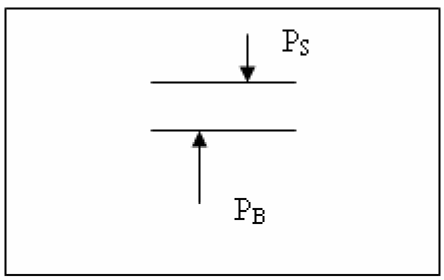

Figure 3.1a: Supplier's floor price is higher than customer's ceiling price

Case2: $P_S = P_B$

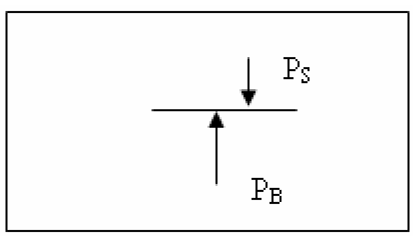

Figure 3.1b: Supplier's floor price is equal to the customer's ceiling price

Case3: $P_S < P_B$

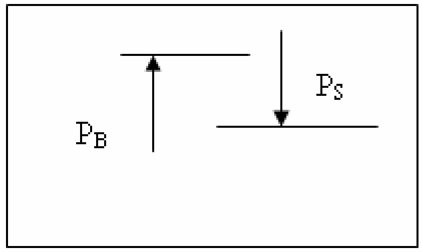

Figure 3.1c: Supplier's floor price is lower than the customer's ceiling price

Considering only Cases 2 and 3:

Gain, Gi = $([P_b - P_{Si}]/P_b)$

Best overall match is when we maximize Gi and minimize ($\sum_{j=1}^{m}$ PCj + VCj + CCj + LCj), where

PCj = Production Cost of Supplier j

VCj = Vulnerability Cost (penalty cost when Supplier j cannot fulfill a customer order in time)

CCj = Communication Cost that customer needs to pay to communicate with Supplier j. It includes (1) the communication overhead per data transmission, and (2) the transmission frequency over the optimization period. (Ceroni, Matsui, Nof, 1999).

LCj = Logistics Cost incurred for ordering and receiving supplies from Supplier j.

The Best-Matching Protocol, whether is applied to a manufacturing setting or to a supply-network, can be generalized and described by Figure 3.2:

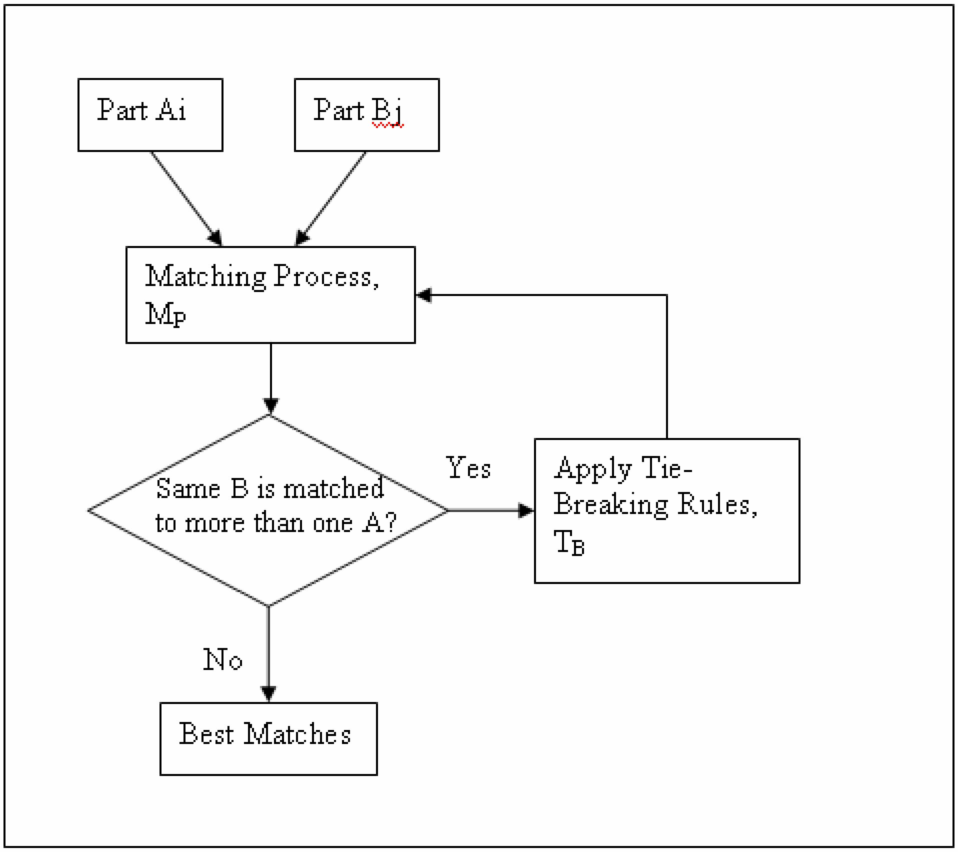

Figure 3.2: Logic diagram for the Best-Matching Protocol

The results from the previous step (from matching buffer) are passed on to the system integrator where they are logged and fed into the actual assembly process.

