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# Ontological-based validation of selected technological resources in integrated machining and inspection process planning

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**Abstract**

Based on previous research carried out to characterise the capacities of the resources involved in the execution of process planning, in this paper a methodology is presented for validating the configurations of resources assigned to the activities of integrated machining and inspection process planning. The methodology utilises concepts from the MIRC ontology and has graphic support that makes it more user-friendly. It also places special emphasis on the preparation activities used in the configurations of the resources and has been conceived as an aid to help in the final steps of the development of the process plan.


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*Keywords:* Integrated process planning; resource capabilities; ontological modelling.

## 1. Introduction

In process planning is essential to validate that the resources selected for each of the steps of the plan have sufficient capability. In turn, to support this validation task, information/knowledge models need to be developed. Among the few contributions that have been put forward in the regulatory field, perhaps the most noteworthy are those included in MANDATE [1], which presents an integrated model for the management of manufacturing resources. Other non-regulatory works that offer interesting contributions are those by Newman and Nassehi [2], in which the resource capability profile is defined as an aggregation of the individual profiles; or the PPDRC (Product

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and Processes Development Resource Capabilities) and MIRC (Manufacturing and Inspection Resource Capability) ontologies [3, 4], where the capabilities of a resource are considered to be necessarily linked to the execution of activities.

PPDRC incorporates concepts from PSL [5] and MANDATE. In PSL, activities and their execution are the core of the ontology. These activities require the intervention of resources. Yet, the description and structuring of resources is not taken into account in PSL. That is why PPDRC considers the contributions of other initiatives, such as MANDATE, that are capable of conceptualising all the aspects of the resources that are needed to carry out the process representation and planning tasks, such as those of capability and capacity. The capability of a resource characterises its participation in a type of activity, expressing the skills required to execute activities of that type and, should it be the case, the level of performance reached in executing them. A capacity, however, is a type of capability expressed in terms of amount of production.

The MIRC ontology is a specialisation of the PPDRC ontology and supports the knowledge needed to make decisions about the tasks involving: (a) configuration and assignment of resources, and (b) evaluation and validation of the plan, within a context of integrated machining and inspection planning, carried out at supervisor level. For determining the technological capabilities of machining and inspection resources, will be essential to determine what preparation activities (loading and setup) are necessary and in what order and with what resources they are to be executed. On the other hand, of all the technological characteristics that MIRC supports, in this study only those linked to dimensional and geometric variability are taken into account.

To carry out all these tasks in collaborative contexts [6], it is foreseen the planning agents should have access to information and knowledge bases that are grounded in the MIRC ontology and they do their work following the methodology outlined below.

## 2. Conceptual framework. The MIRC ontology

Within the conceptual framework of the MIRC ontology, a resource must be considered the fundamental entity that is characterised by its capability executing a type of activity (Fig. 1). A resource can participate in an activity playing different roles (input, mechanism, control and output). When a resource plays the role of a mechanism, that is, as the performer of the activity, its *capability* will depend on the type of activity that it is executing. This *capability* will also be conditioned by the characteristics of the execution of the activity itself (interface), which are linked to the conditions under which it is carried out and which are regulated by the characteristics of the object that plays the role of control, as well as by the fact that the objects playing an input role in this activity fulfil certain characteristics. The resources and their *capabilities* are a consequence of the preparation activities established for configuring them and can be executed at different levels of aggregation (section, cell, machine, etc.) in order to meet the needs of the different levels of process planning (aggregated, supervisor or operational). In order to explain how the ontology is used, this section goes deeper into the characteristics of the resources executing an activity, by means of the graphical representation underlying the methodology outlined in the following section. Before that, however, the fundamental concepts of MIRC ontology and its taxonomy will be reviewed.

