Considering parts in progress in a reconfiguration procedure for FMS

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Abstract: This paper first specifies the reconfiguration procedure relatively to parts, that are present in the workshop when a failure occurs. It gives some trends about reconfiguration strategies (evacuation, quality checking or continuation). These options depend on the failure impact, on the cost associated to the considered part and on the quality required for each part. Then, it focuses on the feasibility of a chosen option. Several reactivity levels are examined according to the failure impact, flexibilities reserved during the exploitation phase, and flexibilities corresponding to the whole potentialities of the architecture. These enable to know if the FMS can react with its current configuration, or if its configuration has to be changed to go on with the production. The reconfiguration procedure is implemented through a model named Operational Accessibility Graph. The model has been emphasised to store data relative to both FMS potentialities and products. Added treatments enable to conclude, for each part, about the feasibility of an option.

Key-Words: Reconfiguration's types, Reaction levels, Recovery, Computer Aided Decision, Operational Accessibility Graph, Parts in progress, Quality checking, Flexible Manufacturing Systems. Proc.pp..2861-2868

1. Introduction

1.1 Context and working assumptions

The study considers Flexible Manufacturing Systems (FMS). They are discrete event systems. The machining of a raw part to a finished good is performed according to a series of tasks. Regardless of the workshop structure, a production type is expressed by a Logical Operating Sequence (Log.Op.Seq.). This is a set of ordered machining functions applied to a family of parts. A function is a service delivered by the FMS. A function implemented by a resource of the FMS is an operation. It results from the flexibility of the FMS, several operations can implement the same function, and that there may be several sequences of operations to achieve a production type.

The study is based on a non-deterministic control. This enables FMS flexibility to be taken into account during the exploitation phase. Indeterminisms are raised either by scheduling (off-line computed) or by piloting [1], that is a supervision module. Supervision has been introduced to take into account dependability objectives in FMS control. It acts on control models in order to react toward failures. It is composed of three modules: recovery, working modes' management and piloting.

In this context, a failure occurrence induces a scheduling malfunction. A reconfiguration process is considered to avoid an FMS stop during the resources' repair.

1.2 Reconfiguration

Reconfiguration is a process that comes after failure's detection and diagnosis. It takes potential flexibilities of the production architecture into account, in order to make available all or part of the machining FMS functions. So that the planned production can be provided. Its effect concerns control, but also resources' working modes. Reconfiguration process is split into two stages [2], [3], [4]: in a first step the new configuration is established, in a second step, the decision is applied (cf. Fig. 1). According to supervision structure, recovery decides about the new configuration of the FMS. It establishes the resources to be set in working mode, the ones to be stopped, and the operations' sequences in order to achieve a given production.

Working modes' management has in charge of applying decisions devoted to resources. It drives the system's resources from one configuration to another. Piloting has in charge of applying decisions devoted to control (mainly the routing of the part in the FMS architecture) by solving the last indeterminisms of the control.

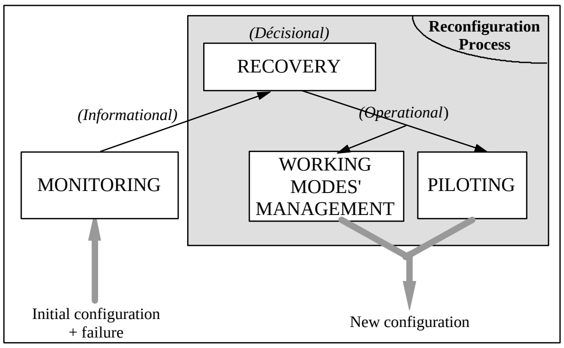

Figure 1: Modules of the reconfiguration process

In the following, only decisional aspect of reconfiguration is considered through recovery module. Before looking for a new configuration that enables to go on with the production type from raw parts set at the FMS entrance, recovery has first to take an interest in parts already present in the workshop when the failure occurs.

