WOOD RESEARCH
58 (1): 2013
113-122

POSSIBILITIES OF RELIABILITY THEORY APPLICATION IN THE PROCESS OF FURNITURE DESIGN

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(Received July 2011)

ABSTRACT

The article presents an example of the reliability theory application in furniture design. Multidisciplinary approach to the development of new products was taken into consideration and most important factors affecting furniture market success were indicated. In addition, it was demonstrated that the omission of the reliability aspect during the designing process generates a number of implication not only in the area of construction but also market competitiveness. Laboratory research was conducted in order to prove the practical application of the above. The reliability was determined on the basis of tests of a wall furniture connection which employs screw 'Confirmat' type connectors.

KEYWORDS: Design process, reliability, quality, furniture, competitiveness.

INTRODUCTION

Much attention has been recently paid to the process of new product development. Bearing in mind growing competition which is no longer local but increasingly global, managers of enterprises operating in highly developed countries keep looking for tools and methods which will allow their organisations to gain a competitive advantage over their rivals and, in this way, achieve market success. Nowadays design activities are frequently associated with the possibilities of company development as well as an increase of competitiveness not only of individual articles or enterprises but also of entire regions. Therefore, growing attention is focused on attempts to make the development of new products a fully conscious and effective activity. Faced with such challenges, both manufacturers and designers should assure multidisciplinary character of the entire process of new products creation and take into consideration a wide range of expertise, knowledge and experience comprising issues associated, among others, with furniture construction, strength, safety and reliability. This kind of approach makes it possible to concentrate, during the design process, on various product traits and therefore offering users complex and well-thought-out solutions.

The objective of this research project was to examine the possibilities of reliability theory application in the furniture design process as well as the methods of reliability determinationas exemplified by the selected furniture joint.

Design versus reliability

In the subject literature, design is understood as a broad, multidisciplinary approach to article creation comprising the whole range of company activities accompanying a product during all phases of its life cycle. It should, however, be emphasised that in practice, the highest amount of attention is usually paid to the designing aspect associated with the aesthetic shaping of the product form. There are, nevertheless, other areas such as: designing of individual product features (e.g. mode of action, operating comfort, method of utilisation, quality, durability) or shaping and organisation of the product manufacturing process (machine park, utilisation of new production methods, composition modification, number of components) which can also exert a very strong influence on the majority of the economic activities results carried out by a given enterprise (Solum and Hubak 2004). It should be remembered that only one product is the cheapest on a given market. Thus, all other products must attract the purchaser attention by other characteristics, i.e. compete for the buyerby design (Ginalski and Pawliszewski 1994). It has been stressed that design is one of the most cost-effective methods of increasing competitiveness of individual articles, especially by the utilisation of the combination of four areas connected with:

- Brand, aesthetic form, product added value and marketing.
- Product strength and quality.
- Manufacturing methods.
- Components and materials.

During the designing process, it is essential to remember that product is a complex category in which it is possible to distinguish a number of trait levels, making up its image on the market (Kotler 2000, Kotler and Armstrong 2002) Therefore, when developing a new article, designers can have influence on many of its aspects affecting market success. In the case of furniture, these levels can be described as follows: when designing the core (essence) of the article, it is necessary to focus not only on the product shape, its external form but also on its construction, i.e. the applied solutions associated with, among others, appropriate connections, optimal cross sections of individual elements as well as functional features of the product (Fig. 1).

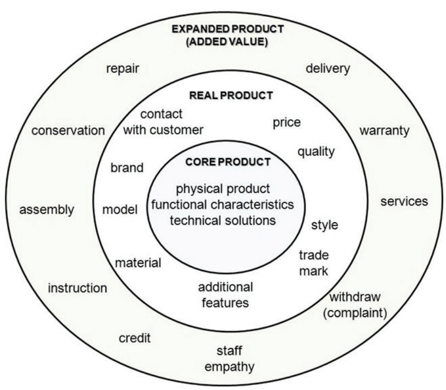

Fig. 1: Diagram of the product trait levels in case of furniture (Kotler 2000).