### *2.1. Concepts and entities of the MIRC ontology*

In terms of the taxonomy, the individuals in the Resource class can be classified according to different criteria. A Generic_Resource is an abstract resource whose participation in the execution of a certain activity must be understood as the participation in that activity by one of the Specific_Resources included in that generic resource. Moreover, resources may be of the Resource_Group or Resource_Element type, depending on whether they are made up of other resources or not. The Resource_Group that plays the mechanism role in the Operations is called Machine and is made up of an individual of the Machine_Base type and one or several individuals from the Tool and Fixture classes. Together with Operations (Machining or Inspection), MIRC supports another types of activities, such as Preparations (Loading and Setup), which establish the capabilities of the resources that participate in the Operations.

The quantification of the capabilities of a resource can be carried out in different ways. Specifically, to take into account dimensional and geometrical aspects, three specialisations for Variability regions have been considered

(Fig. 1): Dimensional_Variability (DV), Own_Geometric_Variability (OGV), and Reference_Geometric_Variability (RGV). DV regions express variability in lengths and angles. OGV regions express intrinsic geometric variability. Finally, RGV regions express orientation and position variability. Other regions needed to complement dimensional and geometrical specifications are Roughness, which is a Limit_Value region, and Stroke, which is a Nominal_Value region.

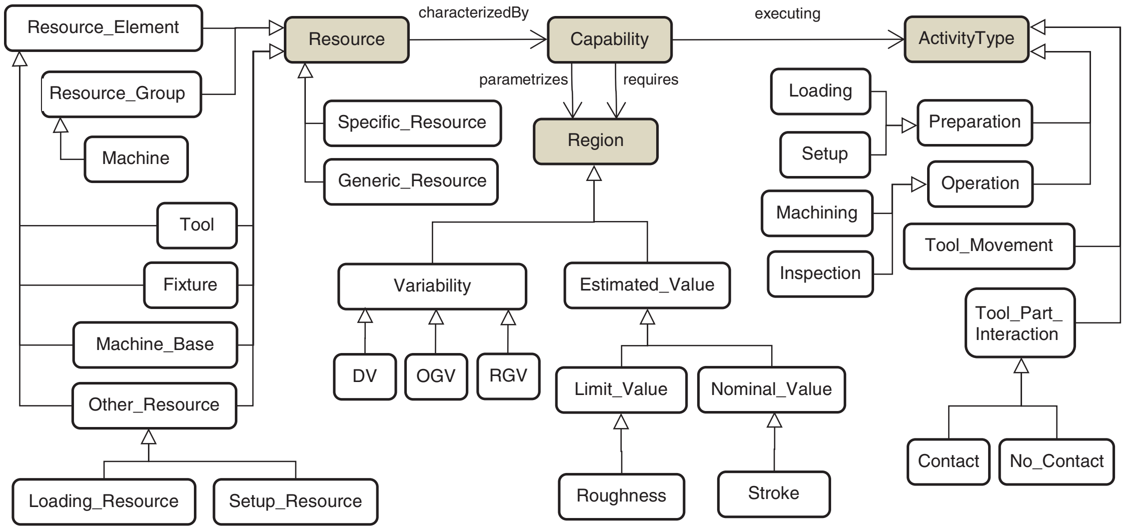


Fig. 1. Taxonomy of the entities Resource, Region and ActivityType in the MIRC ontology.

Furthermore, MIRC possesses a whole series of predicates, some of the most noteworthy being parametrizes, which expresses the relationship existing between a capability and the regions that quantify it, and requires, which expresses in a quantitative manner the requirements that must be fulfilled by the characteristics of the object on which the activity is being performed, in relation to the level of performance of the capability of the resource executing activities of that type. More detailed information on the relationships between classes and predicates in the MIRC ontology can be found in [4].

## *2.2. Graphical representation of the activities in process planning*

Everything outlined above concerning the activities can be seen in Fig. 2(a), which shows how the characteristics of the output object, represented by an arc drawn with a solid double line, are dependent on the characteristics of the objects that participate in the execution of the activity with input, mechanism and control roles, which are represented by arcs drawn with dotted lines, solid lines and dashed and dotted lines, respectively. They also depend on the characteristics of the interface of the activity, which act as a kind of hinge (interface) on an axis that represents the execution of the activity itself.

