Development of the Internet-Based Customer-Oriented Ordering System Framework for Complicated Mechanical Product*

Mingwei ONG** and Keiichi WATANUKI***

Recently, as consumers gradually prefer buying products that reflect their own personality, there exist some consumers who wish to involve in the product design process. Parallel with the popularization of e-business, many manufacturers have utilized the Internet to promote their products, and some have even built websites that enable consumers to select their desirable product specifications. Nevertheless, this method has not been applied on complicated mechanical product due to the facts that complicated mechanical product has a large number of specifications that inter-relate among one another. In such a case, ordinary consumers who are lacking of design knowledge, are not capable of determining these specifications. In this paper, a prototype framework called Internet-based consumer-oriented product ordering system has been developed in which it enables ordinary consumers to have large freedom in determining complicated mechanical product specifications, and meanwhile ensures that the manufacturing of the determined product is feasible.

Key Words: Individual-Oriented Product, Specifications, Restriction, Internet, Data Mining, Apriori Algorithm, Fuzzy Set Theory, Artificial Intelligence

1. Introduction

Figure 1 shows the difference of mechanisms between manufacturing of general product and individual-oriented product. Currently, mass production and small-lot multi-variety production system comprises largest proportion of all production systems. In these production systems, market survey is often conducted in order to understand the customers' needs, the survey result is then conveyed to the maker or designer, and finally general products that fulfills most of the customers' needs are manufactured. On the other hand, in order to produce an individual-oriented product, intimate communication between maker and individual customer is necessary for the maker understands the needs of the individual customer, and for the individual customer understands the constraints of the maker as well. From Fig. 1, it is trivial that manufacturing of custom-made product may consume more time and energy per each, which is one of the reasons for many manufacturers trying to avoid manufacturing custom-made products.

However, recent trend has shown that in countries where consumers have relatively strong buying power, consumers prefer buying products that reflect their own personality and characteristic. For instance, manufacturers of personal computer, electrical home appliances and even vehicle tend to increase their products range to fulfill various needs of consumers. Hence, it is almost certain that individual-oriented product is gaining importance day after day. In conjunction to the escalation of this trend, one may foresee that current custom-made production system may not be able to cope with huge demands of individual-oriented product in the future. Likewise, in mass production and small-lot multi-variety production systems where by the information technology systems, such as enterprise resource planning (ERP), supply chain management (SCM), customer relationship management (CRM) systems and so on, are utilized to support the production systems, custom-made production system also needs to have its own information technology-based support system to boost the efficiency of its production flow. In this research, we are concerned about the mutual understandings between the maker and the customer, thus proposes a prototype framework named, Internet-based consumer-

* Received 22nd November, 2004 (No. 04-4237)

** Graduate School of Science and Engineering, Saitama University, 255 Shimo-okubo, Sakura-ku, Saitama-shi, Saitama 338–8570, Japan.
E-mail: omwong@mech.saitama-u.ac.jp

*** Department of Mechanical Engineering, Saitama University, 255 Shimo-okubo, Sakura-ku, Saitama-shi, Saitama 338–8570, Japan.
E-mail: watanuki@mech.saitama-u.ac.jp

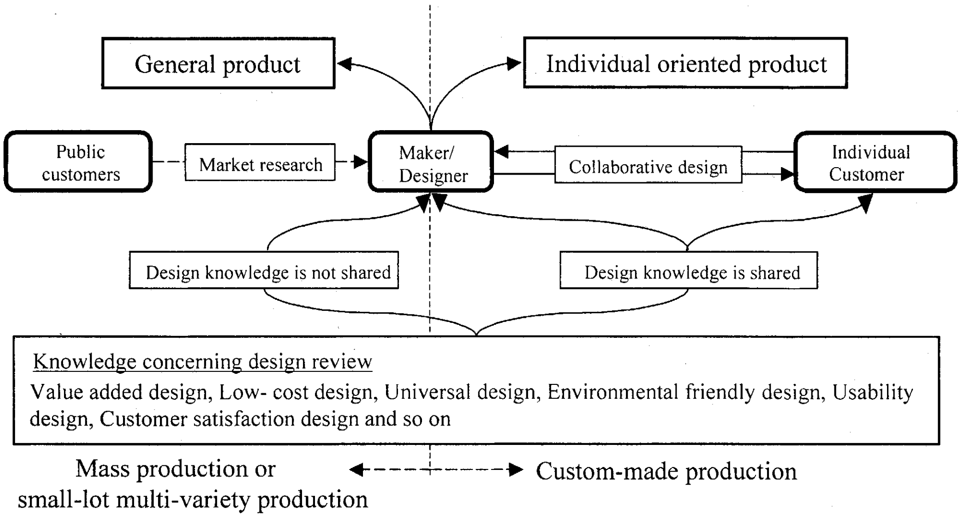


Fig. 1 The procedures of manufacturing individual oriented product

oriented product ordering system that enables ordinary consumers to have large freedom in determining complicated mechanical product specifications, and meanwhile ensures that the manufacturing of this product is feasible.