4. Experiments

Excel experiments are set up to investigate the matching between parts given dimensions generated by the following four statistical distributions and their corresponding parameters:

Table 4.1: Statistical distributions used for matching

Distribution	Mean	Standard Dev	a	b	Formulation
Normal	5	2	N/A	N/A	ABS(NORMINV(RAND(),5,2))
Lognormal	5	2	N/A	N/A	LOGINV(RAND(),5,2)
Uniform	5	1.1547	3	7	*Data Analysis tool in Excel
Exponential	5	5	N/A	N/A	(1/5)*(LN(5)-LN(RAND()))

For each distributions, six experiments were performed. In each experiment, 8 part As and 8 part Bs are to be matched with each other. Tie-breaking rules illustrated in Section 3.1 are used for matches where tie-breaking is necessary. Matches performed by using the Best-Matching Protocol are compared against matches which are randomly made. Graphs and ANOVA tables are constructed to show such differences. They are shown in Section 5.1.

4.2 Applying the Best-Matching Protocol to non-geometrical specifications

The matching of suppliers and customers in a supply network is used to illustrate the use of the Best Matching Protocol to match non-geometrical specifications. Assuming that the suppliers and customers are in the manufacturing industry who supply the matched parts Ai and parts Bj and demand, respectively, these matched parts. Another assumption made is that the double match is applied from the customer's point of view. For example, several suppliers offer the same services (or supplies) to a customer. This protocol can be applied by the customer to match his/her requirements with the supplier that can provide the optimum combination of price and quality. The following provides the definition and application of the double-match.

The Best Matching Protocol in this case is defined as:

$\Omega_{M, NG}$ = {Si, C, M_P, T_B}

Where Si: Supplier i

C: Customer (or buyer)

M_P: matching process

T_B: Tie-breaking rules

Customers in this industry are not only concerned with the quality of their suppliers; they are also concerned with the quality of the matched parts from these suppliers. Due to the additional consideration and factors that are present during the matching process, a double-match is to be used.

The double-match is defined as a combination of a match of parts, and a match of criteria defined by both the suppliers and the customers. As defined in Section 3.2.

Psi = Supplier i's floor price, i.e., the lowest price that suppliers are willing to sell their products at,

Pb = Customer's (or buyer's) ceiling price, i.e., the highest price that the customers (or buyers) are willing to pay for the products by the suppliers.

Gain, Gi = $([P_b - P_{Si}]/P_b)$

The following outlines the procedure of matching the supplier with the customer.

i. Individual gains, Gi, is computed for each supplier:

G1 = (Pb – Ps1)/Pb

G2 = (Pb – Ps2)/Pb

…

Gi = (Pb – Psi)/Pb

ii. If Supplier k provides the biggest Gain to the customer, the Gain to the customer is denoted as Gk.

Double-match index ψ is defined as ψ = Gk* (1/β(Ai, Bj)). ψ is computed for each supplier and each possible β(Ai, Bj).

iii. The maximum of all ψ's is chosen.

The supplier chosen following this protocol may not offer the best price, nor the best quality of matches. However, the combination of the offered price and the quality of product is the best among all the options.

5. Results of Experiments

5.1 Results of Experiments for geometrical matches

Results from experiments described in Section 4.1 show that that dimensional matches with application of the Best Matching Protocol has higher Best Fit Index (∑ β(Ai, Bj)) than those without the use of the Best Matching Protocol i.e., Random Fit Index (∑ φ(Ai, Bj)) in this case. ANOVA show that the value of Best-Fit Index is significantly different from the value of Random-Fit Index. A graphical comparison between these two ways of matching is shown in Figure 5.1.

