16th International Research/Expert Conference
”Trends in the Development of Machinery and Associated Technology”
TMT 2012, Dubai, UAE, 10-12 September 2012

MODELS FOR DESCRIBING THE STRUCTURE OF PRODUCT AND PROJECTION OF MANUFACTURING CYCLE

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ABSTRACT
For a successful planning and management of a production of a complex product, it is necessary to present its structure adequately. This paper shows a method for structure modeling of a complex product which can serve as a base for application of a general concept for projection of manufacturing cycle. That way we have created circumstances for Just-in-time concept application in productive and business cycle. Viewed from that perspective of time dimensions, it represents a base for value measuring of projected and accomplished solutions.
Keywords: model, product structure, graph, manufacturing cycle

1. INTRODUCTION
Management of complex product manufacturing, based on novel manufacturing doctrine, demands a novel approach to describing product structure. The paper depicts a model for describing complex product structure included in the production program of ‘Sloboda’ Co. Cacak. The model displayed will be used for the projection of manufacturing cycles, i.e., for the just-in-time concept application.

2. PRODUCT STRUCTURE MODEL
Production program (PP) can be defined as a finite set of various products: X_1, X_2, ….., X_n with the total number (n) varying as a function of time. The structure of any product (X_i), on the other hand, consists of parts (elements, sub-assemblies, assemblies) that represent semi-finished products (x_j) with respect to finishing operations, so that production program can be defined as a set of finished products delivered to customers and parts that are burden on inventories. Design composition (decomposition scheme) is used to define and shape complex structures of products and is a basis for industrial product manufacturing. Within the framework of design composition a designer defines functional levels starting from elements (positions) that represent the first level, arriving at the final n-th level, i.e., packed product, over sub-assemblies and assemblies. Figure 1 shows a design composition of one product (denoted by A) with four functional levels consisting of 13 parts (E_i, K_i), two sub-assemblies (P_j) and two assemblies (S_k). To unequivocally define each element (x) of product A, shown in Fig. 1, the name, code and drawing are most commonly used..

$$PP = \{ X_1, X_2, ..., X_i, ..., X_p \} = \{X_i \mid i \in N\} \quad ... (1)$$

$$PP = \{X_i , x_j \mid i,j \in N\} \quad ... (2)$$

$$A = \{(E_i \mid i= 1,8 \;\; K_i \mid i= 1,5), \;(P_j \mid j= 1,2), \;(S_k \mid k= 1,2)\} \quad ... (3)$$

If a model of complex product structure, displayed in Fig.1, is applied to production planning, organization and management, it most often promotes the 'supply push' principle, i.e., 'pushing' production forward by procurement and manufacturing, whereby unnecessary inventories are accumulated at all levels. Priorities are assigned at all functional levels and parts, respectively, and it is impossible to view the entirety (product), time dimension and significance of some parts within the framework of the levels described. With respect to production planning and management, complex product structure modeling and attributes adopted from Fig. 1 are unpractical for two reasons. Firstly, irrespective of the coding system, it is impossible to establish exact position of a part in a graph without a design composition. Secondly, adopted notation is difficult to use in mathematical modeling that is the basis for all simulation processes.

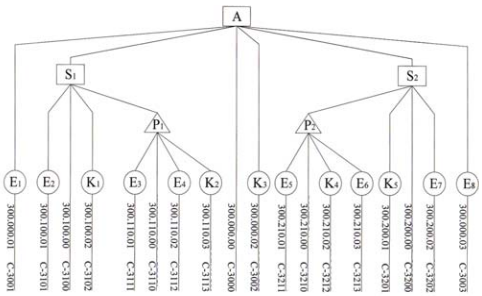

Figure 1. Product design composition

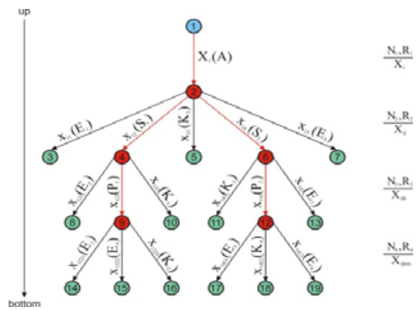

Figure 2. Directed graph of product structure

In order to overcome mentioned deficiencies of design composition, respecting technological and production aspect, using graph theory and novel method based on hierarchical description of parts positions, product structure will be described by the novel directed graph (Fig. 2). Unlike design composition that defines functional levels using the 'bottom-up' analysis, the directed graph in Fig. 2 defines levels (N_i) and spans (R_j) of installing (within the level) all parts (φ), applying the 'bottom-up' analysis. The first description level is the level of the article final assembly or packing. Other levels are defined by parts, beginning from assemblies, sub-assemblies, joints and ending with elements found at the last graph level. Installment levels are defined based on the 'sucking in' principle, starting from the top (first) to the lowest (n-th) level. In this context of complex product manufacturing it is possible to plan with minimal inventories making only what really is needed, 'neither too early, nor too late'. Arcs are denoted by $\mathbf{x_{(notation)}}$, where (**notation**) defines arc's position in a graph. In notation, one integer (i) is used at the first level, two integers (**i, j**) at the second level**,** three integers (**i, j, k**) at the third level ending with (**i, j, k, …n**). Adjacent arcs at subsequent levels are always denoted from left to right by adding to the notation of the adjacent arc, from the preceding level, a number from a set of natural numbers:

$$\textbf{(notation)} = \{\{ \varphi , (N_i, R_j)\} \rightarrow \{i, (i, j), (i, j, k),...,(\mathbf{i, j, k,\ldots,}\, n) \,\forall\, (i,j,k,n) \in N\} \quad ... (4)$$

Using the set theory, the complex product structure can be described by the relation (5):

$$X_1 = \{x_1, (x_{11}, x_{12}, x_{13}, x_{14}, x_{15}), \{(x_{121}, x_{122}, x_{123}), (x_{141}, x_{142}, x_{143})\}, \{(x_{1221}, x_{1222}, x_{1223}), (x_{1421}, x_{1422}, x_{1423})\}\} \quad ... (5)$$

Complex product structure modeling using the relation (5) and graph shown in Fig. 3 allow us to establish dependencies between total number of nodes (Č), lines (L) and parts in a complex product (φ):

$$G = \{Č_i \mid i = \overline{1, \varphi + 1},\ L_j \mid j = \overline{1, \varphi}\} = \{Č_i \mid i = \overline{1,19},\ L_j \mid j = \overline{1,18}\} \rightarrow Č = L + 1 \qquad \text{... (6)}$$

In a graph (Fig. 3), internal (UČ→2, 4, 6, 9, 12) and external (SČ→1, 3, 5, 7, 8, 10, 11, 13, 15, 16, 17, 18, 19) nodes should be distinguished. External nodes define the beginning (1) and endings of the graph (3, 5, 7, 8, 10, 11, 13, 14, 15, 16, 17, 18, 19). Initial (PČ) and terminal (ZČ) nodes define paths in a graph (PG). Graph nodes are used to describe two states, the beginning and ending of each part that is manufactured. Graph lines are used to establish a link between parts and to describe the process of transformation from one into another state (production phases - PF).

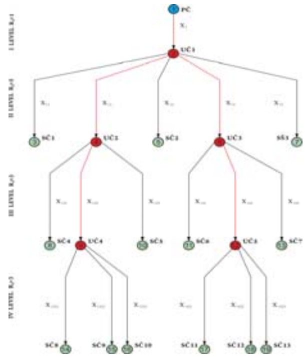

Figure 3. Product structural composition

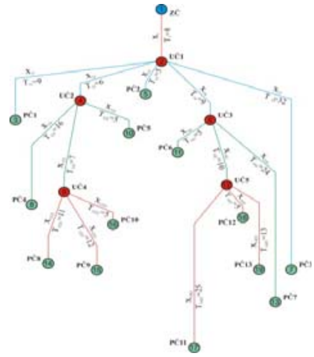

Figure 4. Undirected graph of structural composition with transformed nodes

3. MODELS FOR PROJECTION OF MANUFACTURING CYCLES

If certain numbers or certain functions are incorporated into the components of a set of nodes N and components of a set of arcs L of a finite graph G = (N, L), such a graph is then referred to as a network. Determination of extremal paths in networks is one of the most commonly considered problems in graph theory. With respect to production planning and management, time dimension and the longest path in a graph play a significant role.

3.1. Structural composition graph transformation into Gantt chart

The sequence of steps in the transformation of structural composition graph into Gantt chart is as follows. Step 1: external (terminal) nodes in a structural composition are assigned the meaning of a beginning, while an initial node of a graph is assigned the meaning of production termination. Internal nodes have both meanings. Step 2: one real number is added to each arc in a structural composition, taking into account time dimension of the part's manufacturing cycle. Step 3: the product structural composition is transformed into an undirected graph, taking into account that the distance between graphs is proportionate to cycle duration of corresponding production phases (Fig. 4). Step 4: the lines of a graph in internal nodes (2, 4, 6, 9 and 12) are decomposed and, without disturbing the structure, are transformed into a set of mutually parallel and dependent line segments – activities. Step 5: a coordinate system is set up in the direction of the farthest outermost external node found in a critical (longest) path. Graph lines are bounded by limiters (Fig. 5), instead by the nodes. Production phases times and time reserves can be represented at the latest beginning (Fig. 6) or at the earliest beginning.