2. Internet-Based Consumer-Oriented Product Ordering System

2.1 Merits of using the Internet as a communication platform

The Internet has provided a space that is free from time and location constraints for people around the world to communicate speedily. As more and more users are accessing to the Internet nowadays, many websites have advanced from merely providing information to real time interactive communication systems. From business point of view, the Internet serves, as an essential platform to link up maker and customer, thus doing business with people around the world is no longer a difficult issue. Therefore, our proposed framework is designed to run on the platform of World Wide Web(WWW), so that people around the world can use it and have speedy response without needing to concern about time and location constraints.

2.2 Current situation of product ordering system

Ordering and buying products via the Internet is indeed not a new idea anymore nowadays. However, in the case of selling mechanical devices, websites nowadays only allow narrow range of specification choices to be determined by the customer. Moreover, most of the mechanical products put up on the Internet are manufactured through mass production or small-lot multi-variety production systems. This is mainly due to various constraints such as, the communication problem in custom-made production system as mentioned in chapter 1, complexity of the products, productivity factors and others. Contrary to the existing ordering systems, our research aim to develop a framework that enables the customers to determined their desirable specifications from a vast pool of specifications for complicated mechanical products, and meanwhile encourages the customers to come out with new design alternatives.

2.3 System flowchart

Figure 2 shows the flowchart of our proposed Internet-based customer-oriented ordering system. As shown in Fig. 2, the procedure start with customer as client accesses to the system and selects the specifications of a product from a vast pool of specification choices. Upon each and every selection, the related information will be sent to the server for data processing. In the case, where by product specifications are partially selected, information such as restrictions of specifications combinations, estimations of cost and delivery date and recommendations of specifications will be extracted from the database and sent back to the client. This process is repeated until the customer finishes selecting all specifications that form a product. Then the selected information will be sent to the existing advanced planning and scheduling system (APS) where by the cost and delivery date are calculated and sent back to the client in real time.

2.4 Challenges in developing the framework

Challenges in developing the framework are listed as below,

(1) As the targeted product in this paper is custom-made complicated mechanical product that is formed by multiple inter-related specifications, structuring of product specifications becomes vital because the structure illustrates the relationships of product specifications among one another.

(2) Due to manufacturing constraints and the nature of the specifications, there are combinations of specifications that could not be manufactured. Therefore, the framework must includes a module that prevents those combinations to be chosen by the customers.

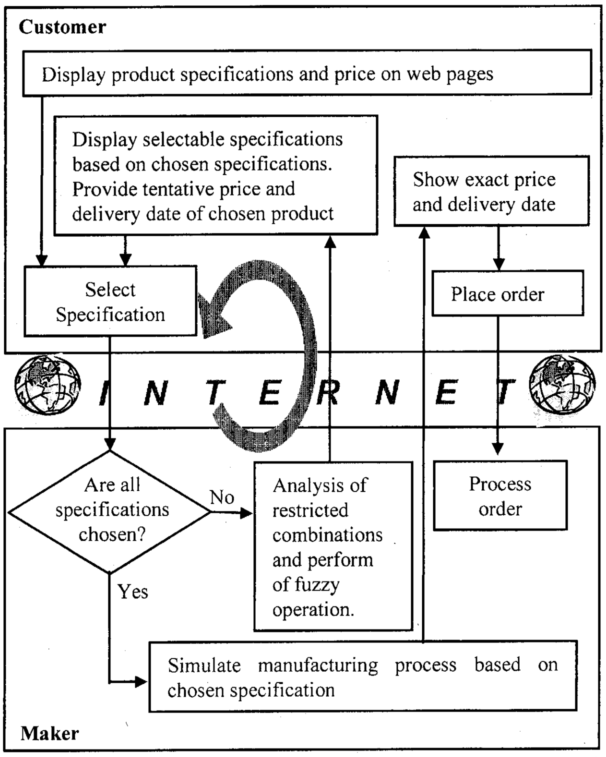


Fig. 2 Flowchart of internet-based customer-oriented ordering framework

(3) Corresponds to the vast pool of specifications choices, it is undeniable that the customers may encounter difficulties in determining their desirable specifications, especially when they are not familiar with the specifications. To solve this problem, artificial intelligent must be embedded into the framework, so that it can support the process of specifications determination.

