Intelligent Manufacturing Operations Planning, Scheduling and Dispatching on the Basis of Virtual Machine Tools

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Abstract. Today, numerical-controlled machine tools are used for flexible machining of increasingly individualized products. The selection of the most economic tool, machining strategy and clamping position is part of the manufacturing operations planning and bases on the employees' practical knowledge. The NC programmer is supported by current CAM systems with material removal simulation and collision detection. This early validation avoids damages and increases the productivity of the machines. The benefit of simulations can be increased by a better model accuracy. In common CAM systems the machine behaviour is often insufficiently reproduced; for example, the dynamic characteristics of axes, the tool change and the chronological synchronization are simplified or neglected. In view of complex operations, a slow trial run on the real machine or substantial safety margins are necessary. The described deficits can be solved by virtual machine tools. Thereby a virtual numerical control and a detailed machine kinematic is used for an accurate simulation. The result is an error-free NC program which can be directly used on the real machine. In addition, the exact processing time is determined and supplied for the operations scheduling and dispatching. Furthermore, virtual machine tools provide promising approaches for an automated optimization of machining operations and machine set up. Parameters for the optimization of the processing time are, for example, different clamping positions or tooling arrangement. Simulating several parameters requires lots of computational power. Hence, the vision of the project „InVorMa" is a cloud application, which supports the operation planning, scheduling and dispatching of machine tools. A computer cluster (cloud) provides noticeably faster results than a single computer. Therefore, the machine tools and the manufacturing equipment of the user are cloned one-to-one in the cloud. The manufacturing documents are optimized by the cloud application before they are forwarded to the shop floor. The optimization involves the NC program for each machine as well as the distribution of orders. The practical knowledge of the manufacturing planner and the results of the optimizations are pre-processed for reuse by an integrated knowledge base.

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1 INTRODUCTION

Manufacturing in high-wage countries requires the efficient use of resources. Increasingly individualized products require a highly flexible production system [1]. In the field of machining of metals, the needed flexibility is achieved by numerical-controlled machine tools. It is the function of the manufacturing planner to ensure a rational use of the operating means. This is based on his practical knowledge and furthermore on the utilization of machine simulations to avoid damage and increase productivity from the office. The aim of the project "Intelligent Manufacturing Operations Planning, Scheduling and Dispatching on the Basis of Virtual Machine Tools" (InVorMa) is a cloud-based simulation of machine tools and it is developed by the Heinz Nixdorf Institute and the Decision Support & Operations Research Lab (DSOR) of the University of Paderborn as well as the Faculty of Engineering sciences and Mathematics of the University of Applied Sciences Bielefeld in cooperation with the machine tool manufacturer Gildermeister Drehmaschinen GmbH. The companies Strothmann GmbH and Phoenix Contact GmbH & Co. KG support the definition of requirements as well as the following validation phase as pilot users.

The current procedure of operation planning was documented with the pilot users as groundwork for the requirements of a simulative assistance in this field. Figure 1 shows the summarised steps, tasks and results.

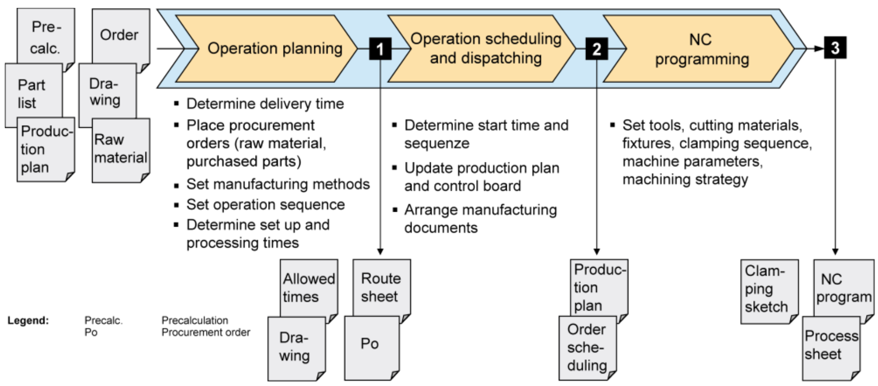

Fig. 1. - Summarized as-is process of operations planning, scheduling and dispatching

In the operation planning, the manufacturing methods, production resources and sequences are determined according to firm-specific goals (such as punctuality, profitability, quality). In addition, the processing time and setting time is predicted on the basis of empirical values and the pre-calculation. In this phase the order of raw and purchased parts are initiated. Results are the routing sheet, the allowed times and the procurement orders.