The aim of this paper is to consider how the FMS is able to deal with parts already present in the workshop when a failure occurs. Strategies, that deal with the production planning and consider raw parts at the entrance of the FMS have been tackled in [4]. The paper is organized as follows. After the presentation of the reconfiguration's process in the first section, the strategies of decision concerning the parts already present in the workshop are introduced in section 2. The feasibility of each option is studied in section 3. Section 4 refers to the implementation of the procedure. A model of the operating part is also detailed in the same section. An example is presented in section 5 and last section deals with the exploitation, in a global strategy, of specific results attached to each part.

Concerning the parts present in the FMS, constraints are the following:

- All parts are not at the same state of evolution;
- They may be affected by the failure;
- They may need an inspection.

So, decisions about these parts should be taken according to each case. As these parts should have their evolution modified, control models have to be rigorously updated.

The presented recovery procedure consists in two main steps: choice of an option and validation. These steps are included in a feedback loop.

2. Decisions' options according to products

Considered decisions' types are taken after actions like freezing or setting in a determined state. The aim of these actions is to avoid failure propagation and to maintain security.

Concerning parts present in the FMS when the failure occurs, decisions depend on the failure impact, on the cost associated to the considered part and on the quality required. The cost associated with a part is generally expressed by a cost issued from raw material and an added value by already performed machinings.

Three types of parts are considered: raw parts, half-machined parts and finished parts. As the case of raw parts has already been studied and presented [4], only half-machined and finished parts still in the workshop are of interest in the following. For these last parts, three cases have been considered:

- The part is not directly affected by the failure;
- The part may be damaged. This mean that it was on resource that suddenly turned out;
- The part is actually damaged. So the continuation of the machining steps will give a badly finished good or may damage the workshop itself.

According to these considerations, three decisions' types have been identified for each part in the workshop:

- To evacuate the part;
- To continue the machining steps of the part;
- To check the quality of the part;

As the two first decisions' types are from the part point of view, the third decision enables a compromise to be done. This checking is indeed followed by an evacuation or a continuation decision. It enables only actually damaged parts to be evacuated.

2.1 Evacuation

This option consists in getting the part out of the FMS, whatever the progress of its transformation is, according to its Log.Op.Seq. Evacuation can be decided for the whole set of parts present in the workshop or only for parts, that may be damaged. It can be manually or automatically performed, depending on the failure's impact (i.e. if there is still a sequence of operations that enables the exit FMS area to be reached by the part).

From decisional point of view, this option is the least complicated. It appears to be the most expensive in term of products. Valid half-machined parts can be delayed, indeed even discarded. This option keeps some interest for part, whose cost is low, or when continuation option is not possible.

2.2 Continuation of the Log.Op.Seq.

This option consists in going on with the transformation steps of the part in order to obtain a finished good. The continuation of the Log.Op.Seq. is decided for parts that are not directly affected by the failure. It is recommended for parts, whose cost is high.

This option may need a complete reorganisation of the FMS. Sometimes it is not always possible. The failure may indeed have been affected a resource, that is necessary to the Log.Op.Seq. completion. For each part, the recovery module has to check the existence of at least one sequence of operations, enabling the Log.Op.Seq. to be completed. This computation may spend some time. Nevertheless, this option has the advantage of remaining close from the production planning.

2.3 Going on a checkpoint

The aim is to know if a part, that may be damaged, still has the requested quality degree, in order to go on with its transformation. The existence of checkpoints is a necessary condition for choosing this option. These areas are of telemetry, positioning checking type… [5] If they are automated, human operator is only requested to check contentious points.

After evaluation, following decisions are proposed:

- The part is evacuated and discarded;
- The part is evacuated and will be manufactured later. It will be later set at the FMS entrance again;
- The FMS goes on with the next transformation steps of the part;
- The machining function has been incompletely performed on the part (case of a failure affecting a machining resource). This function has to be performed again before going on with the transformation steps of the part.

