**Abstract**

In this work, a study to show that Product Semantics (PS) can be used to study the design of machine tools is presented. Currently, different approaches to PS (Semantic Differential, Kansei Engineering, etc.) are being applied to *consumer* products with successful results, but *commercial* products have received less attention in general and in particular machine tools have not yet been studied. Our second objective is to measure the different sensitivities that diverse groups of population have on answering the same test. The stages of the study are detailed: selection of descriptors or adjectives, selection of images and choice of the population that is to participate. The results show that these techniques are applicable to machine tool design and that the perception of the distinct groups of population involved with machine centres is different in certain aspects, and the differences are not reduced to users vs. experts.

**Relevance to industry**

Decisions on which machine to buy or use are usually based on technical specifications. These technical specifications may be measured, yet some important requirements of the machines, such as ease of use, safety, robustness, etc. are not so easily measurable and comparable. This paper shows that the Semantic Differential approach may be a tool to measure the perception of those aspects.

## Keywords

Machine design

Product Semantics

Semantic Differential

## 1. INTRODUCTION

Traditionally, it has been considered that consumer goods (like domestic appliances) should be "beautiful" and "cheap", while commercial products (like machine tools) should be "good", but not necessarily "beautiful". The concept of "good" (quality) is generally quantified by means of a set of objective and well-established parameters like speed, power, etc., i.e. by means of *technical specifications* (TS) that can be measured and compared. Different methods have been described in the literature for selecting, analysing and comparing machines from their TS (e.g. Khouja et al., 2000) because TS for commercial products may be very wide-ranging and sometimes very complex.

However, accomplishing the TS is important but not always enough for a product to succeed. There are aspects that are difficult to quantify but which do influence the design and/or selection of a machine. For instance, a machine tool may accomplish all the TS of current safety norms but, in spite of this, it may be *perceived* by the operator as unsafe. Consequently, operators will be less concerned with producing and more worried about their personal safety, which they perceive as being exposed to danger by the machine. Little attention has been paid to applying procedures to select, analyse and compare the perception that users have of the different machine tools.

In order to measure the emotional context of a product (like the perception of "safety", "friendliness" or "robustness" of a machine), user involvement within the designing process is necessary (Lebbon and McDonagh-Philp, 2000). User-Centred Design (UCD) techniques offer a variety of strategies and approaches that attempt to address the needs and aspirations of users. Different UCD techniques have been used for different applications (Hsu et al., 2000; Chuang et al., 2001; Lin et al., 1996; Hsiao and Wang, 1998), but the most widespread technique is Kansei Engineering (Nagamachi, 1995; Nagamachi, 2002). All these techniques are based on the theory of Product Semantics, which focuses on the communicative language of a product and the relations and expectations of the user.

Semantic Differential (SD) is the measuring instrument that is most commonly used by UCD techniques to obtain the emotional value of products (Osgood et al., 1957). SD has been applied in the design of street furniture (Maurer et al., 1992), office chairs (Hsiao and Chen, 1997), cars (Hsiao and Wang, 1998), table telephones (Hsu et al., 2000), mobile phones (Chuang et al., 2001), micro-electronics (Chuang and Ma, 2001), printers (Chang and Van, 2003), table glasses (Petiot and Yannou, 2003),or even in the design of mascots used in sports events (Lin et al., 1999). However, it must be emphasized that, although SD has already been documented in areas such as architecture, environmental design, ergonomics and product design, SD has been little used for commercial products. One exception is Nakada (1997), where Kansei Engineering was used to study the attractiveness and perception of comfort of seats for construction machines.

On the other hand, little research about the perception of products by different groups of populations has been conducted. Hsu et al. (2000) also used SD to study the differences in the perception of the shapes of telephones among designers and users. The results revealed that great differences exist among the perceptions of designers and users with regard to the same real object and their interpretations from the same pairs of image-words. Another study concerning Product Semantics Analysis (Karlsson et al*,* 1999), shows that differences exists in choosing and evaluating descriptors between users and experts.

In this paper, a study applied to machine tools, and in particular to machining centres (MC), is presented. Its main objective is to determine whether UCD techniques, and more specifically the SD tool, can be applicable to this kind of products (commercial products) to quantify those features that are not easy to measure objectively and could be quantified from the perception of the user/customer. A second objective is to analyse whether the perceptions of the different groups of population concerning this product are the same or not.

## 2. METHODOLOGY

The Semantic Differential (SD) approach was applied to machining centres (MC) and three different profiles of people: production managers, university lecturers of manufacturing engineering, and machine tool operators. The details of the distinct stages of the study are as follows: looking for the appropriate descriptors or adjectives, searching for suitable images and selecting the population.

