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Article

Designing the Assembly Capability Assessment Model for Thai Wooden Furniture

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Abstract: There are many aspects to consider the good assembly model for Thai wooden furniture. The main idea is the assembly can be made in different ways. As a result, the easy to assemble means efficient to produce. The way to make an assembly needs to be considered. The assembly assessment model is evaluated from the assembly's method, the assembly's point, the assembly's direction, the assembly's difficulty and the assembly's motion and time. All these assembly criteria needed to be set to make the assembly easier. Also, the part's size and weight and part direction can affect the result of the assembly. With these assembly criteria, Thai's wooden furniture experts are choosing to select sub-criteria and compare all sub-criteria. Then, the Analytic Hierarchy Process (AHP) is used to calculate the weight of each sub-criterion. With the weight of all sub-criteria when the assessors evaluate the way the assembly makes, the overall score is calculated. The higher overall score means a good assembly model. The second idea is that the assembly can be adjustable and changeable, therefore the assembly's sequence needed to be considered. The sequence assessment model is developed to calculate the assembly time. The sequence assessment model will use an assembly relationship chart and graph to set up all the assembly sequences from the beginning to the finished furniture. The smaller assembly time shows good assembly.

Keywords: assembly criteria; assembly sequence; Analytic Hierarchy Process; assembly chart.

1. Introduction

For Thai wooden furniture industry, the designer or production manager has to understand the physical characteristics of wood, such as swelling shrinkage, and warping whit which depends on the ambient atmospheric moisture (Decharat, 2014). Difference species have different physical and mechanical properties. Variations in the wood properties are due to the differences in location and the presence of extractives (Supadarattanawong & Rodkwan, 2006). Boothroyd (1994) stated the designer must concern about technical and functional product design requirement such as dimensions of the furniture, safety, and exotic touch, because furniture is the product that directly or indirectly serves the lifestyle of the users. The furniture production design is considered not only the production process but also the assembly process. The assembly of solid wood furniture has its own specific production design in jointing patterns, so it is different from other furniture industries. The design for furniture assembly or DFA is a capable tool to reduce the production cost because DFA can enhance the working ability of the workers.

However, the basic DFA assessment process is unsuitable to furniture industry to evaluate the ability of manufacturing and assembling of furniture for dowel joint (Alkan et al., 2018). The assessment process should have been done to suit the specific need for Thai wooden furniture industry (Wherry, 2006). This assessment facilitating assembly planning and suitable assembly process can effectively reduce the assembly time comparing to normal practice (Falck et al., 2016). This is an indicating index factor to assure the improvement in production and assembly efficiency because time is the main factor of production and assembly system. This document contains the guidelines for manuscript preparation and submission. Please adhere strictly to these instructions to assure smooth production of journal article. Please use this template in preparing your manuscript.

2. Design for Assembly (DFA)

The tools, which are widely used in assessing DFA in many industries, are Hitachi, Boothroyd-Dewhurst and Lucas assembly evaluation methods.

2.1. Hitachi Assembly Evaluation

Framework of the Hitachi assembly assessment is divided into 2 parts (Leaney & Wittenberg, 1992; Zakaria, 2009), namely:

A. Direction of Assembly;
   ratings for the analysis of the assembly line as the vertical drop down to all (direction of gravity), it will score high. If it does not slide down the line or vertical direction opposite to that vote, it will be less.
B. Estimated Assembly Cost Ratio;
   Cost ratio is a ratio between total cost of operation for assembly base on the new design and total cost of operation for assembly base on the original design.

