SUPPLY CHAIN SIMULATION AS A SERVICE TO INCREASE ADAPTATION CAPABILITY IN MANUFACTURING

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ABSTRACT

The COVID-19 crisis represents significant challenges for the manufacturing industry, especially for small and medium sized enterprises (SMEs), and further emphasizes the need for supporting the fast and efficient reconfiguration and repurposing of manufacturing lines and supply networks. The European CO-VERSATILE project addresses these challenges by offering the Digital Technopole, a central hub for decentralized services, including manufacturing and supply network simulation, among other vital services in aid of the reconfiguration process. Such simulation services are provided through an external cloud-based platform, the Digital Agora (emGORA). This paper highlights how such novel cloud-based simulation services can be efficiently implemented and offered using the Digital Agora and the Digital Technopole. The presented case study aims to optimize the supply network related to the manufacturing process of silicon facemasks, involving three European SMEs. The implemented solution is offered as cloud-based service to provide scalability, convenient access and reduction of upfront costs.

Keywords: supply chain simulation, cloud-based simulation, simulation as a service, cloud orchestration, Digital Technopole.

1 INTRODUCTION

Manufacturing is in the forefront of the European Economy, with over 2 million enterprises (98% of which are small or medium sized enterprises (SMEs) or mid-caps), and provides approximately 33 million jobs (Eurostat 2022). Therefore, any positive or negative influence on this sector has significant consequences on the entire European Economy. The recent COVID-19 crisis had a major effect on the manufacturing industry. Many manufacturing companies require rapid multidisciplinary assessment to repurpose, adapt and ramp up their manufacturing lines and reorganize their supply network, in light of new challenges, requirements and opportunities raised by the pandemic situation. A global pandemic not only influences demand and supply quantities or the availability of resources, but it also requires the manufacturing of completely new products targeting the pandemic situation, for example vital medical equipment, such as facemasks or respiratory devices. In order to enable quick and successful adaptation to these unexpected changes, the manufacturing processes and the supply network should be designed in a robust way that enable multi-purpose production capabilities. New and appropriate concepts are required for assessing and performing production planning and automation, workforce utilization or supply chain optimization, among others. Performing such assessment and reconfiguration quickly and efficiently not only provides competitive advantage to the manufacturing company itself, but it is also vital at European level when tackling sudden shortages of key supplies, such as facemasks or disinfection and respiratory devices, as it was experienced in the early days of the pandemic.

While large organizations typically have the capability and resources to perform such multidisciplinary assessments on-demand, it is much more difficult for SMEs to address these challenges. As such expertise is not available in-house, smaller companies find it difficult to locate and finance the assessments required for the fast and efficient repurposing of their production lines and supply chain processes. The aim of the H2020 CO-VERSATILE project (CO-VERSATILE 2022) is to democratize access to such services and expertise, and make it available and affordable for SMEs. The key concept of CO-VERSATILE is the Digital Technopole that combines a set of loosely coupled physical and digital services. Although the offered services are available through a central hub, all of them are provided in a decentralized way by various commercial platforms, providers and organizations. The Digital Technopole is a single entry point to access five groups of services, including manufacturing simulation (1), supply network simulation and risk management (2), automation and system integration (3), certification and training (4), and replication and sustainability of manufacturing and supply chain processes (5). The above services can be offered in various ways, including human provided consultancy services, but also as completely digitalized services that are available either for local execution or on a cloud-based platform as a remote service.

To demonstrate and validate the capabilities of the Digital Technopole and its services, seven so called Manufacturing Settings (MS) are implemented currently that all utilize a suitable combination of the five previously named services. A MS represents a case study where the manufacturing line and process (including also the entire supply network) require fast and efficient repurposing and reconfiguration in order to deliver vital medical supplies as demanded by the pandemic situation. The MSs implemented in CO-VERSATILE include the production of silicone facemasks, manufacturing of disinfectant spray systems, ramping up the production of respiratory devices, building reconfigurable mask production machines, and developing resilient automation systems for manufacturing processes.

An important and relevant aspect of the Digital Technopole is the capability of offering some of its services remotely from a cloud computing platform. Such cloud-based service offering provides several advantages; for example the service can scale on demand as resource requirements are increasing, or providing such service on a pay-as-you-go basis can help SMEs avoiding large capital investments and transferring these into regular smaller expenses. While the Digital Technopole itself is not providing such cloud-based service directly, it offers a single entry point for users and redirects them to external cloud-based platforms. Such external platform is the Digital Agora (emGORA) (CloudiFacturing 2022) developed in the CloudiFacturing H2020 European project. Using the Digital Agora and its associated CloudiFacturing Platform, simulation applications (e.g. manufacturing or supply-chain simulation) can be offered as on-demand executable cloud-based services. Digital Technopole users can seamlessly access such services via the external platform (in this case the emGORA) and get billed based on their resource utilization and the actual business model by which the external service is offered.

