A state-time model to measure the Reconfigurability of Manufacturing Areas - Key to performance

Hermann Kühnle

0 Motivation
1 The model
2 Mappings and measurements of states
3 Evaluation of time/change relations
4 Case study
5 Conclusions

0 Motivation

Recent years showed a considerable shift in manufacturing success factors. Quality price, speed and flexibility are already standardized /8, 16, 18, 21/. The new challenge is reconfigurability - the ability of self-driven changes within organizations /3, 4, 5, 11, 17/. Regarding this new requirement for manufacturing enterprises it is essential that reconfigurability obviously can not be measured but it becomes more and more important /1, 3, 13/. Reconfigurability is the main characteristic of recent manufacturing approaches like Agile manufacturing /4, 6, 8, 9, 11/, Bionic / Biological Manufacturing Systems /20, 27/, Viable manufacturing systems /14, 23/, Autonomous and Distributed Manufacturing Systems /19/ or the Fractal Company /16, 17, 18/. Reconfigurable structures are able to organize and optimize themselves /12/. Self-organization and self-optimization are processes of change from one structural state to another /2/. Current approaches of measurement and evaluation of manufacturing areas focus on business processes /7, 9, 10, 13, 24/. The change in structure is not yet extensively investigated, especially with regard to the speed for changes. The measurement of reconfigurability bases on results of
changes. A "high" or "low" reconfigurability can be measured by analyzing change processes and the prerequisites of reconfigurability can be pointed out.

1 The Model

Let MAN be a manufacturing unit.
Following notation and definitions are given:

- \( t_p \) state (MAN) present state of MAN
- \( t_d \) state (MAN) desired state of MAN
- \( t_p, t_d, t \in T \) present time, desired time to achieve state (MAN)
- \( P = \bigcup_{i=1}^{n} p_i \) set of projects \( p_i \) to achieve state (MAN)

These objects are depicted in Fig. 1.
Therefore, the ability to change is the principle of reconfigurability. The basic criteria to measure this ability are:

?? time consumption /22/ and
?? structuring result /10, 25, 26/.

In order to measure the reconfigurability of process structures two steps are emphasized:

1) Mappings and Measurement of states

2) Evaluation of time / change relations
2 Mappings and measurement of states

To define the structural state of a manufacturing area detailed measurement criteria can be given. The criteria based on a model that is specially designed for autonomous decentralized units /12/. Instead of detailed descriptions of every task the manufacturing area can be regarded by states and mappings of states.

A manufacturing area can be modeled as

\[
\text{state (MAN)}(T_w(t), O_k(t), R_g(t), U_f(t))
\]

where

- \( T_w \) T set of tasks
- \( O_k \) O set of objectives
- \( R_g \) R set of resources, materials parts etc.
- \( U_f \) U set of transformation units

\( t \) denotes the time \( t \in T \) where \( T \) is the (ordered) time set \( R_{o^+} \).

Any element of the sets introduced above can be assigned to a scale indicating ratios, multitudes and consumptions of units.

This model is now not to be detailed by tasks-resource assignments or similar relations. For reconfigurability, a purely observable oriented view has proven to be fruitful. In order to quantify results, the state view of the model can be given as follows:
Tab. 1 shows an example several defined components to describe states of a manufacturing area MAN.

<table>
<thead>
<tr>
<th>I</th>
<th>Component</th>
<th>Dimension</th>
<th>Objectives / Resources / Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lead Time</td>
<td>Days</td>
<td>Objectives</td>
</tr>
<tr>
<td>2</td>
<td>Quality</td>
<td>%</td>
<td>Objectives</td>
</tr>
<tr>
<td>3</td>
<td>Budget</td>
<td>$ / Year</td>
<td>Resources</td>
</tr>
<tr>
<td>4</td>
<td>Personnel capacity</td>
<td>h / Month</td>
<td>Resources</td>
</tr>
<tr>
<td>5</td>
<td>Personnel flexibility</td>
<td>% / Year</td>
<td>Transformation unit</td>
</tr>
<tr>
<td>6</td>
<td>Machinery flexibility</td>
<td>% / Month</td>
<td>Transformation unit</td>
</tr>
</tbody>
</table>

Tab. 1: Example of state mapping in a manufacturing area state (MAN) using 6 components

3 Evaluation of time/change relations

Time measurement is introduced due to the requirement that reconfiguration in the manufacturing area must be possible faster than changes of external influences. Therefore, the speed of change is an important figure of success in manufacturing. Change processes that are fast indicate a high reconfigurability. By measuring and comparing the values it is helpful to compare between required time $t_R$ for changes and available desired time $t_D$ for changes. Changes should be neither too slow nor too fast. Changes that run too slow have their origin in a poor reconfigurability and rigid organizational structures. Changes that are possible too fast usually indicate costly redundancies.
Fig. 4: Tolerance logic/current monitoring of projects U,P impact

State mappings can be given for past, present and desired states. Evaluations of desired developments concerning the manufacturing area MAN can be anticipated by initiation of structural changes. Questions like "does our manufacturing fulfill future requirements" can easily be answered using the method. Using the past, the present or the future focus however, the measurement result can be summarized.

Important monitoring positions:

**Position 1**

Expected time for change is shorter than the available time period. In this case, changes can be started and finished before time. The alternative is starting the projects later. This alternative should especially be chosen if project capacities are required elsewhere in
process. Case 1 indicates oversized reconfigurability. Therefore redundancies should be taken out of the set up of the manufacturing areas.

**Position 2**
Expected time consumption for change is longer than available time; acceleration of the change.
In this case there are several alternatives, for example better technical support, introduction of more effective methods or increasing the qualification of the staff. All actions should point to increase reconfigurability.