The remedies for the above mentioned challenges would be further discussed in following chapters.

3. Features in the System

3.1 Structuring of product specification

Structuring product specifications is vital because the structure illustrates the relationships of product specifications among one another. From this structure, the customers may well-understand how a product is formed and thus enable them to select their most desirable specifications for a product. On the other hand, the maker too may find the structure useful when carrying out propagation and alteration of specifications.

In this paper, we have proposed that product specifications are modeled by using a tree. This is because a tree can accurately reflect the relationships of propagated specifications, especially for complicated mechanical product. Figure 3 shows a tree model of product specifications that consists of 3 types of node, namely root, specification subject node and specification node. The root of the tree represents the title of the selection of product specifications.

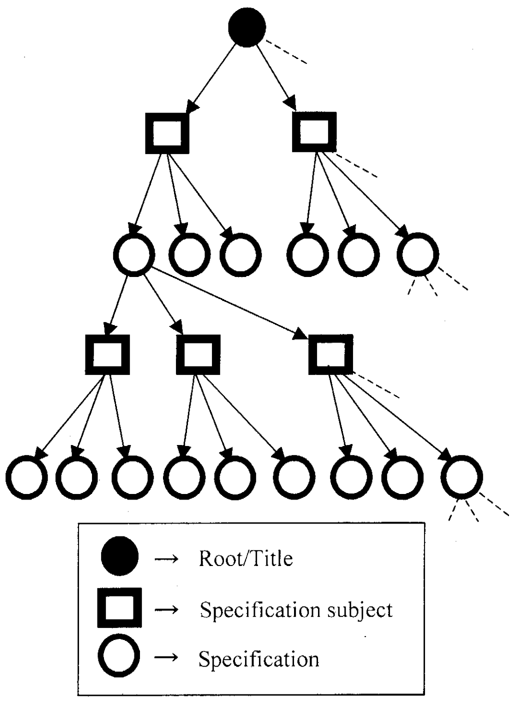


Fig. 3 Tree model of product specifications

Under the root, the specification subject node and specification node interconnecting between one another and propagating corresponds to necessity.

3.2 Setting restrictions among specifications

Increasing the choices of specifications can no doubt provide more freedom to the customer, thus enable the manufacturing of individual-oriented product. However, due to manufacturing constraints and the nature of product, there are combinations of specifications that could not be manufactured in which we have named it as restriction among specifications in this paper. In conjunction to this, our research has studied the nature of the restrictions and proposed effective ways to set and store the restrictions. In this paper, restrictions are divided into two types, namely dimensional restriction and non-dimensional restriction. Both restrictions are explained as follow.

3.2.1 Dimensional restriction In this paper, we define dimensional restriction as restriction among dimensional specifications that can be represented by using mathematics inequality.

3.2.2 Non-dimensional restriction Non-dimensional restriction is defined as restriction among specifications that cannot be represented by using mathematics inequality. This type of restriction can easily occur especially when non-dimensional specifications are involved, such as the specification subject of material that consists of wood, aluminium, steel, stainless steel, and so on. For example, the use of wooden dashboard may be limited to superior car model, or the use of titanium frame may be limited to high quality lens of spectacles.

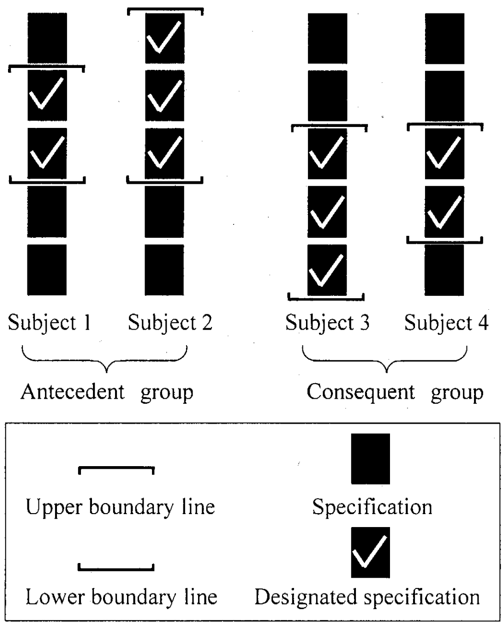


Fig. 4 Setting of non-dimensional restriction

Although sometimes, non-dimensional restriction can be carefully quantified and turned into dimensional restriction, in most of the cases, this type of quantification is not preferred as it may affect the initial understanding of a specification and thus, cause confusion to the customers. For example, material can be anchored to dimensional properties such as toughness or prices. In this paper, characteristics of non-dimensional restriction are studied and effective way to store the restriction data is proposed.

