An Integrated Software Manufacturing Control System for a Software Factory with Built-In Rejuvenation

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***Abstract*—Software engineers have been attempting for many decades to produce or assemble software in a more industrial way. Such an approach is currently often associated with concepts like *Software Product Lines* and *Software Factories*. The monitoring, management, and control of such factories is mainly based on a methodology called *DevOps*. Though current DevOps environments are quite advanced and highly automated, they are based on many different technologies and tools. In this contribution, it is argued that more integrated software manufacturing control systems are needed, similar to control systems in traditional manufacturing. This paper presents a scope, overall architecture and prototype implementation of such an integrated software manufacturing control system. Several detailed scenarios are elaborated that can leverage such integrated control systems to optimize the operations, and improve both the quality and output of modern software factories. The preliminary findings and results of this control system are presented and discussed.**

***Index Terms*—Software Factories; Software Product Lines; DevOps; Control Systems; Evolvability.**

I. Introduction

This article extends a previous contribution which was originally presented at the Eighteenth International Conference on Software Engineering Advances (ICSEA) 2023 [1].

The expression *"Software is eating the world"* was formulated in 2011 by Marc Andreessen [2] to convey the trend that many industries were being disrupted and transformed by software. And indeed, more and more major businesses and industries are being run on software systems and delivered as online services. These software systems include *Enterprise Resource Planning (ERP)* systems to design and manage the business processes, *Supervisory Control and Data Acquisition (SCADA)* systems to manage and control production processes in real-time, and *Manufacturing Execution Systems (MES)* to track and document the transformation of raw materials to finished goods, enabling decision-makers to optimize conditions and improve production output. As software systems become more pervasive to manage and control the end-to-end production processes in factories, it seems logical to have or create such control systems for the software systems themselves, i.e., systems to manage and control the building and assembly of software systems in the software factories. In this contribution, we explore the creation of such systems to manage and control software manufacturing and assembly.

The remainder of this contribution is structured as follows. In Section II, we briefly discuss software factories, the *DevOps* methodology, and situate our approach. In Section III, we describe the software factory used in this case study, and present a model for the assembly lines or units of such a factory. In Section IV, we discuss the scope, software architecture, and the implementation characteristics of the proposed manufacturing control system for software factories. We present various use cases and types of added value for such an integrated control system in Section V. Section VI discusses some preliminary results and findings of the continuous development of the system in the controlled environment. Finally, we present some conclusions in Section VII.

II. Software Factories and DevOps

A. On Software Factories and Reusability

The idea to produce and/or assemble software in a more industrial way, similar to automated assembly lines in manufacturing, has been pursued for many decades. Such an approach is currently often associated with concepts like *Software Product Lines (SPLs)* and *Software Factories*, but can easily be traced back as far as 1968 to the article on *mass produced software components* from Doug McIlroy [3]. The concept of *Software Product Lines* has been extensively described by the Carnegie Mellon *Software Engineering Institute (SEI)* [4], and refers in general to software engineering methods, tools and techniques for creating a collection of similar software systems from a shared set of software assets using a common means of production. The characteristic that distinguishes software product lines from previous efforts is predictive versus opportunistic software reuse, as it stresses that software artifacts should only be created when reuse is predicted in one or more products in a well-defined product line [5]. The term *Software Factory* emphasizes the techniques and benefits of traditional manufacturing, and is for instance defined by Greenfield et al. as a software product line that configures extensive tools, processes, and content using a template based on a schema to automate the development and maintenance of

variants of an archetypical product by adapting, assembling, and configuring framework-based components [6].

The reuse of software artifacts seems crucial in contemporary efforts to realize the benefits of traditional manufacturing through software factories. Nevertheless, the systematic reuse of software artifacts is not a trivial task. Saeed recently argued that software reusability is not just facing legal issues, but methodological issues as well. Even when only reusing software to save time, and leverage off the specialization of other authors, the end-user must also have the technical expertise to search, adapt and merge these reusable assets into the larger software infrastructure [7]. We have argued in our previous work that software reuse is even more challenging, and impeded by some fundamental issues related to software evolvability [8] [9]. The sustained technological evolution leads to a continuous sequence of new versions and variants of the software artifacts that need to be reused. These new artifact versions often require changes in their usage that ripple through the entire software structure, causing an impact that is dependent on the size of the system, and limiting the evolvability of software systems [8] [10].