In this paper the unique capabilities of the Digital Technopole are demonstrated via the example of a supply-chain simulation application that supports three interconnected Manufacturing Settings, all centered around the production of silicon facemasks. The supply-chain simulation is implemented and offered as a service through the Digital Technopole and the emGORA. With such offer, the manufacturing SMEs involved in the design and production process of the facemasks can utilize complex and tailored simulation services on-demand and from a convenient user friendly environment, lowering significantly the entry barriers and supporting the fast and efficient reconfiguration of the manufacturing process and the supply network.

The rest of this paper is structured as follows. In Section 2 an overview of related work in the area of supply chain simulation and cloud-based simulation services is given. Section 3 describes the three interconnected manufacturing settings that represent the problem domain requiring cloud-based supply-chain simulation. Section 4 details the implementation of the supply-chain simulation application, while Section 5 explains how this application has been turned into a cloud-based service. Finally, Section 6 concludes the paper and outlines future work.

2 RELATED WORK

There are several earlier efforts that enable deploying simulation applications as cloud-based services. Cayirci (Cayirci 2013), for example, overviewed several major Modelling and Simulation as a Service (MSaaS) approaches and listed their key research challenges. However, there are still no production ready commercial environments where cloud based simulation services, utilizing diverse sets of technologies and heterogeneous cloud resources, can be offered on a commercial basis. The work described in this paper aims to fulfil this gap and offers such service for manufacturing companies.

Defining the basic concepts related to MSaaS, Johnson (Johnson et al. 2013) and Procházka (Procházka et al. 2017) described efforts of the NATO Modelling and Simulation Group (NMSG) on technical, governance, security, business model and conceptual perspectives of MSaaS. This group investigated MSaaS from national defense perspectives and experiences as part of a developing "NATO M&S as a Service Concept" under NATOs Allied Command Transformation (ACT). They consider MSaaS as being a key enabler for military training, analysis and decision making. They concluded that MSaaS is an architectural and organizational approach that promotes abstraction, loose coupling, reusability, composability and discovery of M&S services with the objective of effectively and efficiently supporting operational requirements (e.g. executing an exercise) and improving development, operation and maintenance of M&S applications.

Regarding concrete MSaaS frameworks, Wang (Wang et al. 2016) developed the Cloud Architecture for Modelling and Simulation as a Service (CAMSaaS) to simplify the deployment of modelling and simulation resources as services in the Cloud. It manages experimental frameworks, infrastructures and resources as services to support modelling and simulation. The authors also elaborated an MSaaS middleware, called CloudRISE, to manage a variety of modelling and simulation resources. Sliman (Sliman et al. 2013) developed the RunMyCode cloud-based simulation platform using the Simulation as a Service (SIMaaS) concept. It provides researchers a simulation and benchmarking platform. This platform allows researchers to disseminate their research and replicate others researchers' artefacts in order to reproduce, enhance, and compare research findings and validity of research results. Rosetti (Rossetti et al. 2012) presented a prototype architecture, called Cloud Computing Architecture For Supply Chain Network Simulation (CCAFSCNS) that directly deploys simulation on the Cloud to support supply chain networks. The framework allows distributed simulation of large-scale multi-echelon supply chains with an arborescent structure. The simulator in the architecture allows users to specify the network structure, the inventory stocking policies and demand characteristics to estimate the supply chain performance. Tsai (Tsai et al. 2011) described the Simulation Software-as-a-Service (SimSaaS) framework with a Multi-Tenancy Architecture (MTA) configuration model and a cloud-based runtime to support rapid simulation development to be deployed and executed in cloud environments. The framework provides modelling services, code generations and deployment services. It also incorporates simulation runtime that offers key infrastructure services and an analysis engine that manages runtime information. The Open Cloud Ecosystem ApplicatioN (OCEAN) project (Biagini et al. 2016) developed an MSaaS framework to offer an experimental environment to consume available MSaaS services and deploy new M&S services.

The closest example to a production ready multi-cloud simulation environment is described in (Taylor et al. 2018). The authors introduce the CloudSME Simulation Platform (CSSP), a generic multi-cloud platform for developing and executing commercial cloud-based simulations. The solution incorporates an application layer including an easy to use AppCenter, a platform layer providing seamless access to a wide range of computational resources, and a resources layer including the actual cloud resources supporting the execution. By design the CloudSME Simulation Platform can be considered as the starting point for the

MSaaS solution described in this paper. However, the CSSP followed a more traditional approach when compared to the scalable and flexible microservices architecture described in this paper.