Figure 4 shows a non-dimensional restriction that involves multiple specification subjects. Here, specification subjects are divided into two groups, which are the antecedent group, and the consequent group with each subject consists of five specifications. In this restriction, combinations of designated specifications in antecedent group and the combinations of designated specifications in consequent group should not be chosen simultaneously. As a result, there exist 36 restricted combinations in this non-dimensional restriction.

In our research, we have observed that specifications in non-dimensional restriction are somehow arranged in certain orders even thought these orders may not be obvious to the customers. For example, when arranging the specification subject of computer processor, its specifications are usually sorted by performance or price. Corresponds to this characteristic, the designated specifications involve in a restriction are often in continuity as shown in Fig. 4. Therefore, non-dimensional restriction has parameters listed as follow

$$\text{Non-dimensional restriction}, R = f(AG, CG) \quad (1)$$

where by AG is antecedent group and CG is consequent group that are expressed as follow.

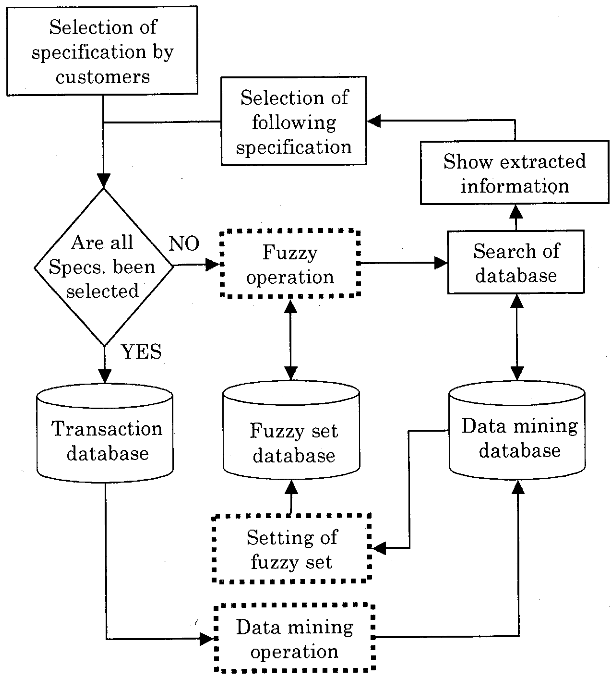


Fig. 5 Flowchart of specification determination support system

$$AG, CG = \{S \mid S \text{ is specification subject}\} \quad (2)$$

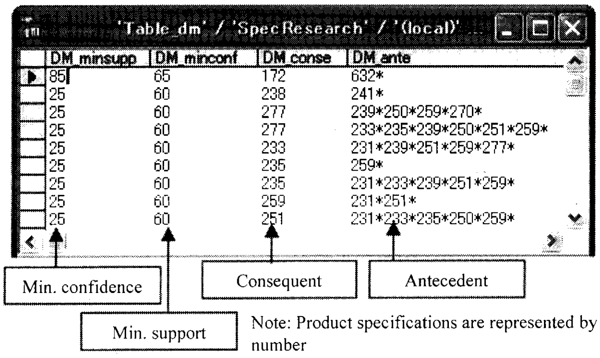
$$S = \{UB, LB \mid UB \text{ is upper boundary}, LB \text{ is lower boundary}\} \quad (3)$$

By having the above-mentioned parameters, non-dimensional restriction data becomes relatively small and this may help to prevent the overflow of database and increase of performance in data extraction.

3.3 Support system

Considering the ability to determine product specifications may be vary for every individual, artificial intelligent module has been embedded into the framework, so that it can support the process of specifications determination. In this paper, artificial intelligent is powered by the integration of data mining and fuzzy set theory. The flowchart of specification determination support system is shown in Fig. 5. The working of this support system is based on the premise that transaction database contains a certain amount of reliable transaction data. Transaction data here means the past combinations of specifications that have been make into real products. Data mining operation is performed on the transaction data at a certain intervals of time or after a certain amount of new transactions is reached. From there, data mining database is created, which later it is used to create fuzzy set database. Once both data mining and fuzzy set database are created, during the specification determination process, appropriate specifications will be extracted from fuzzy set and data mining database for generation of recommendation specifications corresponds to the selected specifications.