The next level, called 'real product' is decisive for the perception of the product on the market. In this area, it is necessary to consider design decisions associated e.g. with materials from which the given piece of furniture will be manufactured, the brand under which it will be sold on the market, product quality, its price as well as additional features. It is also worth paying attention to the sale strategy of the given piece of furniture, interior architecture of furniture stores, corporate identity design as well as methods and quality of customers' service. When developing a new product, it is also worth designing additional advantages defined as 'expanded product'. Within the framework of this product traits level, consideration should be given to the means of product delivery as well as warranty conditions. Moreover a good furniture design should result in the lowest possible percentage of customers' complaints connected with its utilisation. It is evident from the above that the range of factors affecting consumers' decisions connected with furniture purchase is very wide. Ginalski and Pawliszewski (1994), when enumerating these factors, indicate their following connections with design (Fig. 2):

Price →	Partly dependent on costs and ease of manufacture (on which DESIGN has impact)
Availability →	Partly dependent on costs and ease of manufacture (on which DESIGN has impact)
Service →	Partly dependent on costs and ease of manufacture (on which DESIGN has impact)
Ecological features →	DESIGN is decisive factor
Ease of use →	DESIGN is decisive factor
Functionality →	DESIGN is decisive factor
Quality →	DESIGN is decisive factor
Reliability →	DESIGN is decisive factor
Appearance →	DESIGN is decisive factor
Comfort of use →	DESIGN is decisive factor
Effective promotion →	DESIGN is decisive factor

Fig. 2: Factors affecting the selection of a product by a buyer and their connection with design (Ginalski and Pawliszewski 1994).

In view of the above, it is important to emphasise the significance of the multidisciplinary nature of the designing process so that already at its early phases, it is possible to take into consideration a wide range of factors essential for the value of the designed article and determining its market success.

It should also be highlighted that in the course of investigations carried out at Bradford Management Centre (Trueman and Jobber 1998), a strong relationship was found between design and quality since the incorporation of the above-mentioned aspects in the design process results in increased reliability and maintenance of the developed article and adds value to the product.

The above remarks are confirmed by the fact that 81 % of companies surveyed in Great Britain maintain that their clients, when purchasing a given product, select it on the basis of its added value (Design Council 2007). Apparently, it is the result, primarily, of increased quantity of positive emotions associated with the use of a given article (Bloch 1995). The fact is further corroborated by investigations conducted on a group of over 200 new productsintroduced onto the market. The performed experiments revealed that goods of high attractiveness, i.e. products characterised by high quality combined with enhanced functional value, had much greater chance of achieving market success (Cooper and Kleinschmidt 1990a, b). Therefore, it is commonly establishedthat factors other than price are becoming more and more important in shaping new products competitiveness. That is why, designers ought to pay special attention during the entire designing process to guarantee not only the appropriate external, aesthetic form of a given article but also its quality and reliability.

As shown by the performed investigations (Ozanne and Smith 1996), when, in the course of the new product designing process, designers take into consideration also characters associated with its quality, safety and reliability, chances for a market success of such a product increase significantly. Formally, reliability can be defined as the property of an object describing its capability to operate properly throughout the required time and in specified operational conditions, therefore, there is no doubt that it constitutes an important element of developing a product added value. It is obvious that reliability exerts a direct impact on the safety of a given product utilisation. According to the Directive 2001/95/EC (2001), a safe product is one that does not pose any danger when used according to the nature of its application. This means that, according to the requirements of this directive, products – including furniture – should be designed and manufactured in accordance with principles of technical knowledge. It is, therefore, clear from the above that it is the responsibility of the designer to find out what is the probability of working loads to exceed allowable levels resulting in possible health damage of the furniture user. Utilisation of this knowledge makes it possible to design and manufacture better products (Kłos and Fabisiak 2010).

Consequently, taking into account the reliability aspect during the designing process allows to obtain a simpler, improved, more reliable, more maintainable, and less costly product through the:

(1) Reduction of the number of components needed.
(2) Better arrangement of the components in a system.
(3) Better selection of materials.
(4) Proper selection of stress, strain and stress – strain relations when the components are being designed.
(5) Use of probabilistic and statistical methods to establish the optimum design and stress and strength distributions.
(6) Implementation of design, manufacturing, reliability and maintainability checklists to catch design errors and to trigger design improvements leading to optimized reliability and maintainability (Kececioglu 2002).

It is evident then, that the application of the reliability theory in furniture design can bring numerous advantages. In addition, it should also be emphasised that reliability-oriented design process of furniture construction makes it possible to determine the warranty period.

As mentioned earlier, warranty constitutes an important aspect of 'the expanded product' and affects, to a considerable degree, additional intrinsic advantages of a given product. Consequently it exerts influence on customers' decisions associated with furniture purchase. This is an important issue because, generally speaking, manufacturers have no sufficient knowledge regarding probability that a given piece of furniture will fulfil its functions for the assumed period of time. Hence, the manufacturer's warranty period is determined on the basis of experience and marketplace expectations without employing for this purpose tools enabling to establish the length of the failure-free furniture utilisation based onempirical and statistical analyses. Such analyses can be carried out utilising a mathematical model known from the theory of construction reliability.

