Analysis of the most suitable fitting type for the assembly of knockdown panel furniture

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Abstract

In this study, we analyzed the assembly process of the following fitting systems from the aspect of cost: eccentric, inserted bolt lock, T, screw-mounting, screw-in type, and bracket and strip fittings. These are the most preferred fittings in the assembly of knockdown (KD) panel furniture. The fitting system with the least cost was sought. The direct labor, direct material, and direct energy costs, which are called the visible cost elements, were studied in the comparison. The stopwatch work measurement method was used to determine the periods of time needed for assembly. From this, the amounts of the cost elements were calculated. At the end of the analysis, the best fitting systems were determined as follows: 1) the eccentric fitting system was best for labor costs; 2) the screw-in type fitting system was best for material costs; 3) the inserted bolt lock and T fitting systems were best for the energy used during the assembly process; and 4) the screw-in type fitting system was best for the total visible costs. It would be appropriate to use the screw-in type fitting system for cabinets with doors, if the least cost is important, and provided that the consumer in the target market considers it to be suitable. It would be appropriate to use the eccentric fitting system if aesthetics are important, protruding parts are not wanted on the cabinet surfaces, and if a higher capacity is desired in the unit time period for the assembly of the panel furniture.

Furniture can be separated into two assembly types: 1) fixed; and 2) knockdown (KD), which means it can be dismantled and assembled. Glue or other permanent fastening systems are applied to the system elements at the connecting places of the furniture in the assembly of fixed furniture. It is impossible to separate the parts without damaging the furniture, because of the hardening of the glue and the permanent attachment of the elements. The furniture must be moved as a whole piece for all transports. In KD furniture, sometimes called “ready-to-assemble” furniture, the connections of the elements are made to each other by special fittings prepared for this purpose without using glue or other permanent fastening systems. KD furniture can be dismantled and assembled and generally it is assembled where it will be used. The elements can be separated and the furniture can be reassembled at a later time in case it has to be moved for any reason. This characteristic of KD furniture has the following advantages and disadvantages:

1. KD furniture needs a smaller size interim storage space because the furniture parts are packaged as a system and these packages can be stored one on top of the other.
2. KD furniture decreases the unit transport costs, since more furniture can be transported in the same volume for the reasons given above.
3. The risk of damage from hitting and dropping during transport is greater in fixed furniture systems, since they are transported in large masses. This risk is a lot lower in KD furniture.
4. The KD system is more suitable for ease of transport for moving furniture, especially for renters who may move frequently.
5. The KD system is more suitable for the “build it yourself” marketing logic.
6. Unlike fixed system furniture, the KD furniture system does not need special assembly lines and can be assembled on location with simpler tools. This simplifies the production line and is a factor in the reduction of costs.
7. Consumers can move the KD furniture more easily from the furniture store to their homes. What is more important, the
furniture can be moved into places such as apartments and high rise buildings, where larger furniture would not fit because of narrow stairways, elevators, and small doors.

8. KD furniture has to be assembled, either by the buyer or by the assembly team of the furniture store. It could be a disadvantage for the furniture store because special procedures are necessary to check on the work of the assembly team.

Furniture manufacturers must choose from the large number of special fittings for KD furniture produced by different companies and available in the market. Each of the fittings requires different machinery and worker-supported processes for the connection of the fittings to the panel and the connection of the panels with fittings to each other. These differences affect the processing time, and consequently, the production costs. Processing time could be negligible for a single fitting; however, it could constitute significant annual or long-term cost elements for mass or lot production of large numbers of furniture. Manufacturers should make cost analyses to determine which fitting should be used to lower the costs of assembling the panels to each other with the special fittings available in the market.

There are a large number of studies related to the fasteners used in furniture and wood products. Most of these studies are related to the determination of durability performance characteristics, such as tensile, crushing, bending, shear, and embedding strength of the fasteners (Molain and Carroll 1990, Molain 1992, Örs and Efe 1998, Kharouf et al. 1999, Efe and İmirzi 2001, Falk et al. 2001, Güray and Kılıç 2001, Örs et al. 2001, Hwang and Komatsu 2002, Sawata and Yasumura 2002, Yadama et al. 2002, Erdil et al. 2003, Kurt 2003) and the design of fittings (Zahn 1991, Kyanka 1994). No study was found comparing the costs of various fitting systems. This study was made to fill the void.