It is the work task of the operations scheduling and dispatching to determine the start time and sequence of manufacturing orders as well as the allocation of resources with regard to the allowed times, scheduled delivery dates and the disposable machines. The Result is the up-dated master scheduling.

The last step is the NC programming for every manufacturing operation on numerical-controlled machines. Today, CAM-Systems are used for NC programming away from the machine. These provide an automatic calculation of the tool path for predefined shapes (e.g. plane surface, island, groove) deduced from given CAD models of blank, finished part, tool and fixture. The setting of technological machining parameters, used tools and clamping positions is still a manual task of the NC programmer. Hereby, he has a huge impact on the processing time and quality. Results are the NC program, the process sheet and the sketch of set up.

2 APPLICATION OF VIRTUAL MACHINE TOOLS

Nowadays, the CAD supported NC programming includes the simulation of machining. This kind of verification has become quite popular due to the process reliability of machining with 4 to 5 axes [2]. Against the background of reduced batch sizes, the simulation achieves an increasing acceptation also for machines with 3 axes, since it is possible to reduce the test runs for new workpieces and special tools and moreover to reduce the risk of discard. Therefor, common CAM systems provide a material removal simulation and an integrated collision detection. The material removal simulation shows the change of the workpiece during the machining. The automated collision detection reports any unwanted contact between the tool (shank, holder), workpiece und fixture. However, the reproduction of the real machine behaviour is mostly reproduced insufficient by these systems. For example, the dynamic characteristics of the axes, the movement of PLC controlled auxiliary axes, the automatic tool and pallet change, as well as the time synchronization of all movements are only simplified implemented or even neglected [3]. The basis of all common CAM systems is the emulation of the calculated tool paths by an imitated control. Therefore, the machine independent source code CLDATA (cutter location data) [4] is used instead of the control manufacturer specific NC program that run on the real machine. The machine specific NC program is compiled after the simulation by a post processor to adapt the source code to the exact machine configuration. The wear points of integrated simulations are known to the NC programmer, they are compensated by tolerant safe distances. This causes extended processing times and with it unused machine capacities. The result of the integrated simulation in CAM systems is a checked syntax, tool path, zero point and collision-free run of the NC program and additionally the approximated processing time. Nevertheless, a slow and careful test run is still necessary for complex machining operations due to the low modeling accuracy.

The optimized machining by utilization of simulations requires a reliable verification of the operations that are defined in the NC program. The simulations in the contemporary CAM systems can’t provide this due to the mentioned deficits.

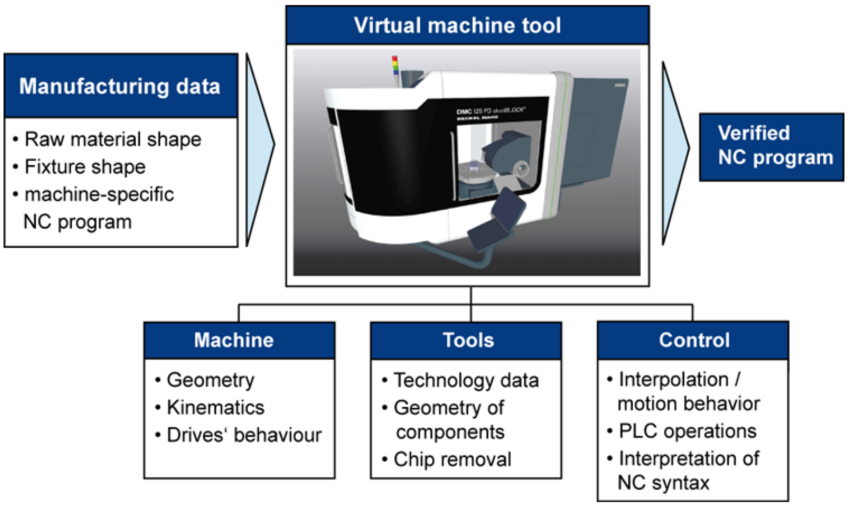

Fig. 2. - The simulation models of the virtual machine tool

An approach to optimize the NC program away from the machine is the realistic simulation with virtual machining tools [5]. This includes the implementation of a virtual numerical control with the used NC interpolation as well as the behaviour of the PLC and the actuators. Additionally the entire machine kinematics, the shape of the workspace and peripheries are reproduced in the virtual machine (figure 2). Input data is the shape of the blank and the used fixture as well as the machine specific NC program. The virtual machine tool enables the execution of the same tests as the real machine. This includes optimizing parameters (for example different clamping positions or tooling arrangements) to reduce the processing time. The result is an absolutely reliable NC program, which can run straight on the real machine. Additionally, the reliable processing time is determined by the simulation and made available to the operations scheduling.

