Copyright © 2002 IFAC
15th Triennial World Congress, Barcelona, Spain

A DATA MODEL FOR MULTI-LEVEL PLANNING OF COMPLEX MANUFACTURING SYSTEMS

Thecle Lecompte, Rachid Alami, Jean-Christophe Deschamps, Jean-Paul Bourrieres

LAP/GRAI, Universite Bordeaux I / ENSERB
EP CNRS 2026
351 cours de la Liberation
33405 Talence cedex
E-mail : lecompte@lap.u-bordeaux.fr

Abstract : MRP-like approach is not always enough efficient to manage distributed manufacturing systems performing various complex products. This paper proposes a model supporting the *desegregation* of technical data, in order to provide to any decision maker in a multi-level management structure, information required to perform planning and scheduling production activities.

Keywords : Management Systems, Manufacturing Systems, Technical Data Models.

1. INTRODUCTION

MRP-like production management, mostly used by companies, consists in optimizing components requirement management by planning and scheduling production activities, according with customer demand forecasting. The known advantages of this approach are (1) *flexibility*, allowing to easily introduce parameters changes and define a new production planning based on updated data, (2) *adaptability* to treat products with complex *lists of references*, and (3) *consistency* in resources capacity management. These properties also contribute to ensure a more efficient production management by reducing in-process products stocks.
Nevertheless, this approach is based on strong and restrictive hypothesis which reduce its efficiency in the case of distributed and complex manufacturing systems organized as extended enterprises (Jagdev, *et al.*, 1998).

MRP is less adapted to production management with a large variety of components. Though computing performances allow to process a large number of data, the practical calculation may lead to irretrievable delays.

MRP is more suitable to pushed flows under stable production conditions than to an unstable market context for which pulled flow management may be more efficient.

Companies trends to look outside their own boundaries for getting new competitive advantages from outsourcing improve the difficulty to master the global management. Today, the planning calculation techniques must consider the distributed nature of production and decision processes.
In this context, this paper presents a hierarchical data structure for providing each planning/scheduling decision with a relevant level of detail. For a decade, researchers have been developing a Hierarchical Planning approach based on the definition of aggregated production entities to manufacture during successive periods. Most of the time (Axater, 1986], (Hetreux, 1996) these aggregated entities are product types and families. The definition of an initial plan determines the production required for aggregated entities. This plan is then refined according to the different levels of product aggregation. Some approaches have been developed to ensure the coordination between levels (Fontan, 1985), (Merce, 1987). The main advantage of this approach is the sizeable decrease of the number of data to be simultaneously processed.

However as those approaches are only concerned with planning, without any consideration of the task-resource allocation problem, a consequent effort is required to obtain feasible schedules.

The approach proposed here is based on a generalized formulation of the load allocation problem according to a multi-level structure of technical data (Lecompte, *et al.*, 2000a). Here, the focus is not put on the allocation problem itself but it is proposed a formal model to support the *desegregation* [1] of technical data while planning and scheduling production activities.

2. MULTI LEVEL PLANNING

The approach proposed consists in the iterative breaking up of planning into multiple decision levels, each of them leading to allocate the work loads to aggregated resources according to their competence and availability.

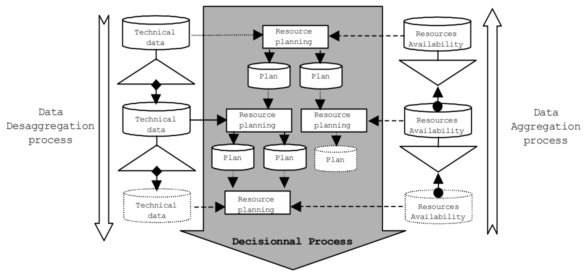


Fig. 1. Multi-level planning process

Each level of decision takes into account both outsourcing and customers/suppliers relationships by ensuring simultaneously the co-ordination and allocation of inner (local manufacturing) and outer (sub-contracted) resource activities, and by integrating all order makers requirements. The decision system is structured in reference to a resource classification, as NBS classification: each resource r at v level ($v=0$ being the physical level) encapsulates a set of internal resources at level $v-1$. For instance, an industrial site is seen as an aggregated resource encapsulating a set of workshops. The product and process technical data are considered as static data, *i.e.* time independent (at least in the short term). All product states (components, semi-finished and finished products) are defined in a product list of references, and product transformation processes are fixed. The technical data available are aggregated according to the planning/scheduling decision level. Data desaggregation is a top-down generic mechanism which links the different levels of decision. At the highest level, the data supplied by an order book describe the nature, volume and delivery of products to be achieved. To assess the work load required by the order book - given the current status of stocks -, the product amounts are converted into work amounts expressed at each decision level as quantities of transformations to be performed.