In order to complete the information provided by Fig. 2(a), in Fig. 2(b) emphasis is placed on the fact that the characteristics of the objects with input and mechanism roles are the result of the execution of other previous activities, thereby making up the chain of characteristics that represent the execution of the plan. The links (or arcs) of this chain are represented by adding a symmetrical arc in each of the planes in Fig. 2(b). This arc represents the same characteristic of the object but with a different role that allows it to link up with the execution of other activities. Moreover, to facilitate the visualisation and interpretation of the characteristics shown in the spatial representation, from now on a set of flat representations will be used, like those shown in Fig. 2(c) and 5, which are the result of the abatement of a combination of the planes Input (I), Mechanism (M), Control (C) and Output (O) with respect to their line of intersection, and the projection according to that line of intersection. In this last case (projected view in Fig. 5), the arrows shown correspond to the planes I, M and O, while the Control (C) plane is omitted. In order to show that the characteristics of the resulting object are directly dependent on the characteristics of the resource and the activity execution interface, in Fig. 2(c) the arc of the input object characteristic connects with that of the resource capabilities and, likewise, the one from the control object connects with that of the characteristics of the activity interface. This interface is established among the geometries that are active during the activity and which belong to physical objects, such as parts, tools, measuring probes and fixtures.

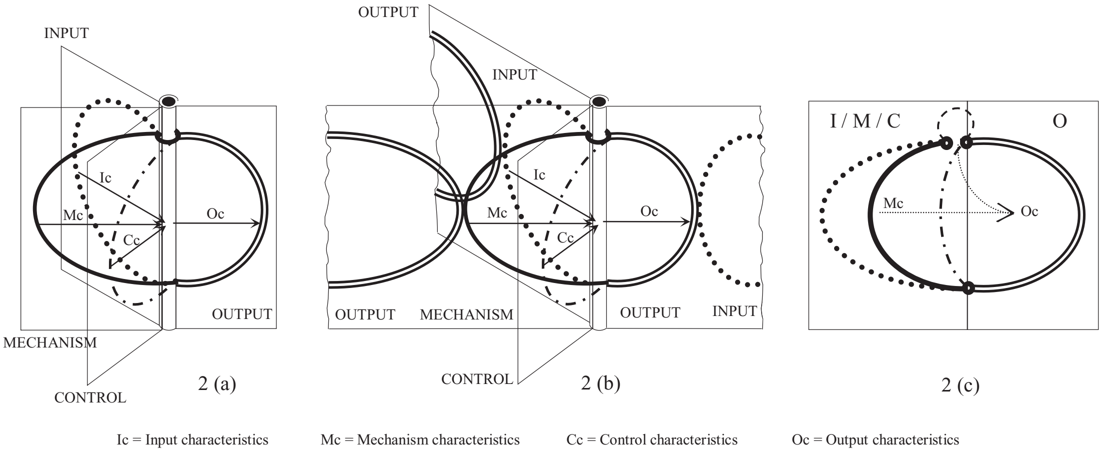


Fig. 2. Spatial and plane representation of the characteristics associated to the execution of an activity.

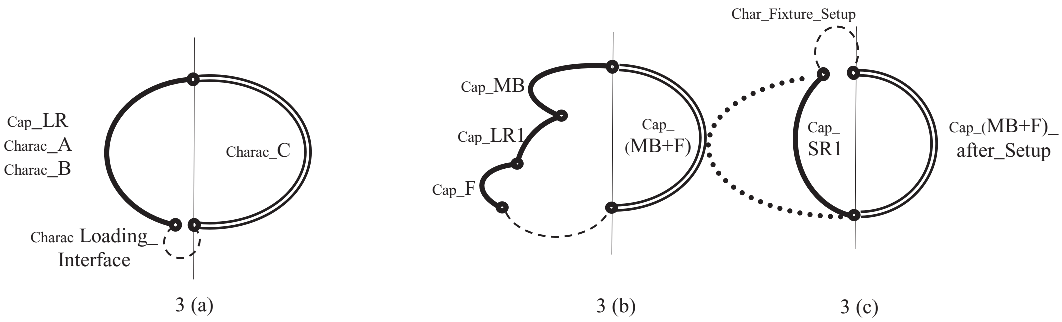


Fig. 3. Plane view with the execution of Loading and Setup activities.