3.3.1 Application of data mining In this paper, Apriori Algorithm by Agrawal and Srikant[1] is used to



DM minsupp	DM minconf	DM conse	DM ante
85	65	172	632*
25	60	238	241*
25	60	277	239*250*259*270*
25	60	277	233*235*239*250*251*259*
25	60	233	231*239*251*259*277*
25	60	235	259*
25	60	235	231*233*239*251*259*
25	60	259	231*251*
25	60	251	231*233*235*250*259*

Fig. 6 Relational database of datarmining

search the associate rules among specifications contained in transaction database. Apriori algorithm is widely used in the field of marketing analysis but application on the support of mechanical product specifications is limited. Apriori algorithm is explained as follows.

Given a set of transactions, each described by an unordered set of items, an association rule $X \Rightarrow Y$ may be discovered in the dataset D, where X as antecedent and Y as consequent, are conjunctions of items. Association rule carries an intuitive meaning where by transactions in the dataset D, which contain the items in X tend to also contain the items in Y. Corresponds to this, two thresholds, namely support and confidence, are often used to quantify the associate rule. Support is the percentage of the number of transaction for which the rule is valid, divided by the total of transactions, whereas confidence is the percentage of the support of sets that contain X and Y, divided by the support of sets that contain X. Given a minimum confidence, *minconf* and minimum support, *minsup*, Apriori algorithm is able to search all associate rules corresponding to the confidence above *minconf* and the support above *minsup*.

Figure 6 shows that associate rules among multi-specifications antecedent part and single specification consequent part are mined corresponding to various values of *minconf* and *minsup*. Upon every determination of specification by the customer, the consequent parts of associate rules in the database are extracted by matching the combination of selected specifications with the antecedent part. Each extracted consequent part consists of only one specification s_i, where by its weight w_{s_i}, is a function of *minconf* and *minsup*.

$$w_{s_i} = f(minconf, minsup) \qquad (4)$$

As the values of *minconf* and *minsup* are proportional to the frequency of consequent part been selected under a given antecedent part, the weight calculated may naturally represent the intensity of recommendation for the extracted specification.

3.3.2 Application of fuzzy set theory The implementation of data mining on transaction database can

```
Create Fuzzy Set Algoritme ( SpecsSubject S, DataMiningDatabase DM) {
  Forall specifications s ∈ S {
    Forall datamining data dm ∈ DM {
      if (consequent of dm := s) {
        currentante := antecedent of dm
        currentweight := f (minsupp of dm, minconf of dm)
          Forall datamining data dm1 ∈ DM {
            if (antecedent of dm1 := currentante) {
              μ(dm1) := f (minsupp of dm1, minconf of dm1, currentweight)
      }}}}
  }
Return all μ(dm1) and dm1 corresponds to every s
}
```

Fig. 7 Algorithm for generating fuzzy set for every specification in one specification subject

no doubt produce the data needed to support the process of specification determination by the customers. However, due to the consequent part which is used as recommended specification, is rigidly depended on past similar selected combinations of specifications, the support system may loose its function when a totally new combination of specifications is formed during the process of specification determination. In order to avoid such a case, fuzzy set theory is applied in the framework to examine the interrelationships among specifications. By doing this, additional combinations of specifications related to the selected specification combination are generated during the process of specification determination. With these extra combinations of specification as antecedent parts in data mining database, correspondent consequent parts, which are used as recommended specification, may naturally increase in number. Figure 7 shows the algorithm for creating fuzzy sets for every specification in one specification subject while Fig. 8 illustrates the image of fuzzy sets of all specifications in one specification subject.

As shown in Fig. 5, fuzzy operation is carried out upon every determination of specification. The combination of specifications selected by the customer and the fuzzy sets stored in the fuzzy set database will be used for creating additional related combinations of specifications. The procedures of creating additional related combinations of specifications are illustrated and explained in Fig. 9.