3 CASE STUDY: SILICONE MASK PRODUCTION

The CO-VERSATILE consortium incorporates seven SMEs manufacturing different pandemic-related products, such as facemasks or disinfection systems. The R&D process as well as their production are used to demonstrate the consortium's capabilities of supporting fast reconfiguration and ramp-up of manufacturing lines in case of emergency situations. Three Manufacturing Settings (MS 1, 2 and 3) are involved in developing and manufacturing a silicon facemask with an option for exchangeable nonwoven disposable filters, which is the topic of the case study presented here. The main innovation driver is to create a washable, thus reusable silicone face mask being more sustainable than current single-use disposable masks on the market. Equipping rubber molding entities with facemask molds would enable them to rapidly start a local production of facemasks and hence to reduce world-wide supply chain dependencies for non-woven masks. Product development and manufacturing workload are shared among the manufacturing sites. Mask and mold design are shared between all MSs, mold manufacturing is done by MS1, mold surface functionalization by MS2, and mask molding by MS3.

Within the CO-VERSATILE project, two cloud-based simulation activities were applied during the development phase of the silicone facemask and its mold. On the one hand, manufacturing simulations were performed to optimize mold-flow for higher mask production quality and shorter molding cycles (i.e. higher manufacturing output) – these will not be discussed further in this paper. On the other hand, supply chain simulations were conducted to support mask manufacturing activities during production phase. The supply chain under investigation is arranged around MS3, an Israeli SME manufacturing molded rubber products in particular for aviation, medical and industrial markets. In the case studied here, MS3 reconfigures a part of their production lines towards silicone facemask molding. The supply chain model comprises of five stakeholders: (1) supplier for uncured silicon rubber compound (based in Italy, delivery by air), (2) supplier for textile filter sheets (Israel, delivery by air, or Italy, delivery by air), (3) rubber molding SME (MS3, Israel), (4) customer 1 - public hospitals (Israel), (5), customer 2 - private market (Israel).

Although the supply chain considered here is comparably short and simple, simulations are valuable. Based on the customer demand (quantity ordered over defined period) supply chain simulations provide information on the degree of capacity utilization at MS3. For instance, working shift patterns and dedication of production machines can be aligned with the order. Furthermore, a medium to long-term production pattern can be derived, in particular if make-to-stock will be necessary to cover periods with high demand.

In addition, supply chain simulations elucidate factors like improving material delivery patterns and delivery quantities between suppliers and the manufacturing site MS3. Particularities of the transportation mode "by air" can be taken into account as well as the extra-EU trade, including customs services between Italy and Israel. For example, by simulation, specific pandemic risks such as delays at customs clearance can be easily considered and conclusions can be drawn, e.g. by increasing stock of uncured rubber, supply frequencies or supply lead times.

4 SIMULATION SERVICE COMPONENT FOR A RELIABLE SETUP OF A SUPPLY CHAIN WITH PART CAPACITY LIMITS AND UNDER PANDEMIC RISKS

Supply chains of modern manufacturing processes have grown to a complexity, which makes it difficult to manually estimate the potential impact of risks and the effectiveness of countermeasures. In order to overcome this lack of insight into the behavior of a supply chain, modern *Supply Chain Simulation Suites* are used to create a *model representation* of the network of production plants, their suppliers and distribution channels. Those simulation models connect the supplier to the demand in the form of markets, dealers or even down to a single customer level (Fraunhofer IML 2022).

The model representation can then be used to simulate the supply chain's behavior step by step in a *discrete event* manner. Events within a supply chain are processed in a continuous sequence according to their order in simulated time and most often trigger subsequent events, which in turn lead to an addition to the event queue. Using this approach, it is possible to simulate the behavior of a supply chain and to make fairly accurate predictions about impending bottlenecks, various risk factors or the need for alternative suppliers or distribution routes.

In the underlying case of the CO-VERSATILE project, it was intended to create a service component that is applicable for a majority of manufacturing SMEs. But usually, simulation models cover a high complexity and are very individualistic with a specific focus on a particular company. This caused the major challenge during model creation, as a the general application of the simulation model was required.

To approach this challenge, the purpose of the general model is based upon the needs within the case study described in Section 3. It shall evaluate a new production setup under pandemic risk factors and capacity restrictions integrating part and raw material capacity limits. To reflect the availability of a specific part (or raw material) at a supplier, the model integrates a supplier with a specific capacity restriction for each part category, e.g. for silicon with high quality, silicon with food grade and silicon with lower quality, even though it is a single supplier that provides all quality categories. This allows the flexibility to expand the model to several product qualities with a specific capacity limit. Those suppliers deliver the raw material to the production plant, which again has a capacity limit for the final product. The capacity restrictions integrate all pandemic risk factors that reduce availability, e.g. manpower shortage due to illness or capacity restrictions due to material shortages at the supplier. In addition, another pandemic risk category affects the time requirements for the distribution of the material, e.g. due to pandemic border closure or port closures, which, i.e., caused severe delays of container (Mishra 2020, BME 2021). These pandemic risk factors are covered by integrating two distribution channels per supplier. One distribution channel reflects the usual time requirement, while the other incorporates a time delay. According to the requirements in risk management, a routing component contains the entry probability of the delay while the delayed distribution channel integrates an expected time window for the arrival of delayed shipments. The simulation aggregates the upcoming risks and shows their impact on the production in the results. Figure 1 shows the setup of the simulation and the integration of the risks.