B. From DevOps to Integrated Control Systems

The aim of this contribution is to explore the creation of systems to manage and control the building and assembly of software systems in software factories, similar to SCADA or MES systems in traditional manufacturing. The main approach today in the software development and IT industry to control the building and assembly of software is a methodology called *DevOps*. Used as a set of practices and tools, *DevOps* integrates and automates the work of software development *(Dev)* and IT operations *(Ops)* as a means for improving and shortening the systems development life cycle [11]. It also supports consistency, reliability, and efficiency within the organization, and is usually enabled by a shared code repository or version control. As DevOps researcher Ravi Teja Yarlagadda hypothesizes, *Through DevOps, there is an assumption that all functions can be carried out, controlled, and managed in a central place using a simple code* [12].

Figure 1 presents a traditional overview diagram of a typical DevOps infrastructure environment. While the continuous integration of the software development and IT operations is represented by the infinity symbol, the representation also contains a typical set of tools and technologies being used in such an infrastructure. We distinguish for example tools for tracking features and user stories (Jira), source control management (Git and Bitbucket), software quality control (SonarQube), automation of build pipelines (Jenkins), automated testing (Cucumber, JUnit), deployment infrastructure (Kubernetes), analytics visualization (Grafana), logging (Graylog), automated deployment (Docker, Ansible), and connecting cloud providers (AWS, Digital Ocean). While the tools in such a *DevOps* or *Continuous Integration Continuous Deployment (CICD)* infrastructure are in general numerous and versatile, there is a clear need for integrated control systems, similar to SCADA or MES systems, encompassing these processes and tools. However, software factories differ significantly from traditional industrial factories, as software is less tangible and the desired control systems need to interface with — often complex — software tools instead of physical equipment.

C. Related Work and Methodology

While academic research is available on various aspects of DevOps, like maturity assessment [13], and management challenges and practices [14], the development of integrated control systems does not seem to be one of them. DevOps platforms are considered to be based on a mix of open source and proprietary software, glued together and built into the platform by a platform team. At the same time, trade publications describe the necessity to breakdown the DevOps phases and tools to increase security and reduce technical debt [15], and acknowledge the need for solutions to scale up DevOps, as nearly a third of DevOps teams' time is spent on manual approaches that are not scalable [16].

The methodology of this contribution is based on *Design Science Research* [17], where we design the integrated control system for software factories as an artifact, and use a case study to evaluate it in depth in a business environment. Within the context of this case study, this contribution performs a controlled experiment, i.e., study the artifact in a controlled environment for qualities, in order to refine the artifact gradually as part of the design search process.

III. The Software Factory and Assembly Lines

In this section, we describe the specific software factory that is used for the case-based design and evaluation of the software manufacturing control system. Within the context of this software factory, we present a model for an assembly line, a core concept in traditional manufacturing processes.

A. The NST Software Factory Case

To design and evaluate the integrated control system artifact, we use the case of *NSX*, the spin-off company that is developing and operating a software factory in accordance with *Normalized Systems Theory (NST)* [8] [9]. The software factory, described in detail in [18], encompasses both the metaprogramming environment, i.e., tools and code generators to *generate and rejuvenate* applications based on NST, and actual *Normalized Systems (NS)* applications, i.e., multi-tier web information systems generated in that environment. The various DevOps tools and technologies of the NSX factory correspond to a large extent to those in Figure 1. Though the company is limited in size, i.e., about 50 people, its DevOps environment supports the development and operations of a wide range of heterogeneous and interlinked software artifacts.

- *Run-time libraries* providing basic software utilities to various applications and tools.
- *Expansion resources* consisting of bundles of Normalized Systems code generation modules [9].