Activities of the Preparation type (Loading and Setup) determine the capabilities of the machining and inspection resources through actions that involve the formation of complex resources and/or their modification and characterisation. The output object resulting from the execution of a Loading activity will maintain some of the characteristics of the input objects and will take other new that characterise the set as a whole. Therefore, as can be seen in Fig. 3(a), the characteristics (Charac_C) resulting from the execution of a Loading type activity will depend on the characteristics of the execution of the activity (Charac_Loading_Interface), on the capabilities of the Loading_Resource object that executes the activity (Cap_LR) and on certain characteristics of the input objects that are part of the mechanism (Carac_A and Carac_B). Following this pattern, Fig. 3(b) shows the execution of a Fixture_Loading type activity with which a complex resource (MB+F) is obtained from a Machine_Base (MB) and a Fixture (F). In the same way, the MIRC ontology takes into account other Loading type activities: Tool_Loading and Part_Loading.

In Setup type activities, which include a measurement and/or a correction, the capabilities of a Resource_Group are quantified directly, as though they were a single entity. As can be seen in Fig. 3, this is shown by replacing the lines to the left of the vertical line that represents the execution of the Fixture_Loading activity (Fig. 3(b)) by the lines that correspond to the capability of the resource performing the setup (Cap_SR1) and the characteristic of the setup execution interface (Fig. 3(c)).

## 3. Methodology

The ultimate aim of the methodology is to guarantee the validity of the resources, which have been previously configured and assigned to the operations of a certain process plan, so as to ensure the specifications are met. This process is based on the existence of a fully or partially established plan, represented by means of the corresponding operation sequence, and which consists of four steps: (1) construction of the plan graph; (2) construction of the characteristics graph; (3) identification and quantification of the characteristics loop; and (4) improvement. In order to make this easier to understand, the steps of this methodology are explained using the example of a process plan for the part shown in Fig. 4.

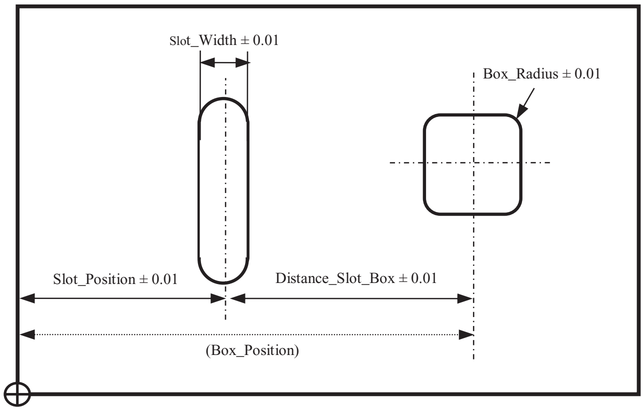


Fig. 4. Dimensional specifications for the part.

Construction of the plan graph. This graph is the projected view of the representation of the activities in the plan (Fig. 5), which includes both Preparation and Operation type activities. In this case, the first three activities are of the Loading type and are used to configure the resource (Machine_123_Part_RM), that is used in the two operations that follow, corresponding to the machining of the slot and the box.

Construction of the characteristics graph. The second step of the methodology consists in representing all the characteristics associated with the execution of the preparation and operation activities by means of the graph plane view. Thus, for example, Fig. 6 shows how, in the case of the activity Fixture_Loading, the lines that represent the capabilities (Cap_MB, Cap_LR1 and Cap_F), together with the one representing the interface characteristic (Char_Fixture_Loading_Interface), are closed by the line corresponding to the characteristic resulting from the resource Machine_12 (Cap_MB+F). Fig. 6 also shows how the characteristic resulting from the execution of an activity is part of the characteristics (capabilities) of the resource that participate in the next activity. In this set of chain graphs, the thick broken lines represent the extension of a point on the graph or characteristic with a null value.