2.2. Boothroyd-Dewhurst Assembly Evaluation

Boothroyd-Dewhurst Assembly Evaluation Method is based on the calculation of the volume of production. Evaluation framework consists of 3 parts. The production volume is much less directly related to the manufacture and assembly. Production is low; it is suitable for using the manual. Production of medium volume is suitable to use robots. In case of the high volume assembly, it is suitable to use high-speed machinery. Using Machinery or robots for production and assembly, it is needed to analyze the production cost of the tools that bring to mind the investment in maintenance, labor, etc.

a. The rating of the necessary parts. If the parts are needed to engage with the rest. Refers to the need of the parts to be separated from each other, they will vote "1" and on the other hand, if you do not want to distinguish by the same piece. From the forming, it will be graded "0" because the lower parts in the assembly to decide what parts you need to split or not. Consider the following.
   - The moving parts associated with the other components are then assembled.
   - Different kinds of parts and components are then assembled.
   - A piece in assembly or disassembly of components to the total. If so, as noted above. Can indicate that it is necessary to assemble the parts.

b. Evaluation of the assembly;

$$\text{Design efficiency} = \text{Ideal Assembly Time} / \text{Actual Time}, \tag{1}$$

$$\text{Ideal Time} = 3\ \text{NM (Handing 1.5 s + Inserting 1.5 s)}, \tag{2}$$

2.3. Lucas Assembly Evaluation

Framework of this model can be separated into three evaluation parts.

a. Functional Analysis; this is to examine, whether it is necessary or not to assemble the wood components. If they are the essential components, it has to be separated into 2 parts: part A (essential) and part B (non-essential component). This can be calculated from the equation: Design Efficiency = No of part A/(No of Part A+No of part B) (3)
b. Handling and Feeding Analysis; the analysis of handing will be used for handling assembly. Examining the difficulty in handling wood piece from one point to the fixing point, the assembling is the index of handling and feeding. The handling and feeding analysis have to have penalty score which can be calculated from the following equation:
   Feeding Index = A + B + C + D (4)
   A; Size and weight of wood piece
   B; Difficulty of handling
   C; Direction of piece
   D; Direction of turning piece
   Feeding Ratio = Total Feeding Index / No Part A (5)

C. Fitting Analysis; the aim of fitting analysis is to measure the efficiency of the assembled products. The analysis depends upon the lyres of working parts. The penalty score is involved if it is difficult to fit or difficult to be tight fitting. To examine the possibility of the some fitting direction the fitting index is established to be the scope for evaluation as follows:
   Fitting Index = A + B + C + D + E + F (6)
   A; Fitting.
   B; Direction of process
   C; Insert Part
   D; Direction of fitting
   E; Setting line
   F; Workforce to Assembly

3. DFA For Thai Wooden Furniture

For Thai wooden furniture industry, there are many aspects to consider the good assembly model. First, the way how to make an assembly need to be considers. The assembly assessment model is evaluated from the assembly's method, the assembly's point, the assembly's direction, the assembly's difficulty and the assembly's motion and time. All these assembly criteria needed to be set to make the assembly easier. Also part's size and weight and part's direction can affect the result of the assembly. Second, because the assembly can be adjustable and changeable, therefore the assembly's sequence needed to be considers. The sequence can change everything. Also, the sequence assessment model is developed to calculate the assembly time.

3.1. Assembly Assessment Model

In the studying process and the improvement of an assessment model for wooden furniture industry, it is tested in the real usage in the industry. The continuously improvement is needed to be done through the variety of case study (Beiter et al., 2000). The result of each criteria can be concluded as followed; assembly's sequence, assembly's point, assembly's direction, assembly's difficulty, assembly's motion and time, part's size and weight and part's direction. After selecting the sub-criteria for each criteria assessment in 7 issues that are Assembly Sequence, Direction of Assembly, Direction of Piece, Insert Process, Size and weight of wood piece, Motion and Time Assembly and Difficulty of Joint, the weight of each sub-criteria is calculated by compare all sub-criteria together one-by-one by AHP approach. Then, using the experts from two main sectors, the tertiary education sector and industrial sector in level of expert supervisors, lead the knowledge of AHP to check the assessment. After the comparison, the sub-criteria weights are calculated.