[1] *Desegregation* is a data conversion leading to observe information with more technical details.

In the following, it is assumed that X_r^v refers to data X used by the decision center r at level v.

3. GENERALISED PRODUCTION MODEL

3.1. Representation of generalized manufacturing processes

Petri nets are here used to describe in a single model all manufacturing processes potentially achievable by any resource, depicting the various product states from components to achieved products, as well as transformation tasks and the amount of products consumed or produced by each transformation (Bourrières, 1998).

With regard to resource r at level v, manufacturing process data are defined by gragh $G_r^v = \langle\, T_r^v,\, O_r^v,\, C_r^v\, \rangle$, with T_r^v the set of feasible transformation tasks[2], O_r^v the set of objects involved and $C_r^v = \left\{ c_{r\,ij}^v \,\middle|\, c_{r\,ij}^v \in Z \right\}$ the incidence matrix of G_r^v. Note that scalar $c_{r\,ij}^v$ takes into account the amount of similar objects consumed and produced by a task t_j on object o_i.

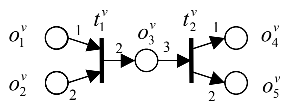


Fig. 2. Example of manufacturing process model

3.2. Product/process data model

The manufacturing processes model introduced above leads to the following *production equation* :

$$\Delta S_r^v = C_r^v\, W_r^v \qquad (1)$$

where :

ΔS_r^v is the stock variation vector referring to object list of references O_r^v

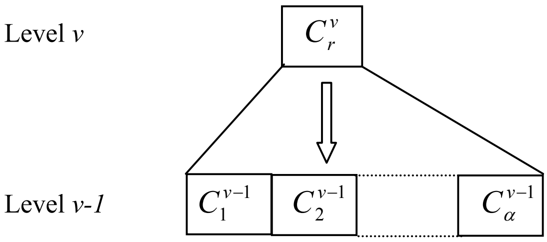
W_r^v is the workload vector referring to task list of references T_r^v

Note that inverting model (1) allows to calculate the amount of works W_r^v necessary to produce stock

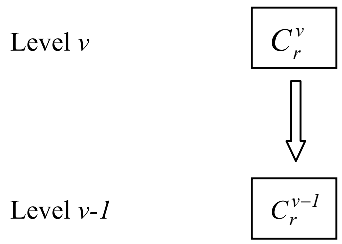
2 A task is here defined as a specific transformation of material objects, whatever the transformation means will be operated, and whatever the detailed procedure (internal view of the task) needed to achieve it

variation ΔS_r^v, which can itself result from a stock management policy ΔS_r^v (Lecompte *et al.*, 1999), (Lecompte *et al.*, 2000b), (Deschamps *et al.*, 2000).

The data model proposed in Deschamps, *et al.*, (2000) is concerned by the allocation problem. Nevertheless, this paper only focuses on data desegregation from a decision level to another, so the resources themselves are not considered in the following. In particular, the distribution of the technical information among the resources is not discussed here. This paper then deals with 'simple data desegregation' without distribution, in other words how to link the aggregated (respectively detailed) manufacturing processes representations C_r^v and C_r^{v-1} of a given resource *r* (Fig. 3).



Data desegregation and distribution



Simple data desegregation

Fig. 3. Manufacturing data desegregation with or without distribution

Data desegregation deals both with tasks and objects:

- Any *v- level task* may be desegregated at level *v-1* as a detailed *process* involving new lists of tasks and objects are defined.
- Any *v- level object* may be desegregated at level *v-1* as a *collection*, which represents all components required for producing an object considered at level *v*.