Another interesting aspect of the graphs worth highlighting are the interface characteristics, such as that of machining represented in Fig. 6 (Slot_Milling). In carrying out this operation, the variability (DV type region) associated to the characteristic Slot_Position will depend on the interface characteristic of the slot milling and on the capability of the resource Machine_123_Part_RM. This capability results from the composition of the characteristics associated to the Loading type activities that have been used to configure the resource and which can be seen in Fig.

7(a). The representation in this figure is more compact as a result of having removed the O-M arcs that link the executions of the activities represented in Fig. 6.

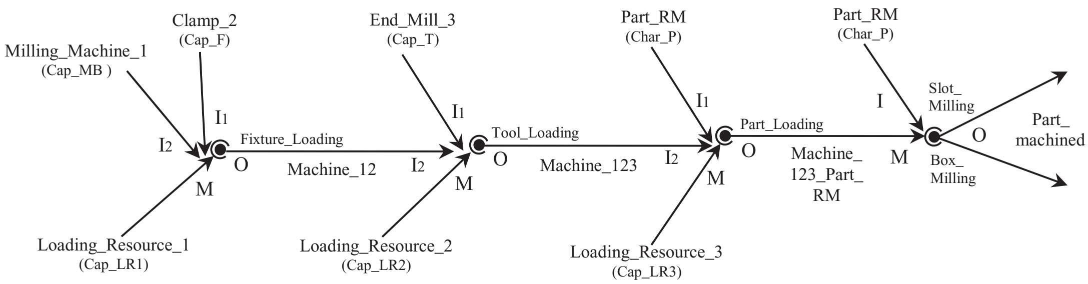


Fig. 5. Projected view with the Preparation and Operation activities of a process plan for a slot milling operation.

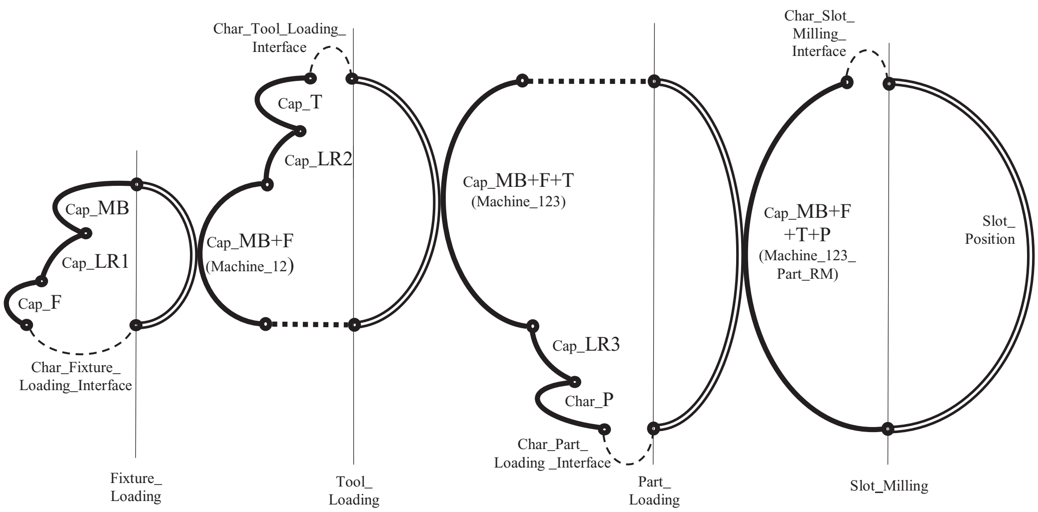


Fig. 6. Plane view with the Preparation and Operation activities of a process plan.

Identification and quantification of the characteristics loop. The third step involves quantifying all the components of the loops corresponding to the characteristics that are going to be validated.