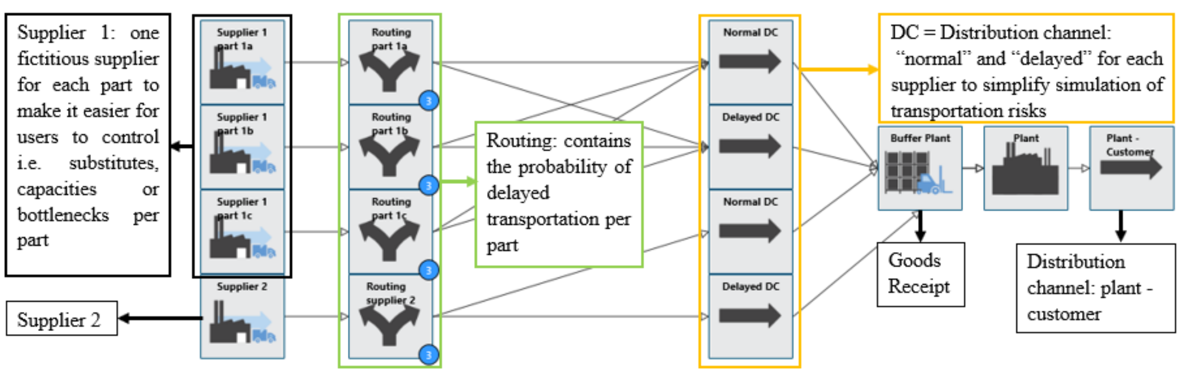

Figure 1: Setup of the supply chain simulation model with capacity restrictions and pandemic risks.

To be able to apply the simulation model, an SME needs to provide some general information about the plant and information about the supply structure. Such input includes simulation time frame, capacity information, plant location in longitude and latitude and expected demand per product (e.g. three types of masks). Upon data entry, the simulator interface provides a quick deterministic check on the capacity availability.

In addition, the simulation model needs further information about the supplier. This includes the supplier name, the part it supplies and the respective material quality, the longitude and latitude of the supplier and the capacity restrictions per part, if applicable. Moreover, information about the amount of material per end product, weight and volume of the supplied material, and the order and envisaged transportation time need to be included. Figure 2 depicts an extract of the user interface for the supplier information.

1st Tier - Relations

Supplier name	Part	Substitute	1st Tier Supplier	Latitude	Longitude	Working week	Raw material availabilty per month	Recipient (Plant)	Part Quantity Required	Weight (in gram)	Volume (in cm³)
Supplier 1a	Silicon	MedicalGrade	Supplier 1a_MedicalGrade	45,6666670	9,8166670	Monday - Friday	75000	Plant	1	70	65
Supplier 2	FilterCloth		Supplier 2	45,7605560	9,7969440	Monday - Friday		Plant	1	30	23
Supplier 1b	Silicon	FoodGrade	Supplier 1b_FoodGrade	45,6666670	9,8166670	Monday - Friday	100000	Plant	1	70	65

Figure 2: User interface for the integration of supplier information (extract).

The SME also needs to provide information about transport risk settings, by providing information about the probability of transportation delay and a time horizon for the delay (e.g. 5 to 10 days delay expected). Due to the features of the discrete-event simulation, the model evaluates for each single transport event if a delay occurs. The model applies a routing to integrate an entry probability of a transportation delay with a binominal distribution and uses a separate transportation route for the delayed transport. In order to represent the unpredictability of the range of delays during the event of Covid-19 and the considerably small range of this operational risk factor, a uniform distribution is assumed for the transportation delay (Cottin and Doehler 2013; Yüzgülec 2015). An application of other distributions is possible, but often requires further expert knowledge that can be integrated upon request.

1st Tier - Transport risk settings

1st Tier Supplier	Recipient (Plant)	Delivery pattern (delayed)	Min TransportTime [days] (delayed)	Max TransportTime [days] (delayed)	Probability of delayed transportation [in %]
Supplier 1a_MedicalGrade	Plant	Wednesday	5	10	10

Figure 3: User interface for the integration of transport risks.

Upon simulation of the model, the SME obtains the necessary results to analyze the operability of the supply chain. Figure 4 shows the report summary of the simulated supply chain stating the amount of orders that are fulfilled on time, fulfilled with delay, and the amount of orders that could not be completed in the respective time frame. The resulting overview enables to evaluate the type of bottleneck with a quick check on lead times, transport times, and capacity restrictions.