However, the variation of parameters (for example the clamping position) or adaptations (to minimize unnecessary operations and tool changes) have to be done manually by the user in the NC program. A new simulation run is necessary after each change and the result must be analysed and compared to previous simulations by the user. This is an iterative process until a subjective optimum (concerning time, costs, quality) is found. The simulation on a single PC runs only 2 to 10 times faster than the real processing time depending on the complexity of the workpiece. Today, the simulation of complex and extensive machining takes too long for multiple optimization runs.

3 VISION: CLOUD-APPLICATION TO SUPPORT PROCESS PLANNING

The illustrated possibilities of virtual machine tools offer promising approaches for optimizing the machining and setting up of the machine. The vision of the project InVorMa is a cloud application, which supports the employees in the planning, scheduling and dispatching of manufacturing operations on tooling machines (figure 3). Instead of passing the manufacturing order and documents directly to the shop floor, the relevant data is previously optimized by the cloud application. The optimization involves the NC program of individual machines as well as the efficient scheduling and dispatching of orders to individual machines. The user obtains the service over the internet from a cloud service, this provides considerably more rapid results compared to a simulation on local hardware. Recent market studies emphasize the potential benefits of an automated routing sheet generation, the integration of expert knowledge and the planning validation through simulation [6].

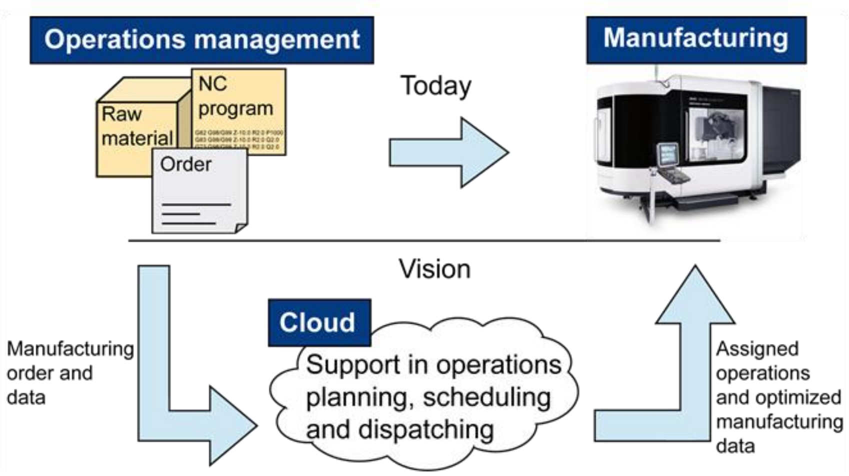

Fig. 3. - Cloud application for supporting the operations planning, scheduling and dispatching

4 FIELDS OF ACTION

In the light of the presented tasks of operations planning, scheduling and dispatching as well as the exposed potentials and disadvantages of virtual machine tools, there are four fields of action (figure 4).

1. A significant increase in simulation speed is the basis of the intended optimization. The main approach is the use of powerful hardware in a computer cluster. For some time, “Cloud computing” is a highly topical technological trend [7]. However, this technology has not yet been used for the simulation of virtual machine tools.

2. The optimized machining result from the evaluation of possible resource combinations and parameters. Depending on the workpiece shapes to be manufactured, there are different combinations of available tool machines, tools, fixtures for the machining. For example, the machine configuration and parameters can be used to control the clamping position, the tooling arrangement in the magazine and the superposition of the feed speed. To optimize the machining process, the possible combinations have to be simulated and evaluated automatically.
3. Optimizing the machining on each machine does not necessarily lead to an efficient scheduling. This requires a cross-machine optimization witch considers the processing time, the resource management and the occupancy rate of all machines. Waiting orders have to be economically dispatched to available machines. The operation scheduling needs to adapt continuously to the current situation, such as new orders and failures of machines or workers.

   Nowadays, operation planning is based essentially on the experience of the responsible manufacturing planner. The combination of resources as well as the machine settings is chosen with regard to the shape and the mechanical behaviour of the workpiece. If the machining result does not reach the expectations, this will be considered in further planning tasks. Therefore, a computer-aided optimization requires an aimed processing and reuse of technical and practical knowledge.