4. Case Study

In order to verify the usefulness of the Internet-based consumer-oriented ordering framework, handrail, which is a pure mechanical custom-made product, has been used as design target. Although handrail seems to be a very simple gadget, it is not mass-produced because its specifications highly depend on inconstant factors. For instance, the length of handrail depends on the space of installation, the cross section shape of handrail depends on the

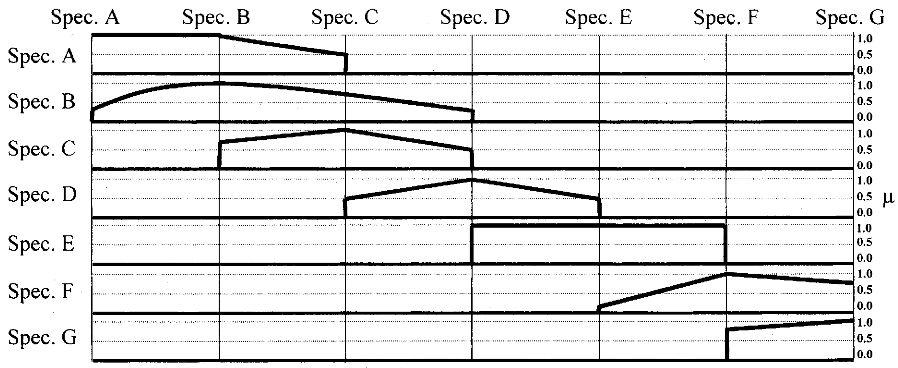


Fig. 8 Graphical expression of fuzzy set for specifications in same specification subject

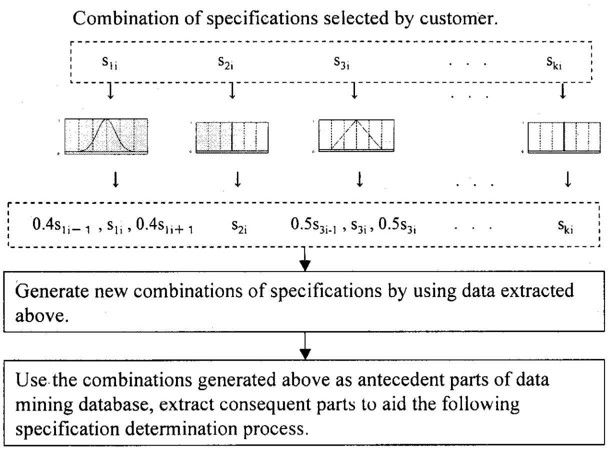
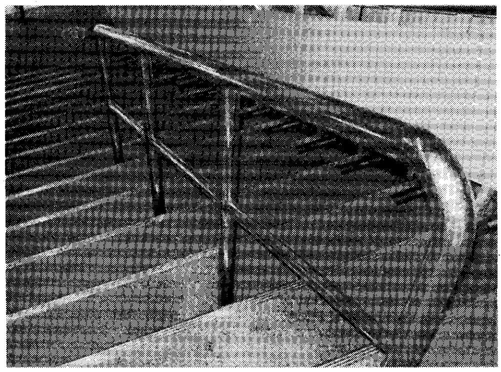
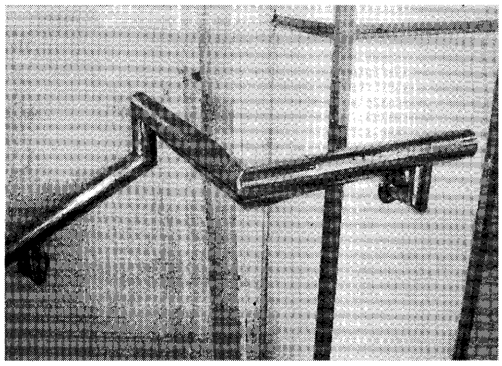


Fig. 9 Fuzzy operation for creating multiple related combinations of specifications



(a) Ground-type handrail



(b) Wall-type handrail

Fig. 10 Types of handrail

purposes of handrail, and the cosmetic design of handrail depends on the class of environment where it is installed and favors of customer, and many others. Therefore, communication between maker and customer is essential in order to come out with an optimum design for the handrail. Figure 10 shows two kinds of handrails that can easily be spotted in our daily lives. In conjunction to this research, we have cooperated with a handrail maker and manage to obtain the past order records of handrail. These records are then used as transaction data and the framework has been improved based on the feedback from the handrail maker. In this paper, to enable the analysis of case study, we have simplified the specifications of handrail. The details of case study are stated as below.

4.1 Preparation for of case study

(1) Specifications of handrail: In this paper, the customers are given the freedom to choose their desirable specifications from 43 specifications that are categorized under 5 specification subjects, namely, length of handrail, cross section of handrail, interval distance between vertical supports, cross section of vertical support and ends design of handrail. The specifications contained in these specification subjects are shown in Table 1.