As the geographical information of the supplier and the weight and volume of the part is given, the simulation automatically calculates the respective transport costs, also displayed in the report summary. With regard to the analysis of the production plant, the result shows capacity restrictions and the respective amount per week. In the underlying example, the unfulfilled orders are due to a capacity bottleneck at the production plant during calendar weeks 18 to 21. Furthermore, the report highlights the necessary maximum daily stock per material providing insight on necessary storage space at the final production plant.

Different countermeasures like the application of different material can be integrated into the simulation model, i.e. via the user interface for the supplier information. A comparison of the resulting reports evaluate the improvements in terms of a timely fulfilment and costs for the transport per unit.

Having integrated the data by the company, the simulation run and the extraction of the results depend on the complexity of the supply chain setting. The intention is to gain results within an hour. For the complexity of the underlying case study, the simulation run and the extraction of the results require about 30 minutes with an Intel i7 CPU of 2.90 GHz and 8 GB RAM.

Report Summary (CO-VERSATILE)

Summery of orders						
Amount of orders	2702000					
Amount of timely fullfiled mask orders	1629670	60.3%				
Amount of delayed fulfilled orders	527665	19.5%				
Amount of unfullfiled orders	544665	20.2%				
Supply			**Per Supplier**			
	Across the board		**Supplier 2**	**Supplier 1a**	**Supplier 1b**	**Supplier 1c**
Sufficient Order Leadtime per supplier plant relation?	**Yes**		Yes	Yes	Yes	Yes
Sufficent Delivery Pattern per supplier?	**Yes**		Yes	Yes	Yes	Yes
Maximum waiting time to next transport per supplier						
Sufficient capacity and material per supplier?	**Yes**		Yes	Yes	Yes	Yes
Amount of capacity bottleneck per supplier						
Transport						
Total transport costs	1,076,823.77 €					
Average transport costs per mask	0.50 €					
Executed transports	190					
Production (Plant)						
Sufficient plant capacity	No					
Total amount of weeks with capacity bottleneck	4					
Week (CW) with capacity bootleneck	**2021-18**		**2021-19**	**2021-20**	**2021-21**	
Amount of missing parts	-968		-968	-968	-968	
	Silicon		**FilterCloth**			
Maximum daily stock per part	33153		1075264			

Figure 4: Report summary of the simulated supply chain.

5 SUPPLY CHAIN SIMULATION AS A CLOUD-BASED SERVICE

The supply chain simulation application described in Section 4 can be offered to manufacturing companies as a cloud-based service through the Digital Technopole of CO-VERSATILE. Such cloud-based service offering not only makes the service scalable and provides a ready-to-use solution for the targeted SMEs (without worrying about one-off hardware and software investments and regular operational maintenance), it also offers the possibility for the simulation provider to generalize the service and operate it on a pay-as-you-go basis for multiple companies. The Digital Technopole, being a loosely-coupled hub of external services, provides cloud-based simulation capabilities through the emGORA, a digital marketplace for manufacturing companies, where simulation applications implemented in various simulation frameworks and utilizing a wide range of technologies can be executed seamlessly as cloud-based apps.

In this section we introduce the emGORA and one of its execution engines, the MiCADO cloud orchestration framework (Kiss et al. 2019) that was utilized to deploy and execute the previously described supply-chain simulation application in cloud resources. Finally, we explain and demonstrate how the emGORA and MiCADO were applied when implementing cloud-based simulation as a service.

5.1 Digital Agora (emGORA) and the CloudiFacturing Solution

The CloudiFacturing Solution was developed within the CloudiFacturing project to provide seamless user access to a wide range of cloud-based platforms and technologies. The solution combines three key components/layers: the Digital Agora, the CloudiFacturing Platform and various pluggable artefact (e.g. application or workflow) execution engines.

The Digital Agora (emGORA), the top layer in Figure 5, is a dynamic web application that acts both as user interface to the CloudiFacturing Platform and also as a commercialization hub for community-building around cloud-based engineering software. It provides access to documentation, training, and consultancy, and direct access and execution of all executable artefacts registered on the platform, regardless of the specific execution engine they use. The emGORA allows users to run executable artefacts and process the generated results. It has a commercial purpose, aiming to showcase services, directly sell services to customers, and support the development of a community around the CloudiFacturing Solution.

The CloudiFacturing Platform, the middle layer in Figure 5, provides uniform access to executable artefacts and data resources, and hides the complexity and heterogeneity of these resources from the user. The platform enables storing (EMGREPO) and executing the various artefacts (EMGWAM), transferring data to the location of execution (EMGDATA), managing user credentials and single-sign-on (EMGUM), and providing convenient accounting and billing services (EMGBC).