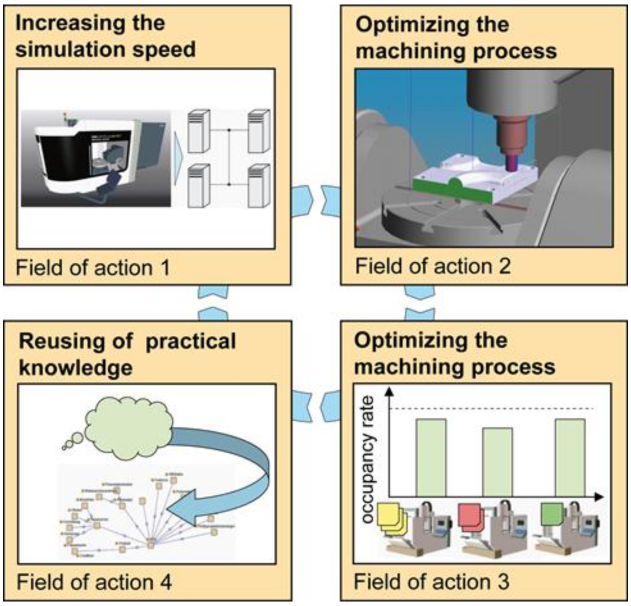

Fig. 4. - Fields of action

5 CONCEPT AS A CLOUD APPLICATION

The operation planning is assisted by the verification and optimization of the NC program and machine set up by the use of simulations. In addition, the operations scheduling and dispatching is improved by a pre-selection of resources and providing of reliable processing times. Figure 5 shows the system architecture of the cloud application with its modules “Production Optimizer”, “Setup Optimizer”, “Simulation Scheduler” and the “Virtual Manufacturing” as basis.

The optimization steps in each module are supported by a “Knowledge Base”, which provides both, technical and practical knowledge from previous simulations.

The interface for incoming and outgoing information is part of this “Knowledge Base”. The user sends the manufacturing order and documents (blank description, NC program) as well as the desired firm-specific goals to the cloud application. This represents the new bridge between the customers’ CAPP-System (Computer-aided process planning) and the shop floor control. First of all, the “Knowledge Base” determines suitable machine tools by reference to the machining operations described in the NC program and the existing resources. The result is a combination of resources – composed of machine, fixture and tool – for each machining step. The selection bases on the description of relations between resources and possible machining operations. Empirical data from previous simulations like the process times are reused to estimate the processing time on each of the suitable resource combination. This outcome is utilized by the “Production Optimizer” to accomplish a cross-machine optimization using a mathematical model and a job shop scheduling. This takes account of the processing time, delivery date, batch size, current resource disposability, machine costs material availability, set up time, maintenance plan and the shift schedule. The master schedule sets the framework for the detailed operations scheduling and dispatching. Scheduling is the assignment of starting and completion dates to operations on the route sheet. Selecting and sequencing of waiting operations to specific machines is called dispatching. Here, the real time situation in the shop floor is provided thru the “Knowledge Base” to ensure a reliable scheduling.

In the next step, the NC program is optimized for the selected machine tool by the “Setup Optimizer”. It varies systematically the parameters of the NC program and evaluates the simulation results from the virtual machine tool. For example, the target is to determine a timesaving workpiece clamping position, to remove collisions, to minimize the tool change times and empty runs or to maximize the cutting speed profile. The parameters that are being evaluated are chosen by a special algorithm in an adequate distance in order to reduce the number of simulation runs and to quickly identify the optimum parameter range. The result is an optimized, verified NC program and the necessary parameters to set up the machine. The results of all performed optimizations are saved in the “Knowledge Base”. It links workpiece information, configurations and technological parameters with already conducted simulation results. Thus, it is possible to early identify parameters with a high potential for optimization as well as relevant parameter ranges for new NC programs. This restriction for the scope of solutions reduces the number of necessary simulation runs too.