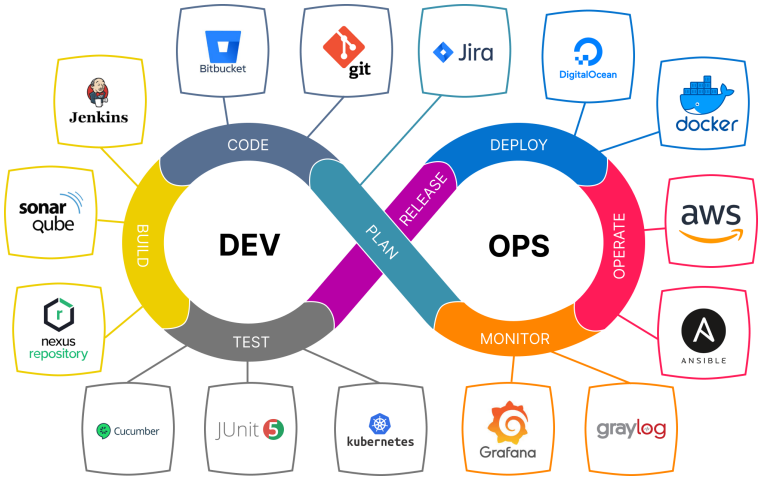

Figure 1. A traditional representation of a typical DevOps infrastructure.

- *Web Information Systems*, software applications based on the *Java Enterprise Edition (JEE)* standard.
- *Domain software components*, JEE components that are shared across multiple JEE applications.
- *Integrated Development Tool*, called *μRadiant*, to enable the model-driven development of NS applications.
- *Small tools and plugins* providing additional features in tools like *Maven* or *IntelliJ*, and the *μRadiant* itself.

The various build pipelines, defined in the corresponding software repositories, typically contain the following tasks.

- *Expanding* applications or components based on the NST metaprogramming environment.
- *Building* usable libraries, archives, or executables for components, applications, and tools.
- *Unit testing* of various software coding artifacts within the software repositories.
- *Reporting* on the repositories, such as test coverage or software quality metrics.
- *Deploying* live instances of applications or tools.
- *Integration testing* invoking live deployments.

B. A Model for Assembly Lines or Units

Assembly lines, as an implementation of the *Division of Labor* [19], are crucial to traditional manufacturing processes for mass production. To study and control a software factory, it is imperative to identify and model these basic building blocks that determine the sequential organization of adding and assembling parts. We propose to identify the fundamental assembly primitives of our software factory based on source code *repositories*. These repositories correspond to the units of work where programmers can contribute to the software, and are in general tightly connected to the automated DevOps build pipelines. We also propose to call them *assembly units*, as the number of steps or phases is limited, while the interactions with other units are diverse.

The architecture that we propose for such an assembly unit in the software factory is represented in Figure 2. The core of the unit is a repository, e.g., a *git* repository on *Bitbucket* or *Github*, with a corresponding configuration defining one or more build pipelines for an automation server such as *Jenkins*. Though not always present in every unit, we distinguish in general three activity phases in an assembly unit.

- *Expand phase*
  In the NST software factory, *expansion* or code generation of the skeletons precedes the compilation and building of the applications. Using modules or libraries of expanders, called *expansion resources*, this step is controlled by NS configuration settings that select (versions of) expansion resources. The automation server also performs a feedback cycle on the codebase, i.e., harvesting NS custom code and performing code analysis using tools like *SonarQube* and *Dependency-Track*.
- *Build phase*
  Compilation and building of the codebase is driven by a build automation tool like *Maven*, selecting through configuration the appropriate runtime libraries. The feedback cycle on the generated artifacts include an analysis of dependencies and vulnerabilities using tools like *Renovate* and *Sourcegraph*, and running (unit) tests.
- *Deploy phase*
  Generated artifacts that are executable can be deployed in containers using platform as a service tools and engines like *Docker*. This allows to perform live integration testing, possibly configured by tools like *Cucumber*.

The interaction or integration between the different assembly units is organized through a central repository of *executable artifacts* like expansion resources, runtime libraries, and application images. Assembly units can both retrieve these executable artifacts from, and submit them to, such an enterprise repository or *registry*. These registries are typically organized using tools as *Sonatype Nexus Repository* that offer additional functionality like access control. The reports generated by the various feedback cycles can also be stored and published on this central registry.