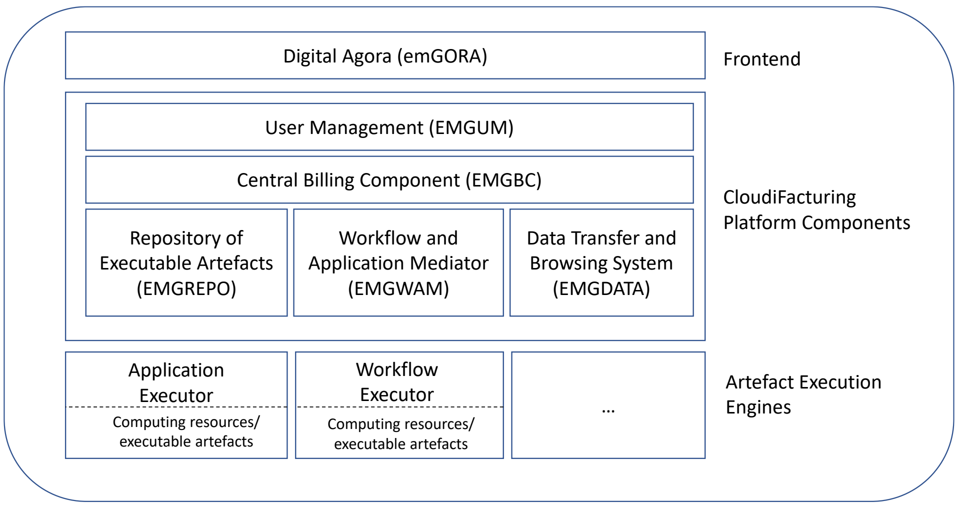

Figure 5: High-level architecture of the CloudiFacturing Solution.

The bottom layer of the CoudiFacturing Solution is composed of the various artefact execution engines. These execution engines are considered as external components to the CloudiFacturing Platform. New execution engines can be added by developing and registering a so called Execution Engine Client (EEC) with EMGWAM. There are currently four execution engines supported by the platform, including a virtual machine focused cloud application executor (CloudBroker Platform) (Taylor et al. 2018), a high-performance computing (SemWES) (SemWES 2022) and a cloud focused workflow engine (Flowbster) (Kacsuk et al. 2018), and a microservice-based multi-cloud orchestration framework (MiCADO).

5.2 MiCADO Cloud Orchestrator

The case study implemented in this paper utilized MiCADO, an application-level cloud-agnostic orchestration and auto-scaling framework as execution engine within the emGORA. MiCADO supports the entire life-cycle of microservice-based cloud applications. An application in MiCADO is a set of microservices that are deployed in Docker containers (Docker 2022). One application can include as many microservices as required. The developer describes the application topology (i.e. all containers, virtual machines hosting these containers and their possible dependencies) in a TOSCA-based (Topology and Orchestration Specification for Cloud Applications) Application Description Template (ADT) (Pierantoni et al. 2020). The ADT also includes the various policies (e.g. scaling or security policies) that govern the operation of the application during runtime. At deployment time, MiCADO receives the ADT and deploys all the necessary virtual machines and containers, as described in the ADT. During the application's lifetime, MiCADO constantly monitors its execution and adjusts the resources (e.g. allocates more or less containers or virtual machines to fulfil the policies defined in the ADT), as required.

A number of cloud service providers and middleware are supported by MiCADO, including both commercial clouds such as Amazon AWS, Microsoft Azure, Google Cloud Platform, or Oracle Cloud Services, as well as private cloud systems based on OpenStack or OpenNebula. MiCADO is fully open source and implements a microservices architecture in a modular way. The modular design (DesLauriers et al. 2021) supports varied implementations where any of the components can easily be replaced with a different implementation of the same functionality.

The high-level architecture of MiCADO is presented in Figure 6. MiCADO consists of two main logical components: Master Node and Worker Node(s). The Submitter component on the MiCADO Master receives and interprets the ADT as input. Based on this input, the Cloud Orchestrator creates the necessary virtual machines in the cloud as MiCADO Worker Nodes and the Container Orchestrator deploys the application's microservices in Docker containers on these nodes. After deployment, the MiCADO Monitoring System monitors the execution of the application and the Policy Keeper performs scaling decisions based on the monitoring data and the user-defined scaling policies. Optimizer is a background microservice performing long-running calculations on demand for finding the optimal setup of both cloud resources and container infrastructures.