2.4 Strategies: sequences of options

For a part, the choice among the three types of decision is mainly determined by the cost associated with the part. According to this criterion, it could be envisaged to evacuate all parts or only parts that may be affected by the failure, or to check whether the affected parts have the requested quality. For non affected parts, the option to go on with the Log.Op.Seq. is considered.

The principle is summarised in Fig. 2. For a part, the cost of which is low, recovery decides to put the part out of the system. So, it spends no time looking for a new configuration in order to go on with the Log.Op.Seq.

For average cost parts, only parts that may be affected by the failure are evacuated. For the other, it is envisaged to continue with the transformation steps of each part.

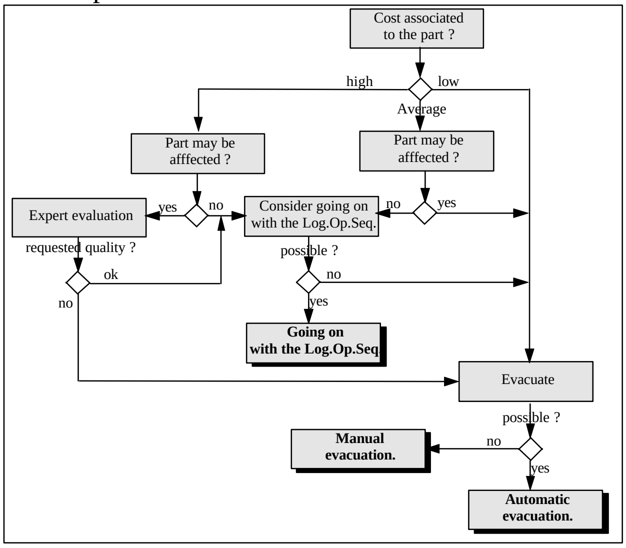

Figure 2: Recovery strategies for present products

In order to recover most expensive parts, continuation option is mainly envisaged. For part that may be affected, a quality check is first requested.

Once an option is obtained, it is necessary to consider the technical feasibility. Results depend on the potentiality of the architecture and the failure's impact. In case of impossibility to implement the considered option, another option, less optimal is chosen. For example, if it is not possible to go on with the Log.Op.Seq., an evacuation is then considered. If the FMS is unable to perform an automatic evacuation, the manual evacuation is then decided.

The step, that validates the choice of a solution, is detailed in the next section.

3. Feasibility of an option

The implementation of an option presented in the previous section may require a more or less consequent reorganisation of the FMS. The strategy consists in taking progressively the FMS flexibilities into account. For a given part in the FMS, recovery computes whether the chosen option is possible, in spite of the failure. Recovery also establishes the resources to be used in order to implement the solution.

Several reaction levels have been established according to the complexity of the implementation. These levels take the working's modes of the resources into account [4], [6]. Three types of resources are identified:

- Resources used in production with a precise configuration;
- Resources used in production with all their possible configurations and idle but switch-on resources. They are called reserved resources;
- Stopped, turned-off, but non out of order resources.

According to this classification, three reaction levels are successively envisaged by the recovery module until a successful validation. The option is considered as not valid if the last reaction level fails (cf. Fig. 3). This principle enables recovery to determine whether the FMS can react with its current configuration, or how the configuration has to be changed to apply the decision.

This comes down to relaxing constraints in order to reach an objective.

3.1 Taking into account reconfiguration types

The three types of reconfiguration, according to the three reaction levels, are now presented. It may be noticed that the reconfiguration time is increasing from minor to major reconfiguration.

3.1.1 Minor reconfiguration

Minor reconfiguration (Reconf.1) only considers resources used in production with their current configuration. It consists in giving new parameters to an active control. As the resources have been used before the failure, the control has already been envisaged in a coordination control level. Piloting and working modes' management have in charge of applying this decision. The working modes' management module prevents from taking a control sequence that requests out of order operations performed by a resource in failure. The piloting module raises indeterminisms left (essentially due to routing flexibility).