3.2. Sequence Assessment Model

The wooden furniture has many ways to be combined. The different sequence of combining gave different levels of performance. As a result, the assembly sequence planning will use an AND/OR graph tool which design and develop from suitability value of assembly sequence planning and an assembly relationship chart table which show a suitability level in the assembly of each related part as follows:

A. Suitable for both ways in current and consequence assembly difficulty and assembly direction

B. Suitable only for one way in current and consequence assembly difficulty or assembly direction
C. Parts need to assemble but does not suitable for any way in current and consequence difficulty and assembly direction

On the basis of the suitability of the assembly relationship chart that is developed, the assembly step that need to do first is the A relationship.

4. Results

4.1. Assembly Assessment Model

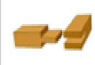
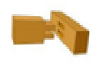
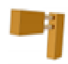
In the studying process and the improvement of an assessment model for wooden furniture industry, it is tested in the real usage in the industry (Purnomo Safaa et al., 2019). The continuously improvement is needed to be done through the variety of case study. The result of each criteria can be concluded as followed; assembly's sequence, assembly's point, assembly's direction, assembly's difficulty, assembly's motion and time, part's size and weight and part's direction.

a. Assembly's Method
To evaluate how good of the assembly, three characteristics of the sequence as follows need to be checked. For example, if the assembly have 33 suitable points for both way assembly and only 11 suitable points only for one-way assembly, the sequence of assembly score 46.76% can be calculated as shown in Figure 1a.
b. Assembly's Point
To check how difficult of the assembly process, the assembly's point need to be considered. The less point assembly show higher productivity. Example of how to evaluate the assembly's point score is shown in Figure 1b.
c. Part's Size and Weight
To make an assembly easier, the easy handling by hand must be used. The big size or heavy weight is not well used because the process needs lifting equipment. Example of how to calculate all criteria is shown in Figure 2a.
d. Part's Direction
The way to make the assembly more effective is to make part symmetry so the assembly is easier. The difficult to be seen different form make the assembly harder. As a result, the characteristic of part's direction need to be considered. Example of how to calculate score of the part's direction that affects the effective of the assembly is shown in Figure 2b.
e. Assembly's Direction
Ratings for the analysis of the assembly line as the vertical drop down to all (direction of gravity), it will show the effective assembly. If it does not slide down the line or vertical direction opposite to that vote, it will be less. All directions that is needed to evaluate are shown in Figure 3a.
f. Assembly's Difficulty
As for wooden furniture assembly, the joint is very important. If the joint is difficult to make, the effective of the assembly is not good. The production time is very high. Also, the point/joint and number of step assemble is used to evaluate the assembly model. All criteria evaluation is shown in Figure 4a.
g. Assembly's Motion and Time
For the motion and time criteria, the evaluations are as follows:
Maximum point assembly and one time clamping
Medium point assembly and one time clamping
Minimum point assembly and one time clamping
The overall score is shown in Figure 4b.

Finally, the overall score which is a summation of all criteria of the closet type wooden furniture equal 36.59% as shown in Table 8. This value analysed in a relatively low level. The lower score means the lower efficiency. Also, there are many topics that can improve to a higher level such as a "time and motion ", or even "The directions of the assembly" and so on.

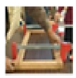
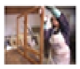
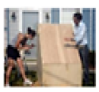
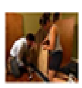
Sequence of assembly		∑=46.76%
33 point 63.46% Weight 53.25%	Suitable for both way in current and consequence assembly difficulty and assembly direction	33.79%
19 point 36.54% Weight 35.50%	Suitable only for one way in current and consequence assembly difficulty or assembly direction	12.97%
0 point 0% Weight 11.25%	Part need to assemble but does not suitable for any way in current and consequence difficulty and not suitable for assembly direction	0%

(a)

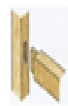
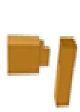
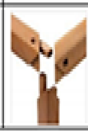
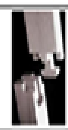
On put assembly				∑=36.06%
28 point 53.85% Weight 46.82%	One point assembly			25.21%
8 point 15.38% Weight 35.84%	Two points assembly			5.51%
16 point 30.77% Weight 17.34%	Many points assembly			5.34%

(b)