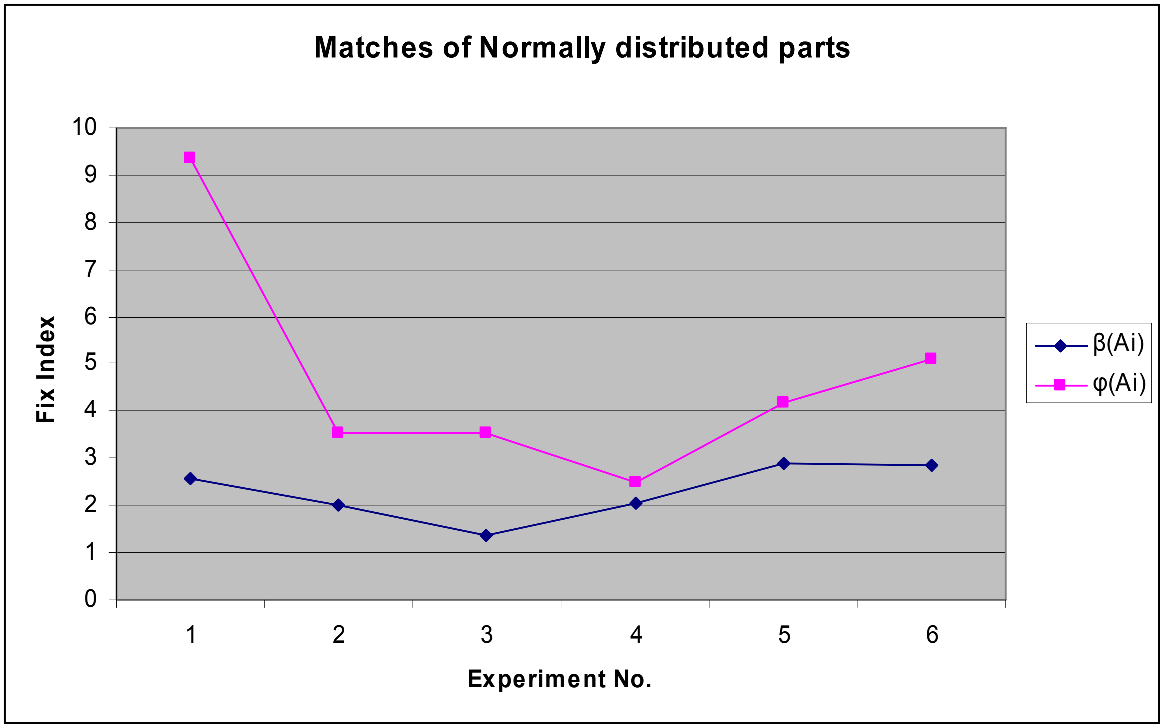

Figure 5.1: Results and comparison between the use of the Best-Matching Protocol and the use of Random Matches for experiments N1 through N6

Defining μ1 as the mean of the β(Ai, Bj)'s and μ2 as the mean of the φ(Ai, Bj)'s, the hypothesis tested is as follows:

Ho: $\mu1 = \mu2$ (there is no significant difference in the means of β(Ai, Bj)'s and φ(Ai, Bj)'s)

Ha: $\mu1 \neq \mu2$ (there is a significant difference in the means of β(Ai, Bj)'s and φ(Ai, Bj)'s)

Since the p-value is 0.040047 which is less than 0.05, Ho is rejected.

It can be concluded that the mean of β(Ai, Bj)'s is significantly different from that of φ(Ai, Bj)'s.

Results of experiments with the other three statistical distributions (Lognormal, Uniform and Exponential) show that matches made with the Best-Fitting Protocol are better matches than those with random matches. Table 5.1 summarizes the experimental results of all four statistical distributions:

Table 5.1: Summary of experimental results of all four statistical distributions

Distribution	**Mean β(Ai, Bj)**	**Mean φ(Ai, Bj)**	**α-level**	**Significantly Different?**
Normal	2.288074	4.704755	0.05	Yes
Lognormal	8.179246	89.3285	0.05	Yes
Uniform	1.886165	4.471716	0.05	Yes
Exponential	1.49617	3.088075	0.05	Yes

5.2 Results of experiments on non-geometrical specifications

Following the procedures and description in Section 4.2, the bigger the G, the lower the Psi (supplier i's floor price) with respect to Pb. Hence, the cost to the customer is also lower. Experiments performed show that supplier 8 is matched to the customer because supplier 8 has the biggest value of Σψk among all the 6 suppliers (Table 5.2). This result show that, although supplier 8 does not offer the best price (supplier 9 offers the best price because the monetary gain of customer with supplier 9 is the biggest) and supplier 8 does not provide the best quality parts (in fact, the lowest quality parts, i.e. Σβ(Ai, Bj) being the maximum value), the combination of supplier 8 and its best fit index is the most desirable.