Quantifying each loop makes it possible to validate how well the resource is suited to obtain a particular characteristic. This will be positive if the composition of the values of both the characteristics of the resource and the characteristics of the activity execution interface is below the value specified for the resulting characteristic. For example, in the case of Slot_Position, it would be necessary to check that the variability of the resource and of the execution of the activity, considered jointly, is below that specified for the characteristic Slot_Position (DV=0.02 mm). Hence, the DV type regions of all the lines (characteristics) of the loop in Fig. 7(a) running from the node Origin (part-fixture interface) to the node Slot (tool-part interface) are constructed by means of a quadratic sum: Char_Part_Loading_Interface, with DV=0.0005 mm to Char_Slot_Milling_Interface, with DV=0.004 mm, the result of which is DV=0.016 mm. If this same procedure is used to quantify the loop corresponding to the characteristic Slot_Width, we obtain a value of DV=0.012 mm. In the same way, the graph represented in Fig. 7(b) could be used to evaluate the capability of the resource Machine_123_Part_RM to obtain the characteristics

Box_Position and Box_Radius, the values being DV=0.016 mm and DV=0.012 mm, respectively. The values of these DV type regions are obtained from the database in the MIRC ontology by using queries [4].

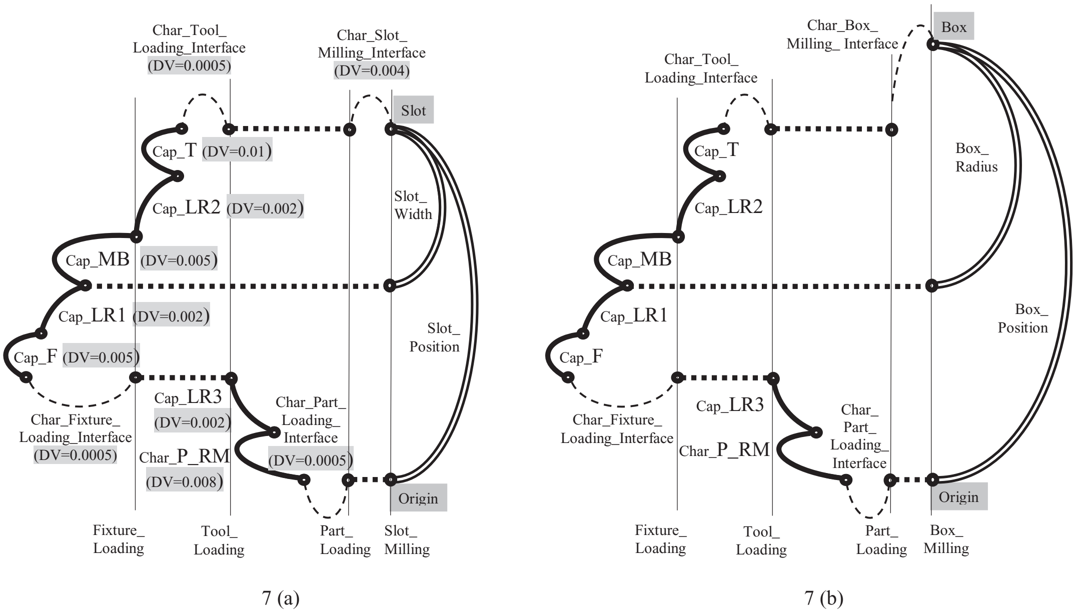


Fig. 7. Plane view with multi-characteristic graphs.