Figure 1. (a) Assembly's method score, and **(b)** Assembly's point score

Size and weight of wood piece				∑=41.01%
36 point 69.23% Weight 48.30%	Easy handling by hand (work by one man)			33.44%
7 point 13.46% Weight 35.80%	Medium size or heavy weight (work by one man)			4.82%
9 point 17.31% Weight 15.90%	Big size or heavy weight or need lifting equipment (work to one more man AND/OR using tools to help)			2.75%

(a)

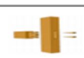
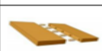
Direction of piece				∑=38.38%
8 point 15.38% Weight 52.12 %	Symmetry			8.02%
39 point 75.00% Weight 39.39%	Easy to be seen different form (left & right or top & bottom)			29.54%
5 point 9.62% Weight 8.49%	Difficult to be seen different form (left & right or top & bottom)			0.82%

(b)

Figure 2. (a) Part's size and weight score and **(b)** Part's direction score

Direction of assembly			∑=23.58%
25 point 48.08% Weight 28.95%	⇓	Straight downward	13.92%
20 point 38.46% Weight 22.04 %	⇔	Move horizontally	8.48%
0 point 0 % Weight 15.79 %	⇗ ⇖	Move diagonally: up/down	0%
1 point 1.92% Weight 12.17%		Turn or lift (down) the whole assembly to insert a part	0.23%
3 point 5.77% Weight 10.20%	⇑	Straight upward	0.59%
3 point 5.77% Weight 6.25%		Turn or lift (up) the whole assembly to insert a part	0.36%
0 point 0% Weight 4.60%		Non form.	0%

(a)

Difficulty of Joint			∑=14.37%
25 point 48.08% Weight 20.47%	One point/joint and one step assemble		9.84%
6 point 11.54% Weight 15.81%	One point/joint and two step assemble		1.82%
7 point 13.46% Weight 8.84%	One point/joint and many step assemble		1.19%
1 point 1.92% Weight 16.05%	Two point/joint and one step assemble		0.31%
0 point 0% Weight 11.16%	Two point/joint and two step assemble		0%
2 point 3.85% Weight 6.98%	Two point/joint and many step assemble		0.27%
1 point 1.92% Weight 9.53%	Many point/joint and one step assemble		0.18%
1 point 1.92% Weight 7.67%	Many point/joint and two step assemble		0.15%
9 point 17.31% Weight 3.49%	Many point/joint and many step assemble		0.60%

(b)

Figure 3. **(a)** Assembly's direction score and **(b)** Assembly's difficulty score

Time and Motion Assembly		∑=28.89%
14 point 26.92% Weight 47.78%	Maximum point assembly and one time clamping	12.86%
8 point 15.38% Weight 33.33%	Medium point assembly and one time clamping	5.13%
30 point 57.69% Weight 18.89%	Min point assembly and one time clamping	10.90%

(a)

Weigh of title		∑= 36.59%
46.67 Weight 41%	Sequence of Assembly	19.17%
36.06 Weight 5%	On put assembly	1.80%
41.10 Weight 6%	Size and weight of wood piece	2.46%
38.38 Weight 8%	Direction of Piece	3.07%
23.58 Weight 14%	Direction of Assembly	3.30%
14.37 Weight 7%	Difficulty of Joint	1.01%
28.89 Weight 20%	Time and Motion Assembly	5.78%

(b)

Figure 4. (a) Assembly's motion and time score and **(b)** Overall score

4.2. Sequence Assessment Model

No.	Part Name	Piece
1	The legs.	2
2	Leg base	2
3	Arm	2
4	Side flap	2
5	Braced legs	1
6	Floor touch	2
7	Seat	1
8	Arm support pole	2
9	Backrest	2
	Total	16