(2) Past order records of handrail: As mentioned in section 3.3, in order for the support system to function accordingly, past order records as transaction data is utilized in order to generate the data mining database and fuzzy set database. In this paper, 30 pieces of records, which are simplified from the real past order records, are stored into the transaction database.

4.2 Experiment procedure

In order to examine the support function for specification determination, two conditions were preset, where by the first condition is to select the specification recommended by the support system, while the second condition is to deliberately avoid the recommended specification and select original combination of specifications. Selections of specifications for both conditions are each conducted

5 times, where by the first specification selected is chosen randomly from every specification subject. To ease the analysis process, the selection of specification is carried out in two continuous step although 5 specifications are needed to form a complete product. Meanwhile, the specification selection process is carried out in the graphic user interface window shown in Fig. 11.

4.3 Result and discussion

Figure 12 shows the result of experiment. The bubble graphs illustrate the relationship between two specifications through data mining process. The size of the bubble in the graph shows the intensity/probability of specification at *Y*-axis has been selected when specification at *X*-axis is first selected. A part from the diagonal regions that indicate the specifications in the same specification subject could not be selected simultaneously, the concentrations of bubble at certain regions shows that there was a tendency for customer or designer to favor some combinations of specifications.

Table 1 Specification subjects and specifications of handrail

Length(m), A	
Code	Specs.
A1	1m
A2	2m
A3	3m
A4	4m
A5	5m
A6	6m
A7	7m
A8	8m
A9	9m
A10	10m

Cross section of handrail, B Round(Dxt), Square(WxHxt) (mm)	
Code	Specs.
B1	Round(27.2x1.5)
B2	Round(32x1.5)
B3	Round(34x1.5)
B4	Round(38x1.5)
B5	Round(42.7x1.5)
B6	Square(7x7x1.0)
B7	Square(16x16x1.0)
B8	Square(19x10x1.0)
B9	Square(30x20x1.5)
B10	Square(35x35x1.2)

Interval distance between vertical support(mm), C	
Code	Specs.
C1	600mm
C2	700mm
C3	800mm
C4	900mm
C5	1000mm
C6	1100mm
C7	1200mm
C8	1300mm
C9	1400mm
C10	1500mm

Cross section of vertical support, D Round(Dxt), Square(WxHxt) (mm)	
Code	Specs.
D1	Round(27.2x1.5)
D2	Round(32x1.5)
D3	Round(34x1.5)
D4	Round(38x1.5)
D5	Round(42.7x1.5)
D6	Square(7x7x1.0)
D7	Square(16x16x1.0)
D8	Square(19x10x1.0)
D9	Square(30x20x1.5)
D10	Square(35x35x1.2)

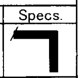
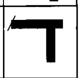
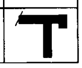
End design of handrail, E	
Code	Specs.
E1	
E2	
E3	

Figure 12 (a) illustrates the selection result of the experiment for the first condition, where by selection is based on recommended specifications. The black dots located the *X*-axis show the starting specifications randomly chosen and the arrow lines lead to the chosen specifications in the following steps. As graph has shown that the arrow lines point towards the regions where the specifications are intensely selected, it is extremely apparent that by selecting the specifications recommended by the support system, it is most likely that product with popular specifications will be formulated. On the other hand, Fig. 12 (b) illustrates the selection result of the experiment for the second condition, where by selection is based on non-recommended specifications. Contrary to the result obtained from condition 1, the arrow lines point towards the regions where almost no specifications are selected, in which this implies that new combinations of specifications had been selected. The selections of this combinations may be caused by the needs of the customer for the specific designs or innovative ideas from the customers.

5. Discussion

In this paper, we have developed a framework for Internet-based customer-oriented ordering system to suit the future trend of customer opting to involve in the product design process. By using the Internet as a design platform, the customer may obtain relevant information, such as the feasibility of design, price and time of delivery almost instantly. From the evaluation and case study done for the framework, it is learnt that the quality of product designed is greatly relied on the precision and quantity of