**Materials and methods**

**Materials**

*Fittings.* — The six most preferred fittings in practice were chosen for the least cost analysis: 1) eccentric; 2) inserted bolt lock; 3) T; 4) screw-mounting; 5) screw-in type; and 6) bracket and strip (Fig. 1).

*Panels.* — The horizontal and vertical panels used in the study were 18-mm particleboard; a solid beechwood with a thickness of 5 mm was glued to their long edges. After top and bottom trimming of the solid wood edge band, the surface of the panels was coated with urea-formaldehyde glue and beech veneers with a thickness of 0.7 mm were glued on the panel surfaces. The dimensions of the panels used and the system diagram showing the assembly of the fittings to the panels are given in Figure 2. A right angle butt joint was used to fasten the panels.

*Machines and screws.* — A gang boring machine and a rechargeable battery-operated screwdriver were used to assemble all of the fitting varieties in the study. Both the horizontal and vertical boring processes can be realized with the gang boring machine and 4 holes can be drilled at the same time. The energy consumption of the boring machine is 0.75 kWh. The energy consumption of the rechargeable battery-operated screwdriver is 0.0163 kWh.

Particleboard screws (3.5 by 16 mm and 3.5 by 20 mm) were used for the pre-assembly of the inserted bolt lock, T, and bracket and strip fittings.

*Time measurement instrument.* — A Casio brand digital chronometer (stopwatch) having a precision of 1/100 seconds and a memory of 10 measurements was used for the time measurements. The chronometer makes it possible to determine separately the total time period with recall of the assembly process and the time of the sub-stages of the process.
The total costs were calculated from the labor and energy costs. The hourly labor cost was accepted to be $4.20 (all amounts in this paper are U.S. dollars). The assembly labor costs according to the type of fitting are given in Table 2.

**Findings and data analysis**

The values of the observations made with the chronometer within the framework of the method just specified are given in Table 1 according to the type of fitting. Table 1 also shows the number of measurements, the adequacy of the number of measurements made, and the ratios of errors of sampling, which are required by REFA work measurement principles. The sampling was considered to be valid as the percentages of error obtained with the calculations were smaller than the percentages of error foreseen (±5%) (Table 1).

The assembly time periods for the panels (average standard time) were 69.11 seconds for the eccentric fitting, 75.12 seconds for the inserted bolt lock fitting, 80.30 seconds for the T fitting, 74.92 seconds for the screw-mounting fitting, 105.94 seconds for the screw-in type fitting, and 105.84 seconds for the bracket and strip fitting (Table 2).

It is also necessary to calculate the direct labor and direct energy costs, besides the direct material costs, in the least cost analyses made by using the visible costs. The total time during which the worker is continuously working (Labor Standard Time), within the process for connecting the fittings to the panels should be taken as the basis in the calculation of the direct labor costs. The total time during which the machinery used is operating (Machine Standard Time) should be taken as the basis in the calculation of the energy costs.

When the total operation processes are taken into consideration related to each fitting given in Figure 3, then the worker is in a working state in all phases related to the performance of the operations, even in the use of the machines. For this reason, the standard times given in Table 2 the working period of the worker related to the operation. Consequently, this time period should be taken as the basis in the calculation of the labor costs. The hourly labor cost was accepted to be $4.20 (all amounts in this paper are U.S. dollars). The assembly labor costs according to the type of fitting are given in Table 2. The analyses were made according to 1,000 fittings because the unit labor costs were very small.

The lowest direct labor cost related to the assembly of the fittings on the panels was $80.63 for the eccentric fitting, followed by the screw-mounting, inserted bolt lock, T, bracket and strip, and screw-in type fittings.

In order to find the energy costs according to the fitting type, the operation sub-stages when the machinery was operating were separated from the operational steps for each fit-
Figure 3. — Process diagrams for the assembly operation of fittings.

ting given in Figure 3. Average machine standard times based on energy consumption are shown in Table 3.