### *2.1 Selection of the appropriate descriptors or adjectives*

The search was done through specialised journals, catalogues and web sites of different corporations. This provided us with more than 100 significant words, all of which were related to MC features. In order to reduce the number of words, different filters were applied. First of all, descriptors or adjectives whose meaning and information were already present in the technical specifications and, hence, were susceptible to quantitative evaluation (such as carriages manufactured in foundry aluminium, index table, number of tools, acceleration, rpm of spindle, etc.) were removed. After this first reduction, 36 descriptors were maintained. Descriptors or adjectives with some conceptual affinity (such as “powerful, potent”, “comfortable to handle, easy-to-use, convenient”, “useful, efficient, reliable”, among others) were condensed. With the 22 remaining descriptors, two engineers, experts in manufacturing processes, conducted a preliminary test to remove the less significant descriptors or adjectives, which finally resulted in the 18 descriptors presented in Figure 1. The adjectives were used in Spanish and translated into English for this paper. This figure also shows the arrangement of the form. Although differences between users and experts in choosing adjectives were already known (Karlsson, et al*,* 1999), in this study, the users were not involved in the production of descriptors/adjectives, because our aim was to study the influence that diverse groups of population have on the *results* of the same test.

To prevent prejudgments, only positive scales were used with a range from 0 to 3 for each of the opposite descriptors belonging to the same pair. An introduction and the nine high quality colour images that are explained in the next section completed the form.

[Insert **Figure 1** about here]

### *2.2 Searching for suitable images*

The images were obtained from the web sites of different corporations. Only recent MC from better-known trademarks, with complete technical information, and including good quality images were selected. The 68 images that were finally selected were classified according to different criteria that could influence the perception of the product. For instance, it is well known the general importance of colour and shape

(Hsiao and Chen 1997, Nakada 1997, Chuang and Ma 2001, Chan 2003). From MC's promotional brochures we did deduce that "shape" includes arrangement, topology, number of bodies and situation of control panel. In addition, according to Nakada and Chuang 01b, and to better show the functions and three-dimensional aspects of MC's it was considered the point of view of the image and the visibility of the chip evacuation system. In sum, the criteria considered were:

- Arrangement of the machining centre: *vertical or horizontal*.
- Topology (global shape): *integrated,* (approximately in one single appreciable shape) or *additive*, (many shapes together forming a whole).
- *Number of bodies* (1, 2, 3, 4 or more) that are distinguishable.
- *Colour.*
- Situation of control panel: *aerial or integrated.*
- Appearance of the doors in the image: *open* or *closed.* This criterion was introduced after a suggestion made by a manufacturing engineer, in the sense that the observation of the headstock could give information that greatly influenced the ratings.
- Point of view of the image: *frontal only*, *frontal-right*, or *frontal-left*.
- The *visibility of the chip evacuation system*.

Again, different filters were applied to reduce the number of images. In a first stage two criteria were used to discard images so that only vertical MCs whose images appeared with the door closed were selected. The remaining 26 images were again filtered to select the most heterogeneous ones according to the rest of the criteria of the classification. A pilot test with the 12 remaining images and the 18 descriptors was then carried out. As the test turned out to be too long and tiring, an engineer who was an expert in machines and manufacturing systems was asked to choose the most diverse MC. The resulting 9 figures of the final test are shown in Figure 2. Before going on, trademarks were removed from images to avoid a priori judgments, and the order in which the images were presented was randomised for every form.

[Insert **Figure 2** about here]

### *2.3 Selection of the population*

Three different profiles were selected: production managers, university lecturers from the ambit of manufacturing engineering, and MC operators. Five different companies were chosen because of their productive experience with Machining Centres: three belong to the ceramic tile mould-manufacturing sector, one belongs to the impression-machinery manufacturing sector, and the last one belongs to the automotive radiators sector. The details of the test (objective, the process and tasks to be followed, and the expected time needed to fulfil the test) were presented to one of the production managers of each company. The selection of the remaining managers and the operators was left to the interviewed manager's discretion. The lecturers of manufacturing processes were selected from three Spanish Universities. A total of 35 subjects participated in the study (Table 1).

[Insert **Table 1** about here]

The participants' experience with MC ranged from 3 to 40 years (mean experience of 13 years, similar in all profiles). Managers' activities were designing, managing and controlling manufacturing processes and, in particular, they were occasionally asked to select and decide on the acquisition of machines. University lecturers are specialists in manufacturing processes and have experience in teaching, as well as in research and development projects in industry. All the operators are used to working with at least traditional tool machines.