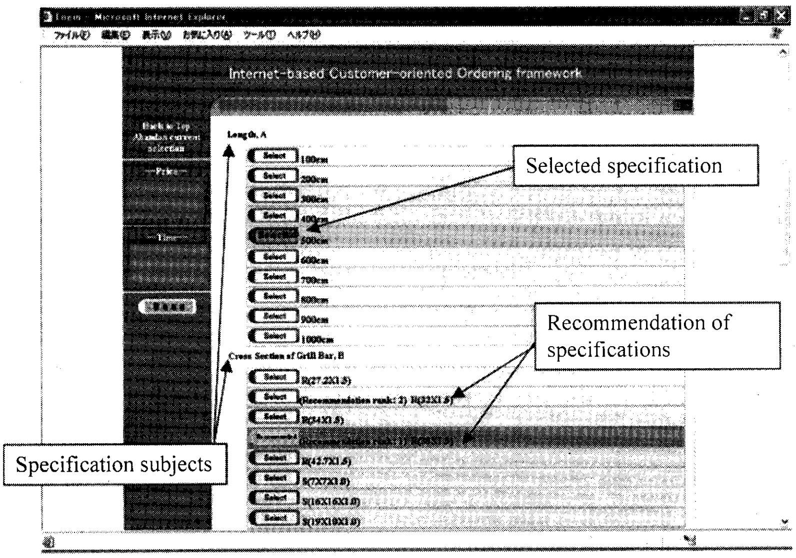
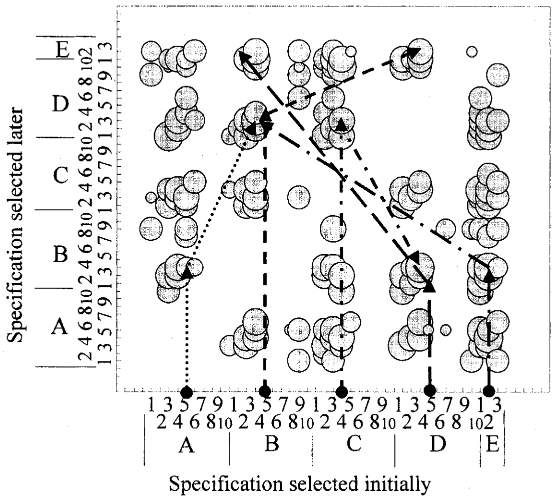
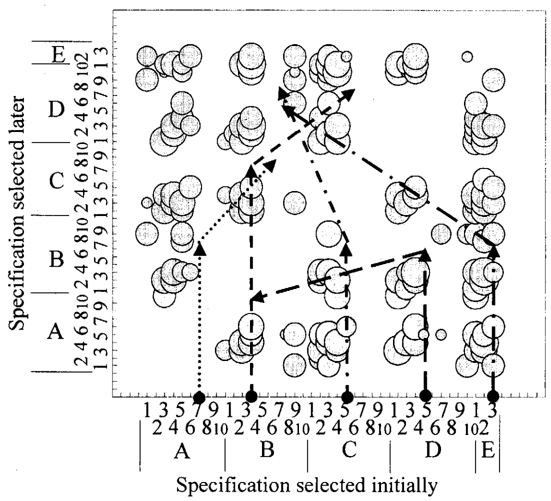


Fig. 11 Graphic user interface of Internet-based customer oriented ordering system



(a) Result of experiment for condition 1



(b) Result of experiment for condition 2

Fig. 12 Experiment results

information input into the system. Thus, the user-ability of the system is greatly depends on how the maker integrates their design knowledge and know-how into the system. Meanwhile, although it is shown in the case study that a support system may aid the specification determination process, the accuracy of the support system is very much depends on the setting of coefficients in the data mining and fuzzy operations. Hence, in order to put the system into good use, the fine tuning of these coefficients deserves special attention as well.

6. Conclusion

In this paper, we have proposed a framework of Internet-based customer-oriented ordering system that is able to provide the customer with greater freedom in determining the specifications of a custom-made product. The framework includes a support system powered by data mining and fuzzy set theory that can support the customers in the process of specification determination, thus enable the manufacturing of individual-oriented product.

References

(1) Agrawal, R. and Srikant, R., Fast Algorithms for Mining Association Rules, Proc. International Conference on Very Large Data Bases, (1994), pp.487–499.

(2) Ong, M. and Watanuki, K., Development of an Internet Based Customer-Oriented Ordering System, Proc. JSME 10th Kanto Branch Annual Meeting, (in Japanese), No.040-1, (2004), pp.489–490.

(3) Ong, M. and Watanuki, K., Development of an Internet Based Customer-Oriented Ordering and Manufacturing System, Proc. the first Asia International Symposium on Mechatronics, (2004), pp.231–236.

(4) Fukuda, T., Morimoto, Y. and Tokuyama, T., Data Mining, (in Japanese), (2001), Kyoritsu Publisher.