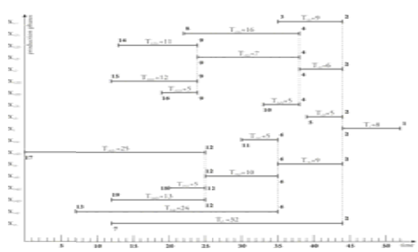

Figure 5. Undirected graph described by a set of activities as a function of time

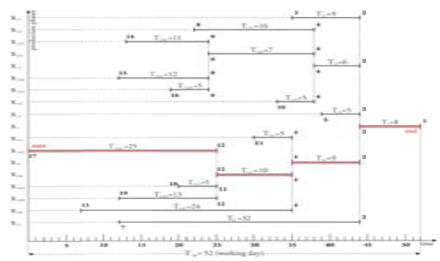

Figure 6. Projection of manufacturing cycle using Gantt chart (demand pull, just in time)

3.2. Structural composition graph transformation into Network diagram

To shape the structural composition graph, Fig.3, into a network diagram, we have to comply with the following procedure. First, a graph opposite of structural composition graph is formed. Second, one of the graph external nodes, found on a critical path, is segregated and other nodes are grouped adjacent to it, along a single axis, within the last level (Fig. 7). Third, graph nodes are transformed into events and arcs are transformed into activities. The segregated external node represents an initial event, an initial node in a graph being product structures, and is transformed into a terminal event in a network diagram. Fourth, to satisfy the rule that a network diagram has only one beginning, an initial event in a network is connected by fictitious activities with other events developed by external nodes. All components in a network diagram are denoted in compliance with a notorious rule (Fig. 8).

Figure 7 shows a graph opposite of structural composition graph with grouped external nodes and a single segregated node (17) found on a graph critical (longest) path. To make the representation of a network diagram clearer, the graph in Fig. 7 is possible to rotate round its own axis 90^0 clockwise. Figure 8 displays a network diagram of complex product that has the total of 19 events and 30 activities, of which 12 are fictitious (F_i) and 18 are real.

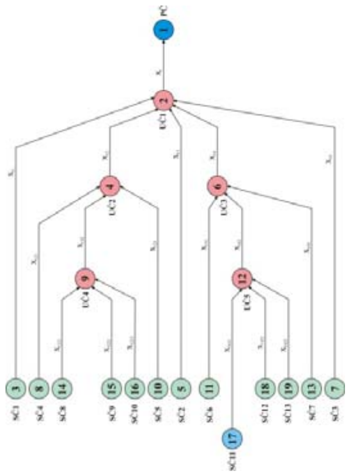

Figure 7. Graph opposite of structural composition graph

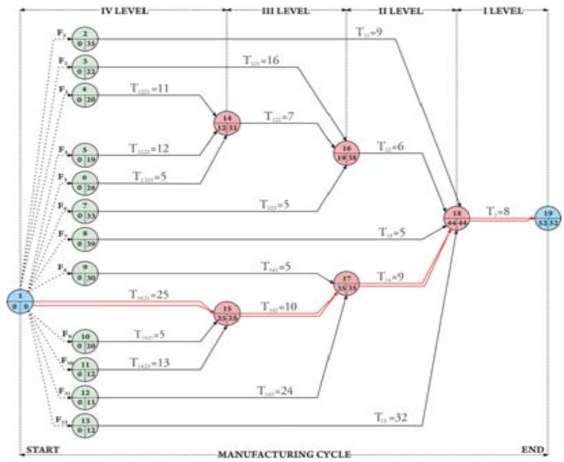

Figure 8. Network diagram of complex product

4. CONCLUSION

The models described enable successful application of the just-in-time concept and applicative software tools in production processes planning and management, especially in cases of extremely complex product structure and large number of product parts. The application of the depicted models in ‘Sloboda’ Co. Cacak enabled efficient management of manufacturing cycles using the lean production principles, whereby current method of work has been promoted, optimal utilization of production resources achieved and losses in production considerably reduced.

5. ACKNOWLEDGEMENT

We express our gratitude to ‘Sloboda’ Co. Cacak for the trust and for the possibility to prove our model theoretical assumptions in practice.

6. REFERENCES

[1] Diestel R.: Graph Theory, Springer-Verlag Heidelberg, New York, 2005.,

[2] Jovanović J.: Project approach to the structure of a complex product, XXXVI Jupiter conference with international participation, Faculty of Mechanical Engineering Belgrade, Belgrade, 2010.,

[3] Luh Ding-Bang, Ko Yao-Tsung, Ma Chia-Hsiang: A structural matrix-based modelling for designing product variety, Journal of Engineering Design, vol. 22, No 1, pp. 1-29, 2011.