3.3. Desegregation processes model

The goal of this section is to provide a formal description to support data desegregation and desegregation consistence checking as well. The following example shows how to apply desegregation mechanisms to manufacturing data (Figure 4). : relation (R1) shows the aggregated object o_1^v as being composed of detailed objects o_1^{v-1} and o_2^{v-1} (for example, the internal components of a kit) in addition to the semantic point of view, this relation also takes into account the quantitative point of view : here the aggregated object o_1^v is composed of one object o_1^{v-1} and two objects o_2^{v-1}. Note that Relation (R2) is a restrictive case of relation (R1) representing, for example, a batch sizing principle.

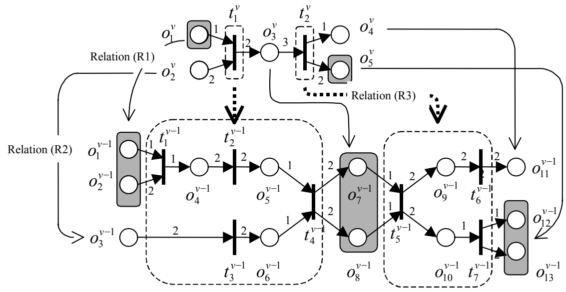


Fig. 4: Example of manufacturing data desegregation

Relation (R3) illustrates the desegregation of tasks into detailed manufacturing processes.

Clearly, some objects at level *v-1* (o_1^{v-1}, o_2^{v-1}, o_3^{v-1}, o_7^{v-1}, o_8^{v-1}, o_{11}^{v-1}, o_{12}^{v-1}, o_{13}^{v-1}) are generated by the desegregation of *v*-level, whereas other objects (o_4^{v-1}, o_5^{v-1}, o_6^{v-1}, o_9^{v-1}, o_{10}^{v-1}) result from tasks desegregation. The object list of references at level *v-1* can then be defined as follows:

$$O_r^{v-1} = \overline{O}_r^{v-1,v} \cup \underline{O}_r^{v-1} \tag{2}$$

with

$\overline{O}_{r,r}^{v-1,v}$ object list of references at level *v-1* derived from object list of references at level *v*

$\underline{O}_r^{v-1}$ object list of references introduced at level *v-1*

Note that a quantity of objects o_1^v involves a proportional quantity of internal objects o_1^{v-1} and objects o_2^{v-1}. The proportionality link between object list of references $\overline{O}_{r,r}^{v-1,v}$ and object list of references O_r^v leads to the linear relation :

$$\overline{\Delta S}_r^{v-1} = M_{r,r}^{v-1,v} \ \Delta S_r^v \tag{3}$$

where

$M_{r,r}^{v-1,v}$ is the *object desegregation matrix*

$\overline{\Delta S}_r^{v-1}$ is the variation of objects stocks that must be performed at level *v-1* in accordance with the object list of references $\overline{O}_{r,r}^{v-1,v}$ to observe production ΔS_r^v at level *v*.

Similarly, any *v*-level transformation task is desegregated into *v-1* process, and the amount of detailed works to be performed at level $v-1$ is proportional to the amount of aggregated works expected at level v. This is characterised by the relation below :

$$W_r^{v-1} = N_{r,r}^{v-1,v} \; W_r^v \qquad (4)$$

with $N_{r,r}^{v-1,v}$ is the *work desegregation matrix*

Nevertheless, objects and works desegregation *mechanisms* are correlated since the consumption/production of objects at level *v* must be consistent with the consumption/production of objects at level *v* objects at level *v-1* must be consistent with consumption/production of objects at level *v*.

3.4. Desegregation of manufacturing data

As stated in the previous section, the data desegregation from a decision level to another is fully characterised by matrices $M_{r,r}^{v-1,v}$ et $N_{r,r}^{v-1,v}$. Concurrently, matrices C_r^v and C_r^{v-1} provide the description of resource *r* feasible processes at level v and $v-1$. Those four matrices are linked by a *consistence rule* as follows.

Relation (2) between lists $\overline{O}_{r,r}^{v-1,v}$ and O_r^{v-1} leads to the following relation between stock variations :

$$\overline{\Delta S}_r^{v-1} = I_{r,r}^{v-1,v} \Delta S_r^{v-1} \qquad (5)$$

in which $I_{r,r}^{v-1,v}$ is a binary matrix with dimensions card $\overline{O}_{r,r}^{v-1,v}$ *x card* O_r^{v-1}.

