Research Synopsis – Mohan Krishnamoorthy

In the past few years, there has been significant technological advancements in different areas of process analysis and optimization. Examples of processes include manufacturing processes, such as assembly lines, and supply chain. These processes often involve physical or virtual inventories of products, parts and materials that are used to anticipate uncertainties on supply or throughputs of machines. Over time, the state of the machines, inventories and the whole process changes until process completion. Such processes are described as Buffered Temporal Flow Processes (BTFP). BTFP can be found in many different areas of manufacturing and supply chain such as in automotive, furniture, smartphones, airplanes and toys. In order to represent and analyze BTFP, we proposed the temporal Manufacturing Query Language (tMQL) in [1]. tMQL allows for modular composition, manipulation, what-if analysis and optimization of BTFP processes, machines and work-in-progress inventories. tMQL is flexible, extensible, reusable and easy to use. Because tMQL allows for process refinement, complex manufacturing processes can be easily modeled. The tMQL framework also contains the concept of a knowledge base where these components (both initial models and query results) can be stored and reused. The language we proposed in tMQL divides the manufacturing floor components into processes, inventories and flows. The processes maps to the atomic machines or a larger composed manufacturing floor. Composed processes can encapsulate other processes, inventories and flows. It is possible to represent storage, distribution, and flow of items through the manufacturing floor at different times across the time horizon using tMQL. This allows for capturing the entire mathematical model of a discrete manufacturing floor in a modular and extensible way that may be reused for different types of queries such as prediction, simulation, optimization and learning.

In order to facilitate a standard interface to model complex manufacturing floor under tMQL, we propose a decision guidance analytics framework in [2] where the machines, inventories and flows of the analytical model can be constructed in a uniform and flexible way. The proposed models have been developed in an open-source standard query and processing language of JSONiq. The proposed models can be used and reused directly in computation, optimization and learning queries. Using these models, we propose that it is possible to create a web service interface that uses data representation format such as JSON to collect all the model, parameter and query information from the user and then submit this information to the JSONiq model that uses algorithms in the backend to compose and query tMQL.

Using a tMQL analytical model of a complex manufacturing floor, the processes operator may want to perform computation, simulation, prediction, optimization, and learning operations. In [1] and [3], we propose make some efforts towards building algorithms for BTFP. The syntax and semantics of the computation and deterministic optimization queries of a BTFP modeled in tMQL is given in [1][5]. The compute query will simply reduce the expressions that are defined in terms of other instantiated parameters and expressions to produce a fully grounded tMQL component. The optimize query uses the Optimization Programming Language (OPL), Mixed-integer linear programming (MILP) solver to find the machine settings so as to minimize/maximize the objective subject to all constraints in the model being satisfied. These computed and optimized models can be stored in the knowledge base for future use. In order to solve the problem of stochastic optimization in BTFP where the task is to find the machine setting so as to minimize/maximize the expected value of the objective subject to the probability of constraint satisfaction being above some threshold, we propose an Iterative Heuristic Optimization Simulation (IHOS) algorithm in [3]. This algorithm uses a deterministic approximation approach where first, the machine settings are found in a deterministic environment and then heuristics are used to find if these machine settings would satisfy a desired confidence level in the
stochastic setting. IHOS is compared with four popular simulation-based optimization algorithms in an initial experimental study. The experimental study demonstrates that IHOS significantly outperforms the other algorithms in terms of optimality of results and computation time.

BTFP type manufacturing floor also needs to be resilient to failures and changes on the manufacturing floor. We make an initial effort in [4] to model a steady state BTFP as a (a) a process model to represent machines, part inventories, and the flow of parts through machines in a discrete manufacturing floor; (b) a predictive queuing network model to support the analysis and planning phases; and (c) optimization models to support the planning phase. These efforts combine models of different nature in a seamless manner. These models can be used to predict manufacturing time and the energy consumed by the manufacturing process, as well as finding the machine settings that minimize the energy consumed or the manufacturing time subject to a variety of constraints. The main goal of this effort is to make the manufacturing floor fault-tolerant and adapt to the dynamic changes in requirements easily and efficiently.

It is required that the stochastic optimization algorithm that we presented in [3] should be useful to optimize real-world machines. Since most of the metrics in the real-world are non-linear, we are currently looking into extending the IHOS algorithms for non-linear objectives. In addition, we are also working on a case-study of modeling and querying a real-world manufacturing floor of injection molding with non-linear objectives and constraints in tMQL. We have also learnt that on manufacturing floors, the decision usually is whether to keep a particular machine on or off rather than tinker with the speed of machine or other controllable parameters. The problem is that this results in a combinatorial search space. Hence we are looking into preprocessing algorithms that can efficiently optimize manufacturing floor with machines that can be on or off. We are also looking to develop a standard hierarchical organization for data representation, manipulation and querying with the help of JSON data format and JSONiq query language. Finally, we also plan to look at applications of tMQL in the areas of electricity, airport management, and other discrete item supply-chain.

**Publications**