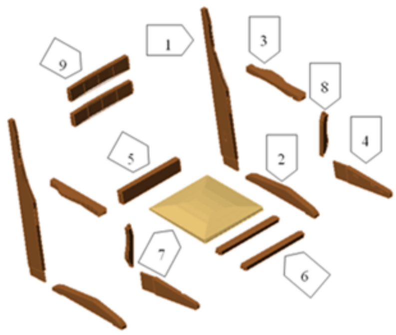


Figure 5. Parts and quantities of 2-legs example chair

	1	2	3	4	5	6	7	8	9
1	-	A	B	B	C	0	0	0	C
2	A	-	0	0	0	0	0	0	0
3	B	0	-	0	0	0	0	A	0
4	B	0	0	-	0	C	0	A	0
5	C	0	0	0	-	0	C	0	0
6	0	0	0	C	0	-	C	0	0
7	0	0	0	0	C	C	-	0	0
8	0	0	A	A	0	0	0	-	0
9	C	0	0	0	0	0	0	0	-

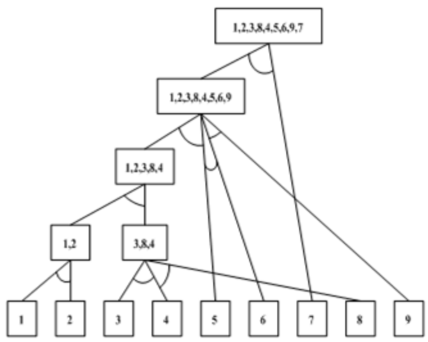


Figure 6. Parts assembly relationship chart to AND/OR assembly sequencing graph

Using the technique of an AND/OR graph to analyze the assembly would help to determine the time of assembly. The longer time mean how difficult of the assembly. The parts and quantities for the 2-legs chair example is shown in Figure 5. By using an AND/OR graph and an assembly relationship chart, the assembly sequence planning is created as show in Figure 6. From the assembly sequence planning, the details of all steps are as as follows: step 1, assembly of part 1 and 2; step 2, assembly of part 3 and 8 and 4; step 3, assembly of part 1, 2 and 3, 8, 4; step 4, assembly of part 1, 2, 3, 8, 4 and 5, 6, 9; and, finally, step 5, assembly of all parts with part 7. All assembly time are calculated as follows:

Assembly time of each step = $(\sum A \leq B) + C + D$ (7)

Assembly time of step number 1 = (Part 1A, 2A) + (Part 1B, 2B)
+ (Part 3A, 8A, 4A)
+ (Part 3B, 8B, 4B)
+ Closes Time (8)
= 31.7502 Min.

Assembly time of step number 2 = (Part 1A, 2A, 3A, 8A, 4A)
+ (Part 1B, 2B, 3B, 8B, 4B)
+ Closes Time (9)
= 21.1668 Min.

Assembly time of step number 3 = (Part 1A, 2A, 3A, 8A, 4A, 5, 6, 9)
+ Closes Time (10)
= 16.4585 Min.

Assembly time of step number 4 = (Part 1B, 2B, 3B, 8B, 4B, 5, 6, 9)
+ Closes Time (11)
= 16.4585 Min.

Assembly time of step number 5 = (Part 1, 2, 3, 8, 4, 5, 6, 9, 7) (12)
= 6.4585 Min.

Conclusively, total assembly time of 2-legged chair assembly which plan with AND/OR Graph (developed, especially, for wooden furniture) is

Assembly Time = 31.7502 + 21.1668 + 16.4585 + 16.4585 + 6.4585
Assembly Time = 92.2925 Min.

With this analysis, the assembly time could be reduced from 122.292 to 92.292 Min.

5. Conclusion

For wooden furniture industry, there are many aspects to consider the good assembly model. The assembly need to be easy. As a result, the assembly assessment model is developed. The assembly's way, the assembly's point, the assembly's direction, the assembly's difficulty and the assembly's motion and time needed to be set to make the assembly easier. Also part's size and weight and part's direction can affect the result of the assembly. With these assembly criteria and the weight calculated using AHP, the assessor can evaluate the way the assembly make and the overall score is calculated. The higher overall score means the good assembly model. Moreover, the wooden furniture assembly sequence can be adjustable and changeable, therefore the assembly's sequence needed to be considers. The sequence can change everything. As a result, the sequence assessment model is developed to calculate the total assembly time. The smaller total assembly time means the efficient assembly sequence.

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