## 3. RESULTS AND DISCUSSION

To show the results, in Figure 1 each pair of descriptors will be referenced by the parameter Di for the i-th pair, and their range will be shown from –3 to +3, where +3 means the maximum value for the left side descriptor, while –3 means the maximum value for the right side descriptor.

Figure 3 shows the mean values of the perception of all the attributes for the MC, by groups of profiles, compared to the global average.

[Insert **Figure 3** about here]

A general analysis of the results shows that the MCs selected for the study have a positive perception in general. Best-valued descriptors (D1 High technology, D2 Intelligent, D9 Efficient, D11 Reliable, D15 High quality, D16 Safe and D17 Durable) refer to the perception of technological quality and functionality, i.e. what they are expected to be. Worst valued descriptors, although always with values above 0, are concerned mainly with human-machine interaction (D4 Easy to clean, D5 Accessible, D8 Simple, D10 Flexible and D12 Comfortable).

Statistical differences (non parametric H-test of Kruskal-Wallis) in the perception of the different groups of population are observed in seven descriptors (Table 2). University lecturers tend to rate higher than the others (in 13 descriptors), while MC operators give lower ratings in another 13 descriptors. Production managers' ratings for almost all the descriptors are near the mean. Operators seem to be more critical in rating attributes related to occupational safety and health, such as robustness, comfort and noise, and others related to operational functionality, such as accessibility and easiness to clean.

[Insert **Table 2** about here]

As far as one profile of experts and *two* different profiles of "users" have been differentiated, it can be concluded that more that two (i.e. users and experts) population "classes" exist, at least in evaluating descriptors of commercial products. The ratings of the different populations in the study also express the potential of these techniques: MC operators are more concerned with their safety and the human-machine relationship than other populations are. In this aspect, in further studies the sample of subjects should be extended to other industrial sectors such as MC design engineers.

Figure 4 shows mean values of all the attributes for each MC again compared to global mean values.

[Insert **Figure 4** about here]

As may be observed there are statistically significant differences (non parametric H-test of Kruskal-Wallis) in the perception of each MC in almost all the descriptors (Table 2).

The observation of which machines had the highest and lowest mean values for each descriptor shows that two machines concentrate the highest values for 12 out of the 18 descriptors and another two machines concentrate the lowest for 13 descriptors. No other machine concentrates more than two highest or lowest descriptors, so that MC4 and MC9 (figure 5) were considered the 'best' machines and MC3 and MC7 the 'worst' ones. As positive values for the descriptors were assigned to the features publicized in promotional material (i.e. positive value for High Technology, negative value for Traditional), images of MC4 and MC9 should be better claims than MC3 and MC7.

[Insert **Figure 5** about here]

The results of this pilot study show that semantic differences are clearly perceived by people related to MC. Thus, future work should be centred on the investigation of which design attributes of the MC contribute positively or negatively to the different perceptions expressed. For instance, the results may indicate that when the MC is integrated or has a shape consisting of a maximum of two bodies the opinions of stability, robustness or reliability are favoured, while the location of the control panel (aerial or integrated) is not an influential attribute. These hypotheses should be contrasted in a wider study with this purpose.

Further studies must determine whether managers, engineers and operators are influenced or not by the semantic perceptions they have about the products. It must be studied whether "fashion" is relevant for this product, i.e. whether decisions on which machine to buy, or which machine to use are based not only on technical specifications.

## 4. CONCLUSIONS

In this work, a pilot study based on Product Semantics was conducted to determine the applicability of these techniques to machine tools, and more precisely in machining centres (MC). It has been proved that semantic differences are clearly perceived by people related to MC, and there are statistically significant differences in the perception of each MC.

Moreover, the different profiles of people that have participated in the study perceive some aspects in different ways, and more than two (i.e. users and experts) population "classes" exist, at least in evaluating descriptors of commercial products.

Further studies must determine whether managers, engineers and operators are influenced in their decisions or not by the semantic perceptions they have.

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## FIGURE CAPTIONS

**Figure 1.** Opposite pairs of descriptors or adjectives.

**Figure 2.** Selected images.

**Figure 3.** Global mean (thick line) compared to the mean of each profile.

**Figure 4.** Mean values of each MC (thin line) compared to global mean value (thick line) for each descriptor.

**Figure 5.** Best and worst rated MCs and their most significant descriptors (left and right sides, respectively).

## TABLE CAPTIONS

**Table 1.** Profile and distribution of the population.

**Table 2.** Statistically significant differences between profiles and between MCs for all the descriptors. (* = $\alpha < 0.05$; ** = $\alpha < 0.01$).