Table 5.2: A comparison of Double-Match Index and Best-Fit Index (Normal Distribution)

Gk	Σψk	Σβ(Ai, Bj)
4	411.3863	2.569903
5	2838.633	2.011564
6	2045.014	1.356042
7	1314.321	2.059333
8	2840.528	2.885285
9	826.0147	2.846315

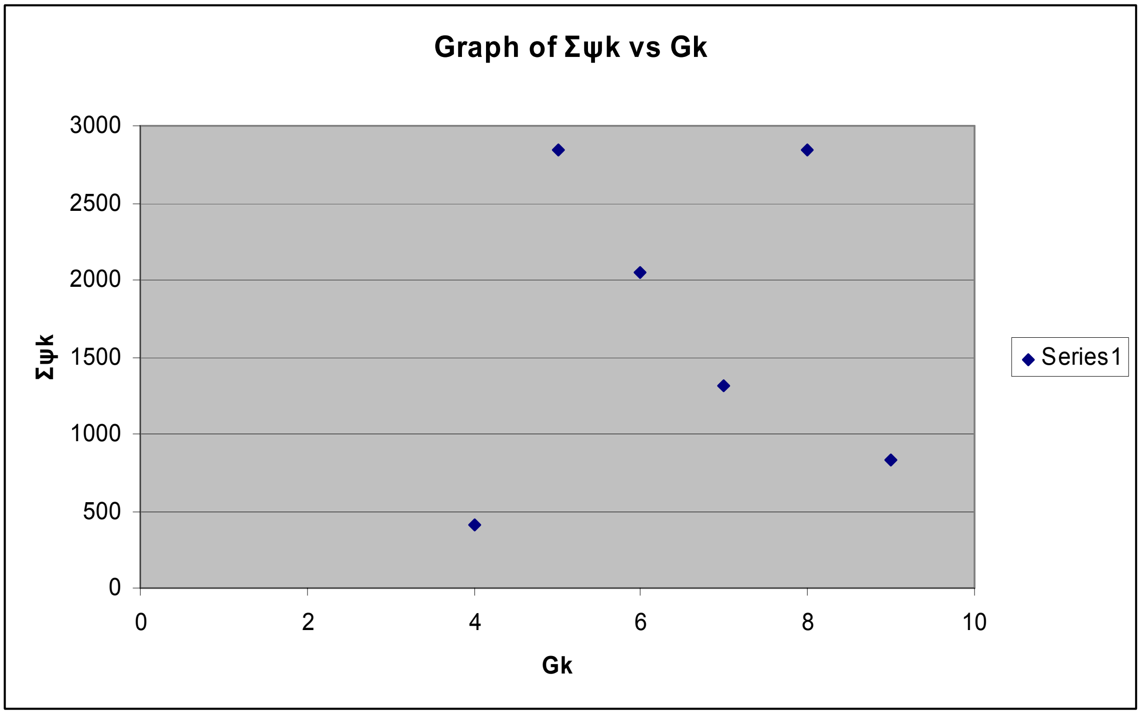

Figure 5.2: Graph showing the scattered plot of Σψk vs Gk. This scatter plot can be used to show the order of preference for choosing a supplier.

From Figure 5.2, the next best choice of supplier is supplier 5 because it has the next highest value of Σψk, followed by supplier 6, 7, 9 and 4. This methodology shows the trade-offs between price and quality of parts supplied. Similar tables can be constructed for parts that follow different statistical distributions.

6 Conclusion and Recommendation

In this research, the Best-Matching Protocol is developed, defined, applied and analyzed. This research explains and demonstrates the use the Best-Matching Protocol both in a manufacturing environment as well as in a supply network. The purpose of this protocol is not only to serve as an interface between different dimensions of a distributed system, it also yields desirable results in terms of matching "appropriate" parts to each other based on a pre-defined set of rules. This is a major ingredient for moving toward a better quality product in the manufacturing setting as well as cost reduction and proper supplier selection in the case of a supply network.

Experiments for both geometrical and non-geometrical matches are performed in this research using four statistical distributions. In every experiment performed, matches which are made using the Best-Matching Protocol have better Fit Index than those which are randomly matched.

A double-match is defined and used for matching a supplier to a customer. The double match makes use of suppliers floor price, customer's ceiling price, production cost, vulnerability cost, communication cost, logistic cost, as well as the Best Fit Index defined for geometrical matches to match supplier with customer. The supplier who is matched to the customer may not offer the best price, nor produce the best quality products, but the combination of his/her price and quality is the best.

6.1 Future Research Recommendation

There are untapped areas which are related to this research. Some of these areas which need to be investigated are as follows:

1) Extension and application of the Best-Matching Protocol to a more complex manufacturing systems and supply network. Three or more matches can be investigated using an extension of the protocol to provide a more realistic scenario of a manufacturing setting as well as a more realistic replica of a supply network which consists of more than two members.

2) A larger sample size can be used in the simulation and the experiments in order to provide a more statistically sound comparison between matches made with and without using the Best-Matching Protocol.
3) Different types of matching procedure can be investigated. This research compares the use of Best-Matching and Random-Matching. Other types of possible matching are First-In-First-Out, Last-In-First-Out, Earliest-Due-Date, etc.

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