Combining *(1)* with *(5)* leads to :

$$\overline{\Delta S}_r^{v-1} = I_{r,r}^{v-1,v} \; C_r^{v-1} \; W_r^{v-1} \qquad (6)$$

then, according to *(3)* et *(4)* :

$$M_{r,r}^{v-1,v} \; \Delta S_r^v = I_{r,r}^{v-1,v} \; C_r^{v-1} \; N_{r,r}^{v-1,v} \; W_r^v \qquad (7)$$

and finally, given *(1)* :

$$M_{r,r}^{v-1,v} \; C_r^v W_r^v = I_{r,r}^{v-1,v} \; C_r^{v-1} \; N_{r,r}^{v-1,v} \; W_r^v \qquad (8)$$

The following relation may be extracted :

$$M_{r,r}^{v-1,v} \; C_r^v = I_{r,r}^{v-1,v} C_r^{v-1} \; N_{r,r}^{v-1,v} \qquad (9)$$

Property (9) ensures the consistency of the desegregation defined by $M_{r,r}^{v-1,v}$ and $N_{r,r}^{v-1,v}$ and is illustrated by Figure 5 in which the recursive aspect the desegregation process can be seen.

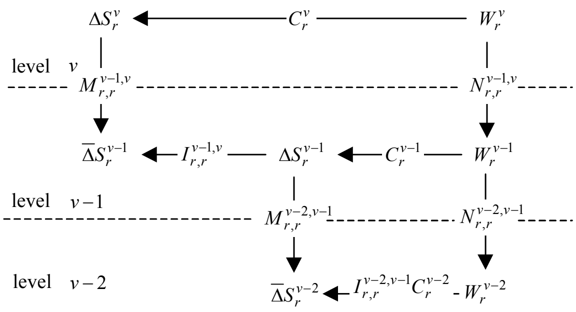


Fig. 5 : Recursive consistent desegregation process

4. CONSISTENCE CHECKING

The manufacturing processes shown on Fig. 4 at level v and $v-1$ are defined by the following matrices C_r^v and C_r^{v-1} :

$$C_r^v = \begin{pmatrix} -1 & 0 \\ -2 & 0 \\ 2 & -3 \\ 0 & 1 \\ 0 & 2 \end{pmatrix}$$

$$C_r^{v-1} = \begin{pmatrix} -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ -2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -2 & 0 & 0 & 0 & 0 \\ 1 & -2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2 & 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 2 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2 & -1 & 0 & 0 \\ 0 & 0 & 0 & 2 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 2 & -2 & 0 \\ 0 & 0 & 0 & 0 & 2 & 0 & -2 \\ 0 & 0 & 0 & 0 & 0 & 2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 2 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

The desegregation of objects (see Fig. 4) is specified by matrices $M_{r,r}^{v-1,v}$ and $I_{r,r}^{v-1,v}$:

$$M_{r,r}^{v-1,v} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 2 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 3 & 0 \\ 0 & 0 & 0 & 0 & 2 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

$$I_{r,r}^{v-1,v} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

The left term of consistence property (9) is :

$$M_{r,r}^{v-1,v}\ C_r^v = \begin{pmatrix} 1&0&0&0&0\\ 2&0&0&0&0\\ 0&1&0&0&0\\ 0&0&1&0&0\\ 0&0&1&0&0\\ 0&0&0&3&0\\ 0&0&0&0&2\\ 0&0&0&0&1 \end{pmatrix} \begin{pmatrix} -1&0\\ -2&0\\ 2&-3\\ 0&1\\ 0&2 \end{pmatrix} = \begin{pmatrix} -1&0\\ -2&0\\ -2&0\\ 2&-3\\ 2&-3\\ 0&3\\ 0&4\\ 0&2 \end{pmatrix}$$

whereas the right term is :

$$I_{r,r}^{v-1,v}\ C_r^{v-1}\ N_{r,r}^{v-1,v} = \begin{pmatrix} -1&0&0&0&0&0&0\\ -2&0&0&0&0&0&0\\ 0&0&-2&0&0&0&0\\ 0&0&0&2&-1&0&0\\ 0&0&0&2&-1&0&0\\ 0&0&0&0&0&2&0\\ 0&0&0&0&0&0&2\\ 0&0&0&0&0&0&1 \end{pmatrix} N_{r,r}^{v-1,v}$$