**Position 3**
Expected time consumption is longer than the available time; extension of available time period.
This option is the most frequent case but dangerous. Especially in turbulent environments any extension of time for necessary changes result in diminished success. Nevertheless, there can be special situations where the extension of available time for change be a strategic advantage.

**Position 4**
Expected time consumption for change is longer than available time \( t_A \); acceleration of change plus extension of available time period - superposition of case 2 and case 3. To increase or decrease reconfigurability a number of catalyzing actions can be given respectively ( table 3 ). Tables like this can be used to control the reconfigurability in cases of an in adequate speed of change processes.
Projects to improve reconfigurability

Goal commitments

<table>
<thead>
<tr>
<th>Increase of outside-orientation of goals</th>
<th>?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identification of core processes</td>
<td>?</td>
</tr>
<tr>
<td>Integration of tasks for flexibility</td>
<td>?</td>
</tr>
<tr>
<td>Decentralization</td>
<td>?</td>
</tr>
<tr>
<td>Self-controlling</td>
<td>??</td>
</tr>
</tbody>
</table>

Tab. 3: Projects and parallel actions taken to change abilities of reconfiguration and speed up changes (Position 4)
4 Case Study

The method was applied to the manufacturing area of company producing electrical devices. Unsatisfying lead times and inability of on-time delivery as well as unsuccessful reengineering projects showed insufficient reconfigurability in the manufacturing areas. This insufficiency has been verified by comparison of past, present and forecasted state mappings of the structure. Several manufacturing units A – D were looked at. Figure 6 represents the mapping with satisfying results in the assembly unit B. On the other hand it is obvious that in the other units A, C and D still show differences between the intended values and the actual achieved values. Therefore actions had to be taken to accelerate change processes within these units. To increase reconfigurability a list of project steps was emphasized.
Fig. 6: State mappings of manufacturing area after change (at time $t_d$)
In this example the desired time $t_d$ for change was limited to 40 weeks. Forecasts for values mapping future states $t$ state (MAN) at time $t$, showed $t_E$?40 week by far. Basis where mappings of $t$ state (MAN) and it’s trajectories for each dimension. But $t_E$?40 would mean considerable disadvantages on the market resulting in loosing market shares to competitors. (Case 2) Project efforts had to be taken into account as well as deep cuts into the organisation. As splendid result the reconfiguration was completed after 38 weeks. Therefore, the organization verified their reconfigurability due to the implementation of action catalogues. Selection of concret actions enabled the company to do this important restructuring process, that had failed several times before.

$\begin{array}{c}
t_0 \text{ state } \text{MAN} \\
\text{Projects and actions} \\
- \text{Selection and training of team leaders} \\
- \text{Staff selection and training} \\
- \text{Technical concept} \\
- \text{Tooling concept} \\
- \text{New communication oriented layout} \\
- \text{Information of all participants} \\
- \text{New floor} \\
- \text{New electrical facilities} \\
- \text{Machine layout} \\
- \text{Technical qualification} \\
- \text{Initiation of Continous Improvement} \\
\end{array}$

t_d \text{ state } \text{MAN}
Processes
- Design of new information and communication boards

$ t_0 \rightarrow t_d \rightarrow 38 \text{ weeks} $

Fig. 7: State mapping shift of manufacturing area.

Manufacturing area before actions

<table>
<thead>
<tr>
<th>Disposition</th>
<th>Operat. controll</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>C</td>
<td>D</td>
</tr>
<tr>
<td>E</td>
<td>F</td>
</tr>
<tr>
<td>G</td>
<td>H</td>
</tr>
<tr>
<td>I</td>
<td>J</td>
</tr>
<tr>
<td>K</td>
<td>L</td>
</tr>
</tbody>
</table>

Order flow

Manufacturing area after actions

<p>| |</p>
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Order flow

\[ A \quad TC\ 260 \quad B \quad Sawing \quad C \quad Big\ presses \quad D \quad Cutting \quad E \quad Front\ panel\ manuf. \quad F \quad NC-stamping \quad G \quad Stamping \quad H \quad Mechanics \quad I \quad Bending \quad J \quad Grinding \quad K \quad Profile\ manufacturing \quad L \quad Pre-assembly \]

\[ M \quad Materials\ of\ stock \quad N \quad Material\ center \quad with\ raw\ mat.\ stock \quad and\ cutting \quad O \quad Manufacturing\ cust. \quad anonym.\ parts \quad P \quad Manufacturing\ cust. \quad orient.\ systems \quad Q \quad Manufacturing\ cust. \quad oriented.\ parts \]

Fig. 8: Comparising of manufacturing area structure before and after reconfiguration $t_0$ state (MAN) and $t_1$ state (MAN)

5 Conclusions

Reconfigurability is an important success factor in manufacturing. It is essential that manufacturing structures can be changed appropriate...
and within adequate time. Selforganized and autonomous units do not use scheduling and PPC in the classical sense. As soon as objectives are set (by customers or competitors) a manufacturing area is obliged to fulfillment.

In this situation control parameters of structure mappings and forecasted time consumption for parameter shift of mapping can be used in order to determine necessary projects or recommended actions to be chosen.

This paper points out a model that supports change management by measuring the reconfigurability of manufacturing areas with the focus on time consumption for reconfiguration. Time parameters and results of changes are essential criteria. Furthermore the model enables to control the reconfigurability by well defined implementation projects and actions to increase or decrease reconfigurability respectively.

Literature

/1/ Aurich, H.: Bewertungsmethoden und -verfahren. 2., Ed. Chemnitz: Technische Hochschule, 1982


/21/ Patterson, R.: The Agility Revolution – A New Paradigm for Business. 1996 NGMS International Conference, Irvine, February 5 – 9, 1996