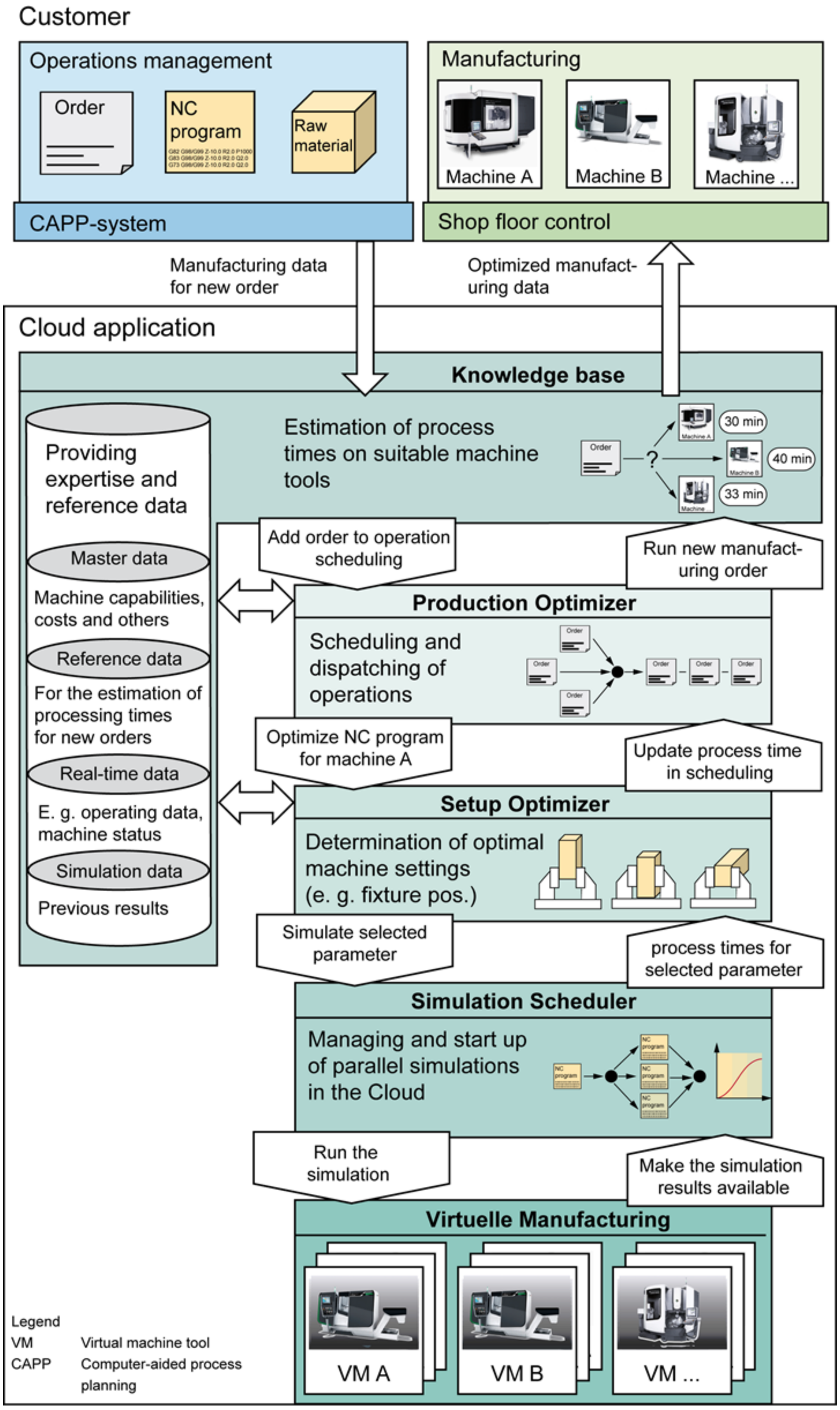

Fig. 5. – Architecture of the cloud application

All simulation orders from the “Setup Optimizer” are managed by the “Simulation Scheduler” and distributed to the virtual machine tools and hardware capabilities. To increase the simulation speed, extensive NC programs are divided into sub-programs, that are simulated parallel and the results combined again afterwards.

The prerequisite for achieving the overall aim is the customized “Virtual Manufacturing” with virtual images of all available machine tools and manufacturing equipment. This includes the virtual machine tool in that current version as well as tools, holders and fixtures as CAD models.

If it is necessary, multiple instances of a virtual machine are generated in the computer cluster of the cloud application. For further improvements, potentials for the parallelization of separated computations are considered. For example, the calculations for the collision detection and the simulation of the numerical control systems can be executed on different CPU cores.

6 CONCLUSIONS

The fully automated operation planning will not be realized in a short period of time. Instead, the paradigm of Industry 4.0 pushes decision-making techniques to support the user. The presented project combines approaches of knowledge reusing, advanced planning and scheduling and reliable machine simulations in a cloud application. Virtual machine tools are used to verify and improve the machining without interrupting the production process on the shop floor. In addition, a more efficient distribution of manufacturing orders to the machine tools is addressed. This enables an increase in efficiency without changing the existing machine tools.

The following tasks are part of the next project phase: Characteristics and a taxonomy to describe manufacturing processes and resources are defined for the “Knowledge Base”. Simultaneously, a concept is developed to speed up the simulation run; this includes software and hardware technologies. Furthermore, a basic model for scheduling and dispatching is developed; this can be adjusted later to the customers’ framework.

7 FUNDING NOTE

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