which finally yields to :

$$\begin{pmatrix} -1&0&0&0&0&0&0\\ -2&0&0&0&0&0&0\\ 0&0&-2&0&0&0&0\\ 0&0&0&2&-1&0&0\\ 0&0&0&2&-1&0&0\\ 0&0&0&0&0&2&0\\ 0&0&0&0&0&0&2\\ 0&0&0&0&0&0&1 \end{pmatrix} N_{r,r}^{v-1,v} = \begin{pmatrix} -1&0\\ -2&0\\ -2&0\\ 2&-3\\ 2&-3\\ 0&3\\ 0&4\\ 0&2 \end{pmatrix}$$

Any matrix $N_{r,r}^{v-1,v}$ verifying the last equation ensures that the data desegregation is consistent, for example:

$$N_{r,r}^{v-1,v} = \begin{pmatrix} 1&0\\ *&*\\ 1&0\\ 1&0\\ 0&3\\ 0&3/2\\ 0&2 \end{pmatrix}$$

which leads to

$$W_r^{v-1} = \begin{pmatrix} 1&0\\ *&*\\ 1&0\\ 1&0\\ 0&3\\ 0&3/2\\ 0&2 \end{pmatrix} W_r^v$$

Symbol * means that any value can be chosen for these terms since task t_2^{v-1} has no effect on o_4^{v-1} and o_5^{v-1} stocks which are not visible at level v. Note also that the entries of $N_{r,r}^{v-1,v}$ are not necessarily binary. Here the right column indicates that each occurrence of aggregated task t_2^v leads to perform 3 detailed tasks t_5^{v-1}, 3/2 of t_6^{v-1} and 2 of t_7^{v-1}. The rational fraction 3/2 implies $w_6^{v-1} = 3w_2^v/2$ with w_2^v et w_6^{v-1} integer, so w_2^v is a multiple of 2 and w_6^{v-1} a multiple of 3.

5. CONCLUSION

The deployment of both integration and distribution paradigms in manufacturing leads to the necessity of facing complexity while operating production systems. This paper deals with the definition of macro technical data for planning and scheduling decision, according to the global multi-level approach presented in Lecompte (2000a). Here the technical data addressed are more or less detailed manufacturing data feasible by a virtual resource. Data desegregation on tasks were presented in Bourrieres (1998) Here the results are extended to joint task and product desegregation to provide a larger applicability in manufacturing and logistics as the precept of an advanced planning and scheduling solver.

REFERENCES

Axäter, S., Nuttle, HLW. (1986). *Aggregation items in multi-level lot-sizing, in Multi-stage production planning and inventory control,* E.Silver (eds). Springer Verlag, NY, 1986

Bourrieres, J.P. (1998). *Multilevel Algebraic Modelling of Complex Manufacturing Tasks*, Proc. of the IFAC/IMS'98 conference, Gramado, pp 261- 265, 1998.

Deschamps, J.C., and J.P. Bourrieres (2000). *A multi-level data model for load allocation to distributed manufacturing ressources*, Proceedings of the IEEE/ISIC'2000, July 17-19, 2000, Patras

Fontan, G., Imbert, S., Merce, C. (1985). *Consistency analysis in a hierarchical production planning system,* Enginnering Costs and Production Economics, vol 9, 1985.

Hetreux, G., (1986). *Multi-level decisional structure for production planning : robustness and coherency of decisions,* (French document), These de l'Institut National des Sciences Appliquees, decembre 1996

Jagdev, H.S., and J. Browne (1998). The extended enterprise – a context for manufacturing, *Journal of Production Planning and Control*, Volume 9, n°3, pages 216-229.

Lecompte T., J.C. Deschamps and J.P. Bourrieres (2000a). A data model for generalised scheduling for virtual enterprise, *Journal of production Planning & Control*, 2000, volume 11, n°4, pp 343-348.

Lecompte, T., and J.P. Bourrieres (2000b). *Data Model and Decision Support Framework for Generalised Production Management*, Proceedings. of the IFAC/IFIP/IEEE MCPL'2000, 5-8 July, Grenoble

Merce, C. (1987). *Cohérence des décisions en planification hiérarchisée,* Thèse d'état de l'Université P. Sabatier de Toulouse, juillet 1987.