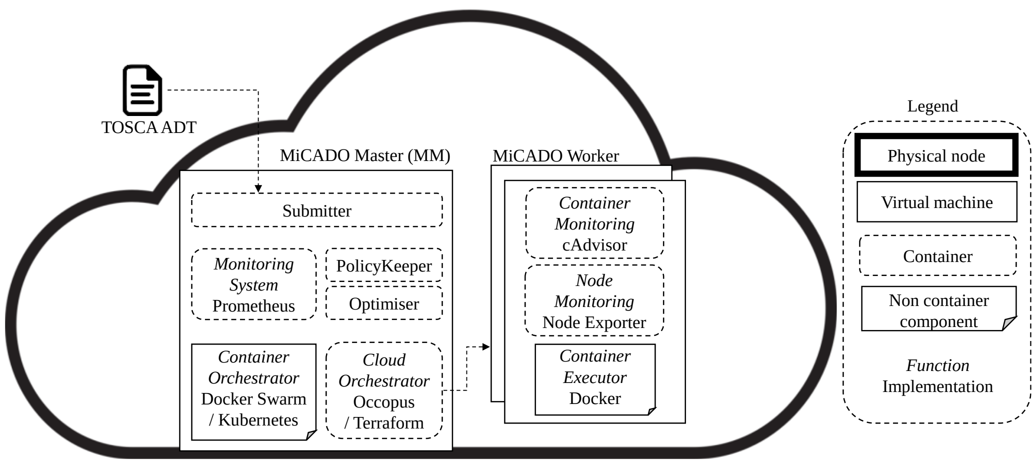

Figure 6: High-level architecture of the MiCADO cloud orchestration framework.

Currently there are various implementations of MiCADO based on its modular architecture, which enables changing and replacing its components with different tools and services. As Cloud Orchestrator, the latest implementation of MiCADO can utilize either Occopus (Kovacs et al. 2018) or Terraform (Terraform 2022). These both are capable of launching virtual machines on various private or public cloud infrastructures. However, as the clouds supported by these two orchestrators differ, MiCADO can support a wider variety of targeted resources. For Container Orchestration, MiCADO uses Kubernetes (Kubernetes 2022). The monitoring component is based on Prometheus (Prometheus 2022), a lightweight, low resource consuming, but powerful monitoring tool. The MiCADO Submitter, Policy Keeper (Kovacs et al. 2019) and Optimizer components were custom implemented.

When integrating MiCADO with the emGORA, an Execution Engine Client (EEC) was implemented. The MiCADO EEC is an external component to the emGORA that needs to be registered via its graphical user interface. After registration, EMGWAM component of the CloudiFacturing Platform can call the MiCADO EEC, instruct it to deploy the MiCADO master node, and pass on the ADT to it as an input. Once the ADT is received, MiCADO deploys the worker nodes as specified in the input description and executes the application. Following execution, the EEC clears up the environment by releasing the master and worker nodes. ADTs are stored in the EMGREPO component of the CloudiFacturing Platform. Users can browse the applications published in EMGREPO and can execute them on demand. The EMGBC component of the platform monitors the costs of the execution and provides the associated bill (also including various operator surcharges, if appropriate) to the user.

5.3 Implementation of Simulation as a Service

Utilizing the technologies described above, the supply chain simulation application introduced in Section 4 has been implemented and published as a cloud-based MSaaS. This "cloudification" process can be divided into five distinctive steps, as explained below. The aim of the process is to create a cloud-based service that is portable between various cloud resources (i.e. avoiding vendor lock-in and allowing companies to select the most suitable cloud provider based on price, availability, trust or other factors) and that can be easily accessed by the end user manufacturing company from a web-based graphical user interface.

The five-step methodology described below and the tools introduced earlier support and follow a microservices approach using container technologies. Such approach strongly contributes to portability as containers (e.g. Docker Containers) can be easily started on any cloud computing resource and incorporate the entire run-time environment that is required for the application. Therefore, the first step of the process (1) is to define clearly the microservices of the application and containerize these. In the case of the presented supply chain simulation application, three microservices were identified. The first microservice (Excel2OTD) takes the Microsoft Excel based supply chain model and converts it to the required OTDDB format of the simulator. This microservice is exposed through a REST (REpresentational State Transfer) interface via HTTP. The second microservice (OTD-NET) is the actual supply chain simulator. Through its HTTP REST-API, it provides endpoints for uploading a new model file, starting and stopping a simulation, downloading the simulation results after completion, as well as direct queries on the result database. Finally, the third microservice (OTD-XLSSim) executes the workflow which orchestrates the two other containers. It handles the input which is provided by the execution environment (emGORA) via a designated directory, sends the Excel model file to the Excel2OTD component for conversion to OTDDB format, and forwards the converted model file to the OTD-NET container for the final simulation. When the simulation finishes, the results are retrieved from the simulator and placed in the output directory which can then be picked up by the emGORA and served to the user.

Following containerization, the second step (2) is making the Docker containers available and downloadable in a suitable repository. For this purpose a private Gitlab repository operated by Fraunhofer was utilized where all three containers were published.