Reliability in the form of function can be presented as (absolutely continuous function) (Murzewski 1989):

$$R(t) = \int_{t}^{\infty} f(s)ds \tag{1}$$

where: *f(s)*–probability density function.

However, generally speaking, the f(s) function is not known and, therefore, it is more convenient to employ in calculations an empirical function of reliability which general form is presented below:

$$\hat{R}(t) = \frac{n(t)}{n} = \frac{n - m(t)}{n} = 1 - \frac{m(t)}{n} \tag{2}$$

where: *n(t)* – function representing the number of objects which, at a given time t, are at a service ability condition,
m(t)- function representing the number of objects which are damaged at a given time t,
n – number of examined objects,
n(t)+*m(t)*=1.

Another very important function which characterises object reliability is intensity of damages which are defined as:

$$\lambda(t) = -\frac{d}{dt}\left[\ln R(t)\right]. \tag{3}$$

In its empirical form, the above equation assumes the following form:

$$\hat{\lambda}(t) = \frac{n(t) - n(t+\Delta t)}{n(t)\cdot \Delta t} = \frac{m(\Delta t)}{n \cdot \Delta t} \tag{4}$$

where: Δt – assumed time interval,
t – time.

The function of damage intensity (hazard function) provides information about what part of objects which survived in serviceable condition in (0, *t*) interval will no longer be fit for use in (*t*, *t*+*dt*) interval (Bucior 2004, Szopa 2009).

Using the above considerations, it is possible to determine reliability of furniture joints and, hence, their usefulness, from this point of view, for practical application.

The example presented below shows the way of reliability determination on the basis of a wall furniture connection which employs screw 'Confirmat' type connectors. They are used to join permanently board elements in cabinet furniture.

MATERIAL AND METHODS

Material selection

The first step in the process aiming at establishing joint reliability is to determine the so called temporary load carrying ability, i.e. a load damaging the joint. In the analysed example, temporary load carrying ability was determined in samples prepared from crude fibreboard 18 mm thick and the samples were subjected to compaction. As mentioned above, screws of 'Confirmat' type were used as connectors in the amount of 2 screws per each joint. The distance between connectors was 320 mm. The examined factors included: joint destroying force and measurement of deflection for the determination of joint reliability.

Description of the course of experiment

Experiments on the temporary load carrying ability were conducted using a ZWICK 1445 testing machine and a special measuring workstation. The way of samples mounting as well as their dimensions are presented in Fig. 3, while Fig. 4 shows a photo of the measuring station.

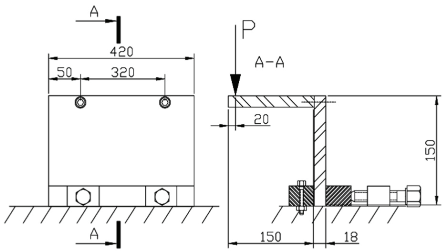

Fig. 3: Scheme of mounting and loading of the connection.

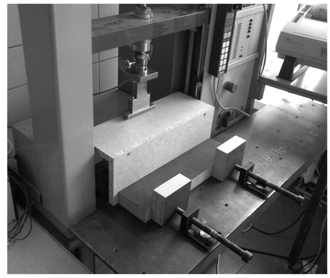

Fig. 4: View of the measuring stand for investigation of immediate load carrying ability.

Establishment of the number of examined samples

In order to determine a representative number of joint samples required to perform investigations and obtain statistically reliable results, the following dependence can be employed (Gajek and Kałuszka 2000):

$$N = \frac{V^2 t^2}{(1-p)^2} \quad (5)$$

where: V- variability coefficient,
t – confidence coefficient for the level of α=95 %; t=1.96,
p – the level of significance.

For this purpose, initial investigations were carried out in the presented example from which it is evident that the value of the variability coefficient V, determining the scatter of measurement results around the mean value $\overline{x}$, amounted to 6.13 % for the joint with two connectors. Therefore, the minimal number of samples determined on the basis of the above formula amounted to:

N = 5.78.

In order to ensure reliability of the performed experiments, ten connections were prepared.

Analyse of joint reliability

A diagram of the measurement station used to determine reliability of joints is presented in Fig. 5. In the discussed example, samples were loaded with a force of 60 % value of the destruction force in order to simulate operational loads which can occur during daily use of the examined piece of furniture.