## FIGURES

| | | 3 | 2 | 1 | 0 | 1 | 2 | 3 | |
|---|---|---|---|---|---|---|---|---|---|
| D1 | High technology | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | Traditional |
| D2 | Intelligent | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | Limited |
| D3 | Easy to use | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | Difficult to use |
| D4 | Easy to clean | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | Difficult to clean |
| D5 | Accessible | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | Not accessible |
| D6 | Robust | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | Light |
| D7 | Compact | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | Inconsistent |
| D8 | Simple | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | Complex |
| D9 | Efficient | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | Inefficient |
| D10 | Flexible | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | Rigid |
| D11 | Reliable | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | Unsafe |
| D12 | Comfortable | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | Uncomfortable |
| D13 | Powerful | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | Weak |
| D14 | Stable | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | Unstable |
| D15 | High quality | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | Low quality |
| D16 | Safe | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | Dangerous |
| D17 | Durable | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | Ephemeral |
| D18 | Quiet | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | Noisy |

Figure 1

MC 1

MC 2

MC 3

MC 4

MC 5

MC 6

MC 7

MC 8

MC 9

Figure 2

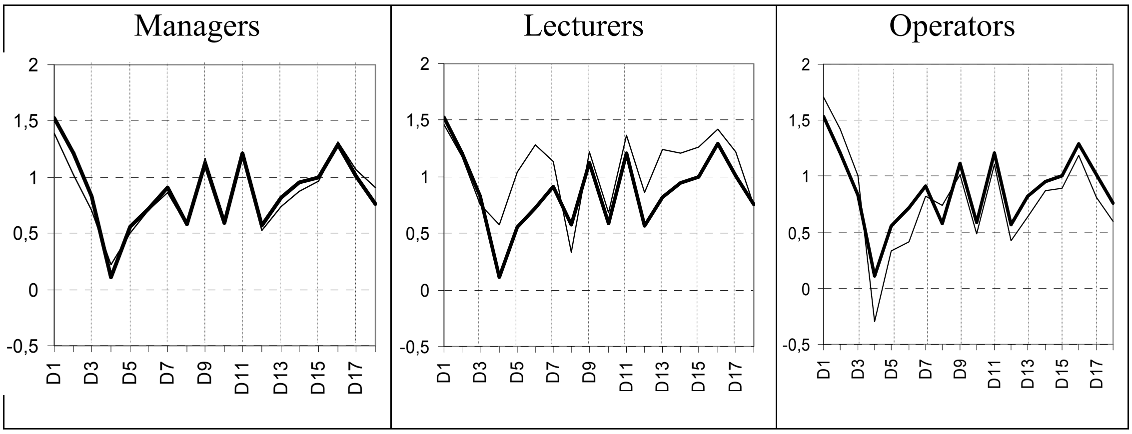
Managers
Lecturers
Operators
2
1,5
1
0,5
0
-0,5
D1
D3
D5
D7
D9
D11
D13
D15
D17