The third step (3) is preparing the MiCADO ADT that describes the three containers, specifies the virtual machines hosting these containers, and describes any dependencies between the various components. This is also the place where the potential scaling or security policies can be described (although in the presented example the focus was on deployment and publication as a cloud-based service and no policies were specified). The containers are all running in the EGI Federated Cloud (Fernández-del-Castillo et al. 2015), a primarily academic cloud computing infrastructure. This cloud is part of a testbed where a version of the emGORA is deployed to develop and host various industry case studies, primarily in the DIGITbrain European project (DIGITbrain 2022). The containers are currently deployed on a single worker node (m1.medium instance, 4GB RAM, 2VCPU, 40 GB disk, running Ubuntu 20.04 operating system), as defined in the ADT. However, these can also be easily split into multiple virtual machines or suitable scaling policies can be defined in the ADT to automatically increase/decrease both the number of virtual machines and containers. Additionally, the flexible and standardized TOSCA-based approach enables easy mapping and portability between various cloud infrastructures, as described in (DesLauriers et al. 2021).

The fourth step (4) is publishing the application in the emGORA. This process is done through the emGORA graphical user interface. After uploading the ADT file into the emGORA and specifying the required metadata, the ADT gets stored in the EMGREPO and the app can be selected by users for execution.

Finally, in the fifth step (5) the user can browse and select the desired app. Once the execution starts, the EMGWAM component of the emGORA takes the ADT from EMGREPO and passes it on to the MiCADO

EEC for execution. EEC launches a new MiCADO master and sends it the ADT. Finally, the master launches the virtual machine(s) as specified in the ADT and the containers. The user can also destroy the deployment after successful execution. Figure 7 shows the emGORA user interface where the application is being executed.

Please note that in the current implementation only the automated deployment capabilities of MiCADO are utilized and there is no further autoscaling or optimization policy applied. These can be considered in later stages of the project, if necessary.

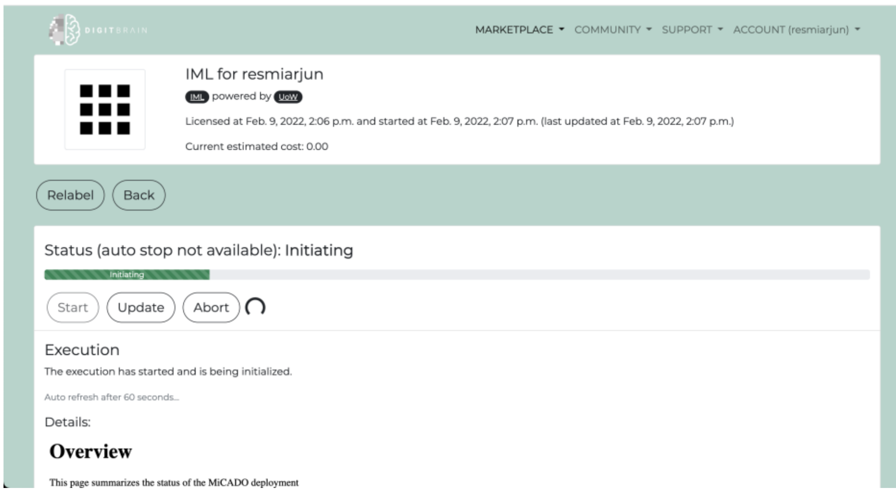

Figure 7: Executing the supply chain simulation app from the emGORA.

6 CONCLUSIONS AND FUTURE WORK

This paper demonstrated how a unique combination of technologies, including Supply Chain Simulation Suite OTD-NET, Digital Agora and its associated CloudiFacuring Platform, the MiCADO multi-cloud orchestrator, and the Digital Technopole can be used to build and offer supply chain simulation as a service for manufacturing SMEs. The utilization and combination of these technologies were illustrated via the example of a manufacturing setting from the CO-VERSATILE project where the supply network of a complex manufacturing process delivering silicone facemasks was optimized. Accessing the developed simulation application as service in the cloud enables the involved SMEs to get access to this tool on demand, without major capital investment and based on a convenient pay-as-you-go business model.

The supply chain simulation service component was developed in a generic way that is applicable for a majority of manufacturing SMEs. Therefore, the developed solution has the potential to be marketed to a wider potential user community. Offering such (as much as possible) generalized services can significantly contribute to increasing the flexibility of the manufacturing sector, especially SMEs, when it comes to reconfiguration and ramp-up of production processes in response to unexpected events and circumstances, such as the current COVID-19 pandemic. The simulation results enable enterprises to adjust their order strategies as well as their safety stocks in order to mitigate risks of transport delays or supply shortages. The simulation times and preprocessing remain uncritical as the supply chain simulation covers periods that are magnitudes greater.

Future work is concentrating on fully implementing the Digital Technopole and the seven manufacturing settings of the CO-VERSATILE project. Each of these manufacturing settings incorporate several simulation applications, a number of which will be offered as cloud-based services. On the other hand, it was also realized that some of the simulations are simply too specific or required to run locally within the factory or by a specialist consultant. Therefore, not all simulation will be provided as a service and traditional human centered consultancy services will further extend the offerings of the Digital Technopole.

After the end of the project, the Technopole is expected to operate on a commercial basis, using the CO-VERSATILE manufacturing settings as first examples and customers.

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