A Manufacturing Process Compiler (MPC) - Vision for a Futuristic Manufacturing Paradigm

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The Need and The Vision: In spite of decades of efforts spent in the search for makers' "holy grail," namely, the ability to automatically generate process plans consisting of precise manufacturing or assembly instructions within a set of given/existing constraints still remains as elusive as ever. The inability to realize this goal stems from the fact that the bulk of the past approaches is based on a linear-mode of thinking, i.e., design followed by manufacturing without substantive feedback, the disregard of existing constraints in a given enterprise that range from process and machine to economy/cost related, and the failure to consider advances in other fields that could have been capitalized upon to solve the problem at hand. In the latter case, this primarily relates to the failure to consider computational and optimization tools and algorithms, data base technologies, inference engines, game theory, the availability of cheap computing and communication resources, to mention a few.

The Definition: In light of the above, one can envision a Manufacturing Process Compiler (MPC) for the compilation/translation of the digital representation of a product into a complete sequence of manufacturing instructions in face of specified constraints. The demonstration of the feasibility of such a concept, of course, could be initially done on a less ambitious scale that is limited to a specific manufacturing domain, e.g., material removal, or even more limited, i.e., material removal for a specific range of part size and type of material.

MPC contains two essential elements, a Design and Manufacturing Language (DML) and a Kernel. A language, by definition, represents the intent organized in a specific systematic way using a set of vocabulary. A kernel transfers from one language input (i.e., digital representation of product) to the desired output (i.e., manufacturing instruction with all the necessary data on machine, processing parameters, tooling, etc.).

The "Design and Manufacturing Language (DML)" is a prerequisite that provides the foundation for MPC. It is a formal language that describes, as subsets, the following four essential groups of information:

(a) *Workpiece features and attributes.* This Workpiece Description Language (WDL) subset could be automatically derived from the existing conventional geometric CAD representation of the product extended to include feature characteristics, e.g., tolerances, surface roughness, etc.
(b) *Process characteristics*. A unified rigorous method in the form of a Process Description Language (PDL) subset is also needed to define the plethora of unit processes in terms of their input and output characteristics.
(c) *Machine/Manufacturing equipment description*. As above, a Machine Description Language (MDL) subset needs to be defined to characterize machine capabilities, capacities, limitations, etc.
(d) *Tool characteristics*. The Tool Definition Language (TDL) subset would define the salient features of the tools that can be used in a certain process. In this context, the tool should be considered in a broad sense. For example, in a chemical machining process the tool is the electrolyte used, etc.

User-imposed constraint definitions are also included in each of the four subsets to constrain the solution space or direct the solutions in a desired direction based on user requirements and considerations.

The system "Kernel" performs the actual manufacturing sequence generation. It constitutes the core of the system in which the actual sequence or plausible alternative manufacturing sequences are determined. Here, one can envision numerous approaches or their combinations that can be pursued. Possibilities include, the use of expert knowledge in an Artificial Intelligence (AI) fashion, posing the problem as a Constraint Satisfaction Problem, decision making and optimization structures of all sorts, etc. and their combination. The sequencing process can clearly be constituted as being fully automatic or allowing user input/interactions.

Relationship between CPS and MPC: The Cyber-Physical System (CPS) can be viewed as the host of three different types of users: Designer, Process Planner, Equipment Provider. The designer can be a novice or a sophisticated user who has an idea about what the product will look like and how it will function. Using WDL, the design intent will be framed for the Process Planner. The equipment Provider shares its available equipment and capacities within the CPS system using MDL and TDL. Here, for example, the equipment provider can specify the range of feed rates that one will be allowed to execute on their machine and what type of tool holders they have in the inventory. The process Planner uses MPC to process the information provided from the designer and equipment providers to generate a process plan and route the execution plan. In the advanced stages of development, the CPS system will be able to continuously incorporate inputs received from designers and equipment providers and enable the Process Planner to design a supply chain (i.e., one product can utilize more than one equipment provider) based on cost, quality, customer preferences (e.g., make the product only within a certain geographical location), etc.