3.1.2 Significant reconfiguration

Significant reconfiguration (Reconf.2) considers active redundancies. All switch-on resources may be used. This type of reconfiguration mainly corresponds to a control reorganisation. Recovery takes flexibilities due to both resources used in production and reserved resources into account. Use of reserved resources need no preparation phase. Some portions of control have to be activated at the resource level and at the control coordination level. The following is similar as for minor reconfiguration.

3.1.3 Major reconfiguration

Major reconfiguration (Reconf.3) considers the set of all potentially available resources (switch-on and turned-off). All potentialities of the production architecture are taken into account to check whether the option is possible. For available but turned-off resources, a preparation phase is a necessary step before using them in order to implement the chosen option. The starting procedure, which takes time, is performed by the working modes' management module.

From production architecture point of view, minor reconfiguration comes down to considering a highly constrained architecture. These constraints could be set by scheduling, that has chosen some resources to manufacture parts. For significant reconfiguration, potentialities of reserved resources are added to the preceding architecture. Major reconfiguration amounts to consider the set of potentialities of the architecture, restricted to operations at normal functioning state.

3.2 Studying the feasibility

As summarised in Fig. 3, recovery successively studies if the chosen option can be implemented using a minor, significant or major reconfiguration.

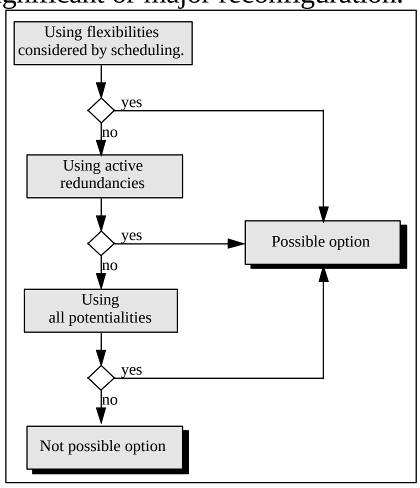

Figure 3: The three reaction levels

4. Implementation

Pieces of information, requested by recovery in order to generate the solution, are represented in an operating part model. This model is named Operational Accessibility Graph (OAG).

4.1 Presentation of the OAG

The OAG is expressed as a digraph (Fig. 5), whose nodes are subsets of operations performed by system's resources and whose oriented edges represent the accessibility and preceding relationships between operations [4], [7].

An **operation** is a function implemented by resource. Several types of operations are considered:

- A transfer operation enables a part to change from physical area. It is achieved by transport system elements;
- A machining operation performs a manufacturing function on a part in the manufacturing resource area;
- A checking operation is defined from checkpoints;
- A stocking operation is defined from a physical area that can receive one or more products, that do not undergo any machining or checking.

So, operations are defined at resources level. Functions are defined at the whole system level. Several operations can implement the same function in an FMS (case of redundant resources). A resource can also perform several operations (case of polyvalent resource). At different dates, one or the other of these operations is active and implements the considered resource functionality.

General features have been defined for each operation or node [4]. Some are updated according to information coming from different external models. For example, feature "operation state" is set to out of order when the operation is detected and diagnosed failing. Other are updated according to changes among various operations features. That is carried out thanks to the graph representation chosen for the model. This enables to use path determination, based on the graph theory. Studies are performed using some of these features such as "Accessible from the entrance", "Blocking to the exit", "function", ...

Accessibility from the entrance (Acc.f.E.) enables to know if there is a path from the entrance to the node. This is a necessary condition for asking an operation completion. It is also a necessary condition for the performing of a logical operating sequence.

Blocking to the exit (Blc.t.E) indicates if a part at a node of the graph will be able to be evacuated from the FMS.