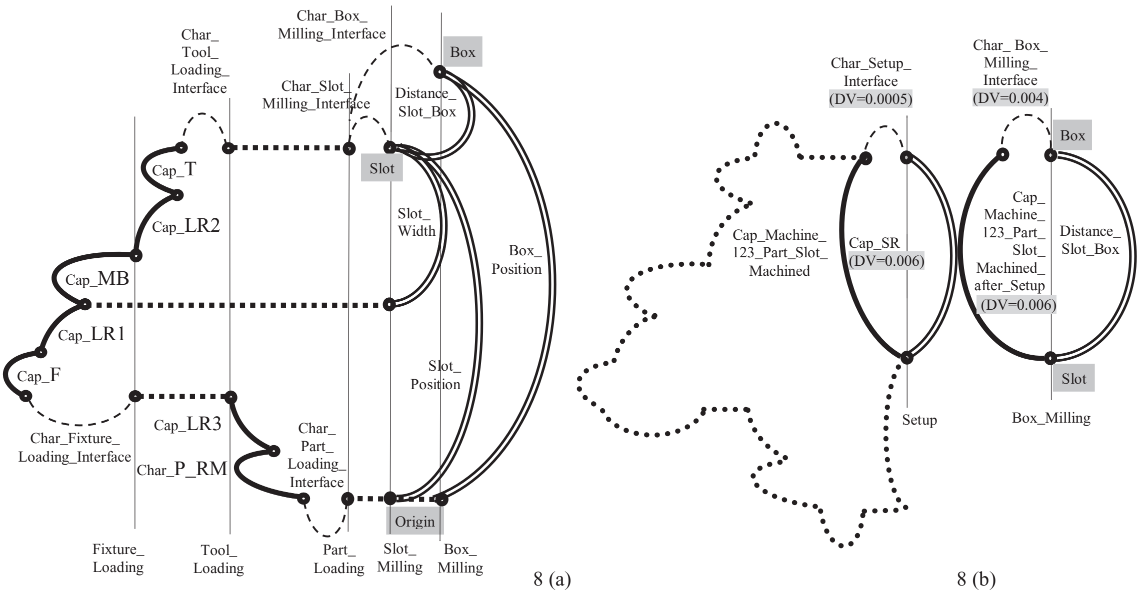


Fig. 8. Plane view with: (a) multi-characteristic and multi-operation graph; and (b) box milling operation after setup.

The two previous graphs show the operations independently, without any link between them, but in fact they are connected to each other in the process plan. This can be seen in the multi-operation graph in Fig. 8(a), which is the result of superimposing Fig. 7(a) and Fig. 7(b).

Improvement. If appropriate, as in the case we are dealing with here, application of the fourth step of the methodology must improve the value of the elements of the loop that have an influence on the final value of the characteristic under consideration. The improvement shown in Fig. 8(b) consists in adding a setup in which the input used is the resource made up of the machine, with a tool, the clamping device, and the part after milling the slot. This is a complex resource whose capability is Cap_Machine_123_Part_Slot_Machined, which has been represented in Fig. 8(b) by a dotted line. The resource that executes the setup is the machine itself equipped with a touch-trigger probe, the capability of which has been estimated as having a value of DV=0.006 mm. Hence, the resource resulting from the setup has the capability to generate the characteristic Distance_Slot_Box with a DV value (0.0072 mm) that is compatible with the specifications. The modifications with respect to the process planning in Fig. 5 (adding of a setup between the slot and box milling operations) are shown in Fig. 9.

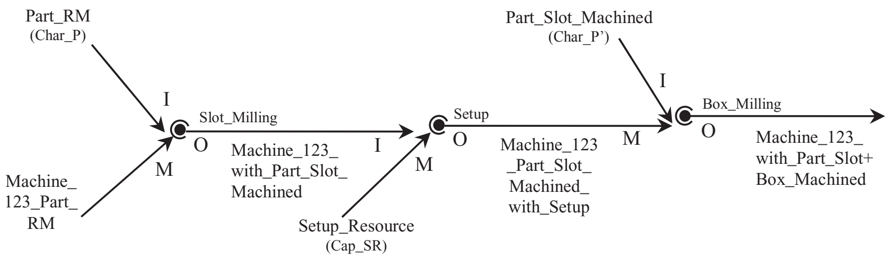


Fig. 9. Projected view with setup and machining operations.

## 4. Conclusions

In this paper we have presented a methodology that allows the resources involved in process planning to be validated and improved; such a methodology has not previously been reported in the literature. It has graphic support and is grounded on the MIRC ontology that characterises the resources in terms of their capabilities. The study has shown how it is used and the benefits to be gained from the evaluation of the plan and its possible improvement, should it be necessary to do so. The improvements that can be considered with this methodology derive from the modifications made to the productive resources involved, either through a change in the definition or configuration of the resource or by including a setup operation, which involves a measurement and a correction.

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