The performed investigations consisted in long-term static loading of the analysed angle joints. Measurements were taken with the assistance of displacement sensors which measured sample deflections under the influence of the applied load. Then, data were sent to an electric signal recorder coupled with a computer. Tests were conducted until destruction of the connection or bending of its arm by more than 50 mm.

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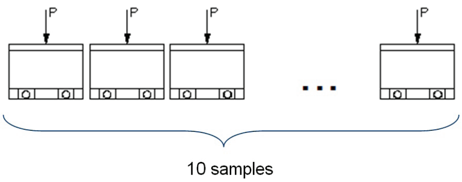

Fig. 5: Diagram of the experimental stand. Source: Own elaboration

Fig. 6: Measuring station for calculating joints reliability.

This value was assumed as limiting and when it was exceeded, the joint was considered damaged. The view of the experimental station is presented in Fig. 6.

RESULTS AND DISCUSSION

Data gathered in the way described above were subjected to statistical analysis. Tab. 1 presents mean value of the breaking force, standard deviation as well as variability coefficient for the examined joints.

Tab. 1: Statistical characteristics of the examined joints.

Joint	Mean value of the breaking force (N)	Standard deviation (N)	Variability coefficient (%)
Joint with two connectors	326.3	20.01	6.13

Joint reliability was calculated using for this purpose the definition of empirical reliability described earlier. Such approach implies the division of the entire time of investigations on reliability into definite time intervals. In the described example, the entire duration of investigations lasted approximately 1000 h and, therefore, it was divided into several time intervals. Tab. 2 presents results of reliability indicators calculated on the basis of formula presented earlier. The table shows only these time intervals in which a significant change of reliability parameters occurred.

Analysing the results given in Tab. 2, it can be concluded that the reliability of the analysed joint during the first time interval was relatively low (0.75) and it remained unchanged until the 550^{th} hour of investigation. This means in practice that the probability of a failure-free operation of this joint amounted only to 75 %. A continuous deterioration of reliability parameters was clearly noticeable from the 600^{th} hour of the experiment.

Based on the obtained results it can be concluded that the analysed joint was characterised by a relatively low reliability. The application of this joint during the designing process of a piece of furniture would result in an additional decrease of the entire constructionreliability. Utilisation of several joints of low reliability in the casefurnitureconstruction affects its global reliability which consists of reliability products of individual nodes (Smardzewski 2005).

Tab. 2: Results of reliability indicators.

Δt (h)	$\hat{R}(t)$	$\hat{F}(t)$	$\hat{\lambda}(t)$
0	1	0	-
0-50	0.75	0.25	0.00267
50-100	0.75	0.25	0.004
…	0.75	0.25	…
550-600	0.625	0.375	0.00444
650-700	0.5	0.5	0.00571
700-750	0.375	0.625	0.00667
750-800	0.25	0.75	0.008
…	0.25	0.75	…

Bearing in mind the obtained results, the designer should make a decision about possible change of the kind of joint or its modification aiming at improving its reliability. Such modification could, for example, consist in the application of additional 'Confirmat' connectors placed in direct vicinity of the existing connectors. An example of a modified joint of improved reliability is presented in Fig. 7. It can be assumed that the distance between connectors is 32 mm. It may provide facilitation of technical manufacturing of the connection (with the usage of for example multiple-spindle drilling machine).

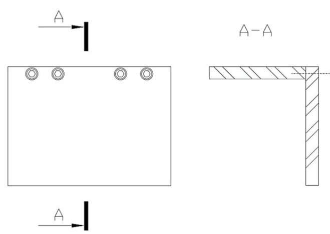

Fig. 7: Scheme of the modified joint of improved reliability.

Such treatment frequently leads to a significant improvement of global reliability which, in some cases, can reach values close to one.

CONCLUSIONS

The above example shows one of the possibilities of joint reliability determination which the designer can utilise in the process of furniture design. Not taking into consideration, already at the stage of designing, issues associated with the reliability of individual elements as well as the entire construction can have various implications appearing to be multidimensional. For the manufacturer, it means generation of additional expenditures associated with costs of possible warranty and servicing of furniture, whereas for users, high furniture unreliability is associated with its low quality and, consequently, loss of confidence in a given brand. The above example proves that in the time of high market competition, utilisation of the reliability theory in furniture design constitutes a very important issue. Thus, producers must pay particular attention to secure high quality of manufactured articles in order to meet growing requirements of consumers and to build a positive company image on the market.

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