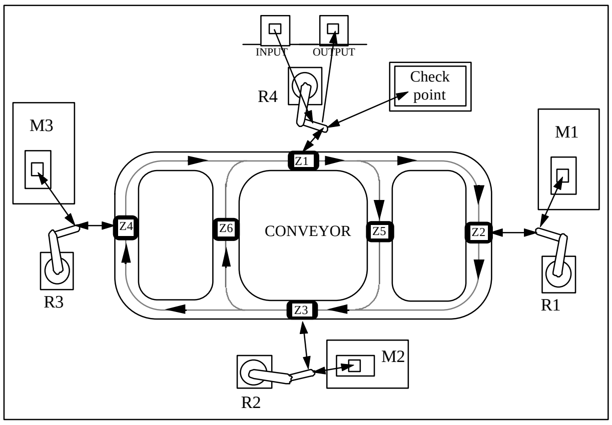

Figure 4: Example of workshop.

Example: The workshop of Fig. 4 is considered. M1, M2, M3 are machining resources. They are respectively performing the following machining functions: M1 (f_1, f_3, f_5), M2 (f_2, f_5), and M3 (f_2, f_4). Ch is a checkpoint. R4 is a robot that can perform transfer operation from FIFO IN to Z1, from Z1 to FIFO OUT, from Z1 to Ch and from Ch to Z1. R1 (respectively R2, R3) is a loading robot affected to M1 (respectively M2, M3). CV is a conveyor, that enables transfer from Z1 to Z2 or Z5, from Z2 or Z5 to Z3, from Z3 to Z4 or Z6, from Z4 or Z6 to Z1. The resulting OAG is represented Fig. 5.

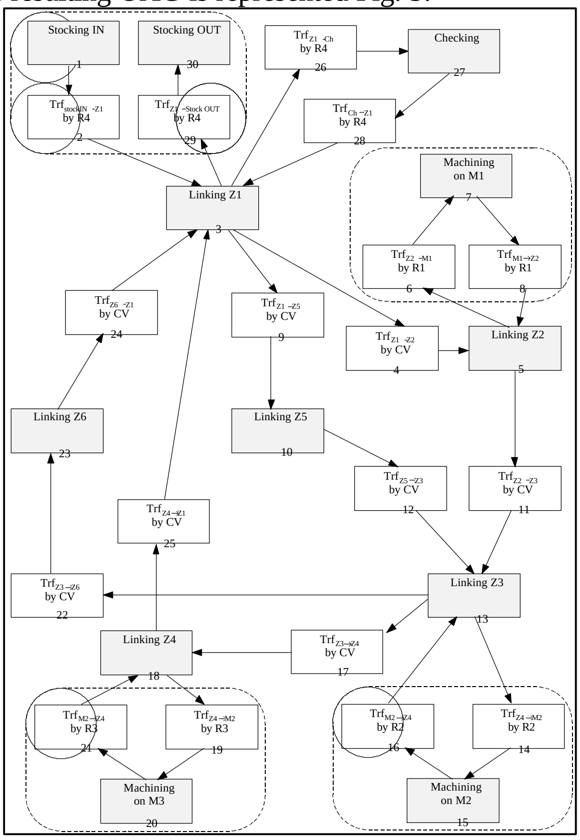

Figure 5: The resulting OAG

4.2 Using the OAG to decide relatively to products

The FMS model is the knowledge base used to deduce the option to be apply for a part. Using the

OAG, it is possible to determine if a part can reach a resource or a check point. It also enables to know whether the resource can perform an operation.

The OAG is used to store information during the normal functioning mode of the FMS. For example, it is able to know the operations, that could be considered in a minor, significant or major reconfiguration. Advance of parts within the FMS architecture, including both transformation state and position, is also noticed in the model. It has to be noticed that the model is not dynamic according to the products. When a failure occurs, the model is used to generate information for recovery, in particular the sequences of operations that can take part in an option completion.

Specific features have been added in order to know the part that may be affected. Feature "*Op. requested by*" takes as values the parts that are waiting for the operation. Feature "*Op. in progress on*" takes as values the part on which the operation is being performed at this moment. Parts, whose indicator is stored in the feature "*Op. in progress on* " of operations that become out of order, are considered as parts that may be affected by the failure.

After the failure detection and diagnosis, directly affected operations, that have the feature "operation state" set to out of order, are removed from the OAG. Consequences for nodes are inferred from operation failure. The general problem comes then down to looking for the existence of some paths [8] in a graph after removing the considered nodes.