Figure 3

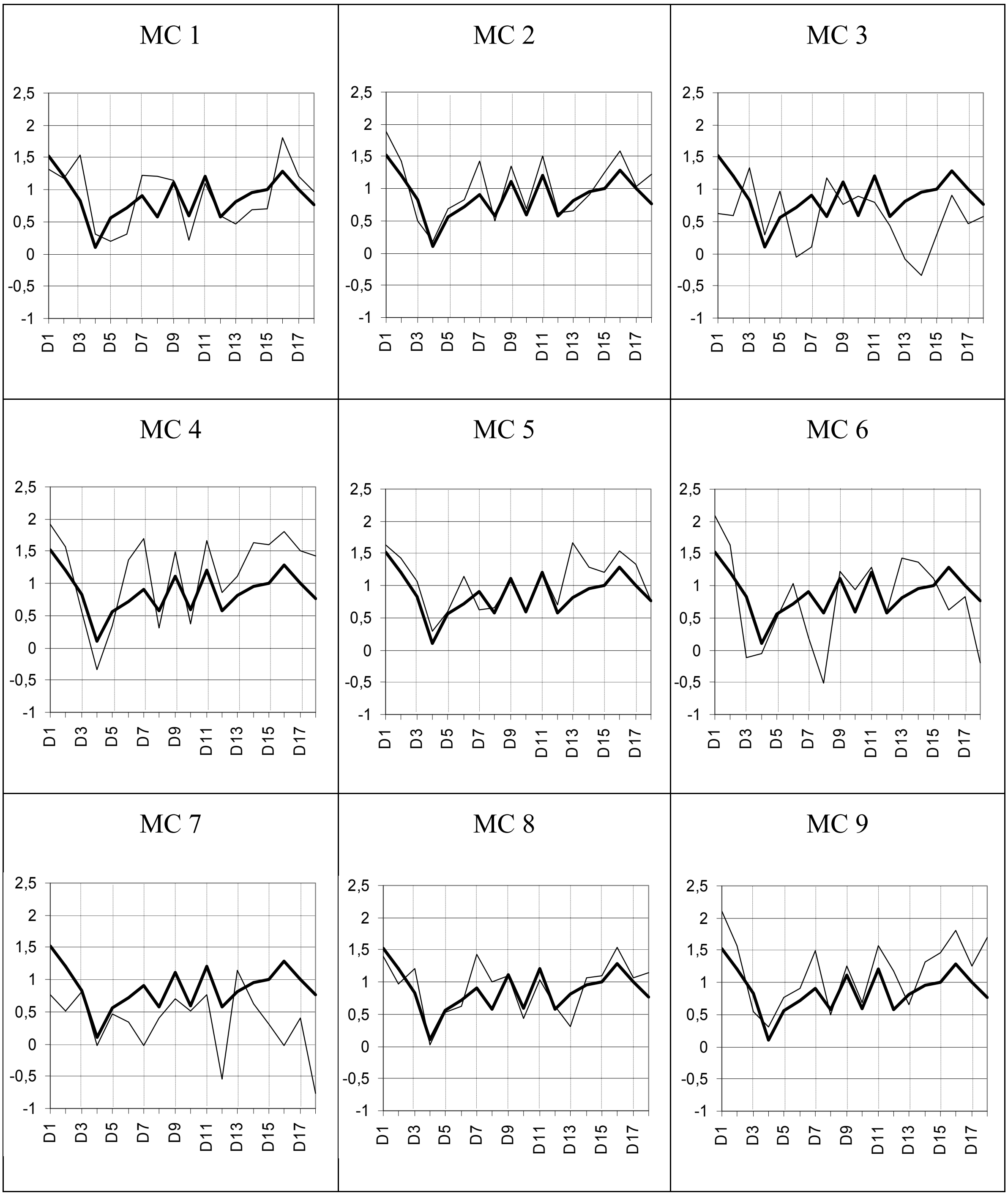


Figure 4

| Descriptors | Value | Best rated MC | Worst rated MC | Descriptors | Value |
|---|---|---|---|---|---|
| Robust | 1.37 | MC 4 | MC 7 | Intelligent | 0.51 |
| Compact | 1.69 |  |  | Efficient | 0.71 |
| Efficient | 1.49 | | | Reliable | 0.77 |
| Reliable | 1.66 | | | Compact | -0.03 |
| Stable | 1.63 | | | Comfortable | -0.54 |
| High quality | 1.60 | | | Safe | -0.03 |
| Durable | 1.51 | | | Quiet | -0.77 |
| | | | | Durable | 0.40 |
| | | MC 9 | MC 3 | | |
| High technology | 2.11 |  |  | High technology | 0.63 |
| Comfortable | 1.17 | | | Robust | -0.06 |
| Quiet | 1.69 | | | Powerful | -0.09 |
| Safe | 1.80 | | | Stable | -0.34 |
| Easy to clean | 0.31 | | | High quality | 0.29 |

Figure 5

# TABLES

| | Tile moulds | Printing machinery | Automotive radiators | Manufacturing engineering | TOTAL |
|---|---|---|---|---|---|
| Production managers | 8 | 2 | 3 | - | 13 |
| University lecturers | - | - | - | 8 | 8 |
| MC operators | 7 | 2 | 5 | - | 14 |
| Total | 15 | 4 | 8 | 8 | 35 |

Table 1

| Descriptors | Profile | MC |
| --- | --- | --- |
| D1 | * | ** |
| D2 | ** | ** |
| D3 | * | ** |
| D4 | ** | |
| D5 | ** | |
| D6 | ** | ** |
| D7 | | ** |
| D8 | | ** |
| D9 | | |
| D10 | | |
| D11 | | ** |
| D12 | | ** |
| D13 | * | ** |
| D14 | | ** |
| D15 | | ** |
| D16 | | ** |
| D17 | | ** |
| D18 | | ** |

Table 2