The machine standard times, the machines used in the operations, the energy amounts expended according to machines and the fittings, and the unit energy costs calculated according to these data are given in Table 4. The calculations have been made according to 1,000 fittings, as the energy expended for one fitting is very small. The lowest energy costs were for the inserted bolt lock and T fittings, followed by the eccentric and screw-mounting, bracket and strip, and screw-in type fittings.

The costs of materials are another visible cost element forming a standard in least cost analyses. The material cost is only the fitting itself for some fittings. The screws as well as the fittings also emerge as a cost element for the inserted bolt lock and T fittings, because the connections are made with
The screw-in type fitting system is the eccentric fitting, which has the lowest assembly time period from the aspect of direct labor, followed by the screw-mounting, inserted bolt lock, T, bracket and strip, and screw-in type fitting systems (Table 2). This information is also important from the aspect of determining assembly capacity in panelized furniture. It is more advantageous to choose a fitting system that has the lowest assembly time when high capacity is more important than cost.

The amount of energy expended during the production processes also influences total costs. In addition to having the lowest costs for direct labor, the eccentric fitting is the second lowest in terms of energy costs expended during the assembly stage of the fittings. The lowest cost methods from the aspect of energy costs are the inserted bolt lock and T systems, followed by eccentric and screw-mounting, bracket and strip, and screw-in type fitting systems (Table 4). The screw-in type fittings are the least expensive fittings from the aspect of direct unit material costs (Table 5). This fitting system has the highest cost from the aspect of the energy used and the labor cost during the assembly process. Since it has a rather low material cost, it is in the position of being the least cost method from the aspect of total cost. In contrast to this, the screw-mounting fitting system has rather low assembly direct labor and energy costs, but its high material costs prevent it from being the least cost method and it becomes the most expensive method.

When it is considered from the aspect of total visible costs, the screw-in type fitting system is the most economical method and it becomes the most expensive method.
The average machine standard times based on energy consumption according to fitting types are shown in Table 3.

The energy costs according to types of fitting and machines used (unit energy cost [UCE] was accepted to be $0.12/kWh) are detailed in Table 4.

Table 5 presents the analysis of the material costs according to the fitting type, while Table 6 shows the total cost for 1,000 fittings.

The method. The eccentric, inserted bolt lock, T, bracket and strip, and screw-mounting fitting systems follow (Table 6).

The direct labor, energy, and material costs, which constitute the total costs, may show differences according to geographical regions. For example, as the differences in labor costs change the total costs, they would also change the order of least cost. If the labor wages are increased fourfold to $16.80/hr, then the screw-in fitting, which is in the position of the least cost fitting according to the total costs, would drop to fourth place for least cost.

In the eccentric and screw-mounting fitting systems, the housing is buried within the panel by drilling holes on the horizontal panels in the diameter and length of the connector housing. Consequently, the housing does not make a protrusion on the surface of the panel. Whereas in the other fittings that are connected directly to the panel surfaces (inserted bolt lock, T, screw-in type, and bracket and strip), a protrusion is formed on the panel surfaces. These protrusions, which stem from the fittings within the cabinets, create an aesthetically unsuitable appearance, especially in cupboards and wardrobes without doors. Furthermore, these make it difficult to
clean the inside of the cupboard and wardrobe and cause a loss of volume for usage. When it is considered from this aspect, it would be appropriate to first of all use the eccentric fitting and secondly the screw-mounting fitting system, especially in cupboards and wardrobes without doors, despite the fact that they are not the least expensive fitting systems.

In conclusion, in situations where the lowest cost is important (provided that it is suitable for the consumer in the target market), then it would be appropriate to use the screw-in type fitting system for cupboards and wardrobes with doors. In situations where aesthetics are important, and where protrusions are not wanted on the panel surfaces, and a higher capacity in unit time related to the assembly of the panel furniture is desired, then it would be appropriate to use the eccentric fitting system.

Besides the least cost based on direct cost elements in the selection of fittings discussed in this study, quality characteristics (functionality, durability, reliability, aesthetic characteristics, and safety) should be taken into consideration. A comparison of quality characteristics could not be made in this study, since there was not adequate data to determine all of the features of these fittings. It would be appropriate to conduct a future study on quality characteristics.

**Literature cited**