To know whether a part is able to be automatically evacuated, it is sufficient to know whether the node, where the part is currently settled, is not Blc.t.E. If the operation is Blc.t.E., then some other architecture potentialities have to be taken into account (Reconf.2 or Reconf.3) or the part is manually taken out.

To know whether it is possible to go on with the Log.Op.Seq. of the part, it is sufficient to find a path from the current area where the part is, to the exit, that successively includes nodes implementing the machining functions in the Log.Op.Seq.

For the option of quality checking, if a check point is Blc.t.E., it is of no use trying to send the part to this area. In the opposite, the GAO enables to determine if the part can reach this area. Depending on the results of quality checking, the procedure will be close from one of the two preceding procedures.

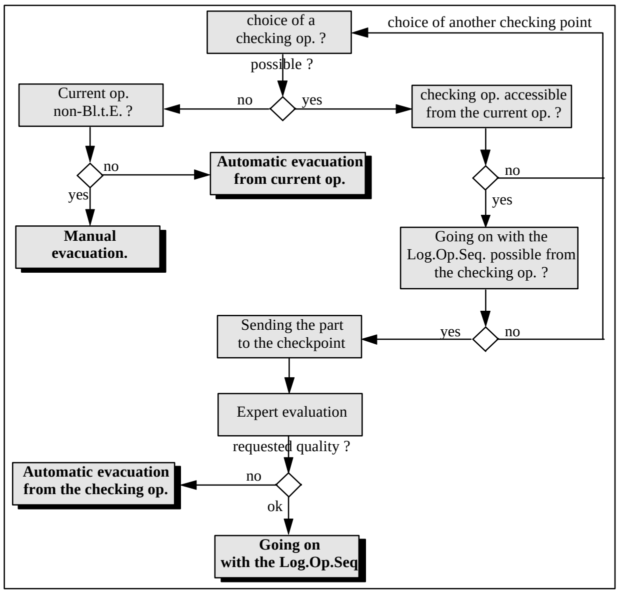

Figure 6: Using the OAG to decide about quality checking option

Fig. 6 summarises how the option of quality checking is implemented using the OAG. Current operation denotes the first operation, of the operating sequence, that has not been yet completely performed on the considered part.

4.3 Using the OAG to validate an option according to reaction levels

In order to implement the strategies, this section specifies the operations considered in the case of minor / significant / major reconfiguration.

In order to consider working mode states of resources (cf. section 3), several sets of operations are defined. "*Used operations*" set takes as value operations that are chosen to manufacture the production. These operations are performed by resources used in production. "*Reserved operations*" set gives information about the operations that are ready in the current configuration. These operations are performed by reserved resources. "*Possible operations*" set gives all the operations that can be potentially used. This is the set of non out of order operations.

Using the OAG, the principle summarised in Fig. 7 consists in checking the feasibility of an option using an OAG composed of the set of "*Used operations*", without the out of order operations (minor reconfiguration). In case of null result, the procedure computes the impact of the failure and then looks for a path in a larger graph composed of the set of "*Reserved operations*" (significant reconfiguration). The third level is to consider the set of "Possible operations" (major reconfiguration).

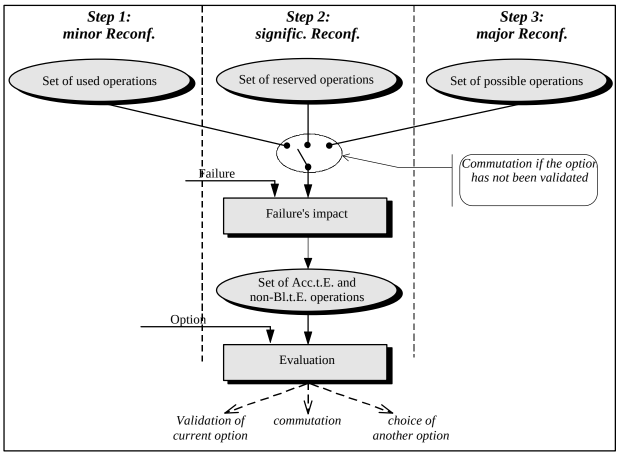

Figure 7 : Validation principle

5. Example

The workshop of Fig 4 is assumed to achieve the Log. Op. Seq. : f_1,f_2,f_3 for part 1, f_4,f_3 for part 2, and f_5,f_2 for part 3. Initial chosen configuration takes all resources into account except R2 and M2. A failure affects the machining resources M3. Operations performed by M3 are both out of order. At this moment, part 1 is on M3; part 2 is on Z1; part 3 is on Z3.

For part 1, machining function f_1 has already been performed. In this example, the cost associated with this part is considered as high. The quality of the part is checked. The part is sent to the checkpoint. Result of analysis is that the transformation sequence can be carried on from f_2. This option needs a major reconfiguration (M2 and R2 have to be set in working mode).

For part 2, machining function f_4 has already been performed. The cost associated with this part is considered as average. Continuation of the Log.Op.Seq. is the chosen option, that requests a minor reconfiguration.

For part 3, machining function f_5 has already been performed. The cost associated with this part is considered as low. The continuation option needs a major reconfiguration. Automatic evacuation can be performed using the current configuration. It should be decided to evacuate, but as the preparation of R2 and M2 has been envisaged for part 1, recovery concludes to continue with part 3.

It should be noticed that in case of failure on R3, it is even not possible to automatically evacuate part 1, that should be manually taken out.

6. Results exploitation

After computation, recovery procedure concludes for each part about the chosen option and the type of reconfiguration that enables the option to be implemented. Results are stored in a table (cf. Fig. 8). It expresses, for a given reconfiguration type, the options satisfying the best each part. For major reconfiguration, the table also indicates, in brackets, the number of resources that need a preparation, before to be set in working mode.

Part	Evacuation	Quality check	Continuation	Manual
1	Reconf.1	Reconf.3(1)	Reconf.3(2)	
2	Reconf.1		Reconf.1	
3	Reconf.1		Reconf.3(2)	

Figure 8 : Example of table

In order to avoid many reorganisations, the problem has to be approached within the framework of global strategy. Results about each part could be integrated in a computer aided decision procedure. The decision will depend on a multiple criteria's analysis, that considers cost associated with parts and cost associated with the number of resources to switch-on and to prepare. These resources may be turned-off because a preventive maintenance is about to be started. A simple application is to threshold the results according to the reconfiguration type or a given number of resources to be prepared.

7. Conclusion

The case of products present in the FMS when a failure occurs was examined. The solving of the problem yields to examine for each part the possibility of reaction of the system, according to a global strategy. The solution depends on the nature of the part, the failure's impact and the potentialities allowed by the FMS. Once an option is obtained, the technical feasibility is examined. The problem is then approached within the framework of a global strategy.

The method is implemented using a model of the operating part. The computation is based on graph algorithms. Decisions presented imply the parts to be case by case considered. This induces a quite combinatorial, but repetitive computation. This could be improved using distributed or paralleled computations. Another option should be to use, as far as possible, precomputed results. In particular, it should be interesting to take critical operations [9] into account. It should be noticed that, for the moment, the order each part is taken into account might have some influence on the procedure.

In the proposed method, the FMS is first cleared of its parts, before going on with new production types. The treatment of parts already present in the workshop is seen as a transitional rate. In our mind, strategies concerning affected parts can not completely be dissociated from strategies concerning parts that will be set at the entrance of the FMS.

Further works would be to consider both raw parts to be set at the entrance and parts present in the FMS in the global decision. The advantages should be:

- to decrease the number of reconfigurations. The same reconfiguration type should be performed both for a part present in the FMS and for new parts;
- to begin to put some raw parts at the entrance of the workshop, without waiting for all the present parts to be evacuated.

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