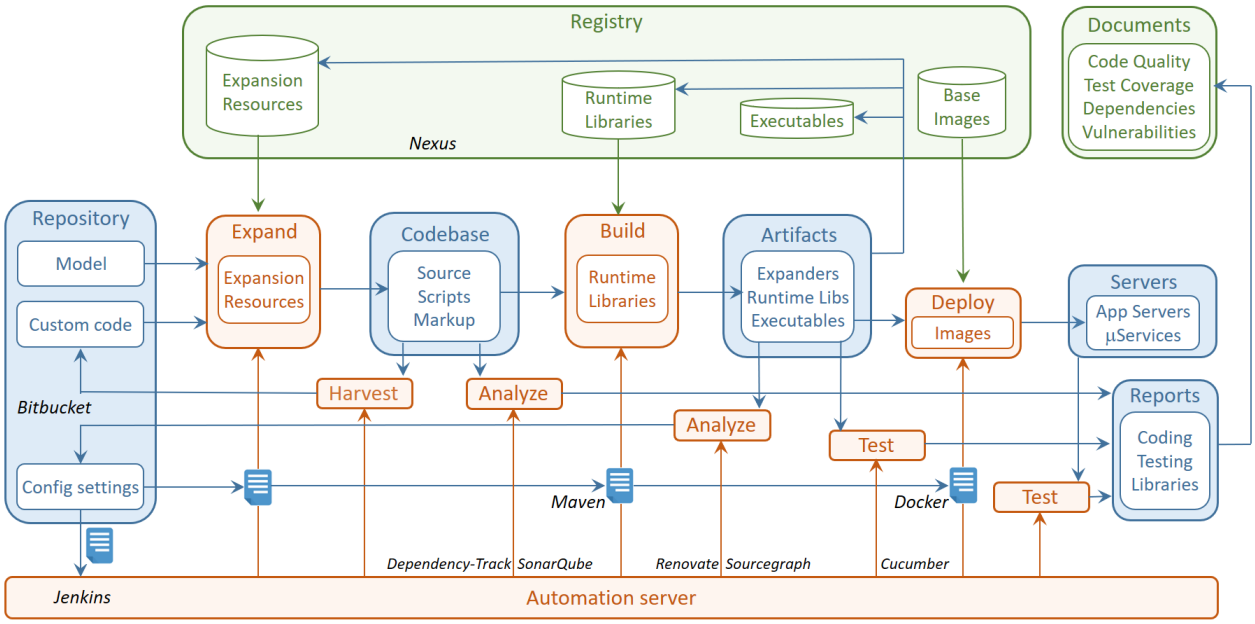

Figure 2. A representation of the architecture of a software factory assembly unit.

C. Hierarchical Structure of Assembly Units

The manufacturing of more complex products implies the existence of hierarchies of assembly lines. For instance, a car assembly line does not transform elementary screws and bolts into a car, but uses higher level modules like engines that are themselves produced in other assembly lines. In the same way, advanced digital platforms or applications cannot merely be built from simple source files, but use higher-level modules as well during their assembly. Explicitating these hierarchical assembly structures should be one of the features of the software manufacturing control system.

At the same time, not every phase or step is present in every assembly unit. For instance, assembly units for basic expansion resources or runtime libraries will neither have an expand phase, nor a deploy phase.

IV. A Software Manufacturing Control System

In this section, we elaborate the purpose, scope, architecture, and implementation features of the software manufacturing control system, i.e., the artifact that is being designed and refined within the context of this case study.

A. Purpose and Scope

Consistent with the overall goal of software factories and product lines, many applications and tools in this DevOps environment are expanded and built by reusing and assembling various other software artifacts that are built in other repositories and pipelines. In order to have an idea of, for instance test coverage and code quality, in a certain version of a software application, we need an overview of these parameters across the versions of all the runtime libraries, expansion resources and components that are being used in that application. In other words, we need a *Software Bill of Materials (SBOM)*, and we want to be able to assess various parameters across this SBOM. Moreover, in the same way that manufacturers attempt to keep track of all the individual parts and ingredients that are part of delivered products, we want to track the various deployments, including the configurations of these deployment instances, for every version of every application.

This type of functionality, i.e., to manage and control end-to-end the building and assembly of software systems in software factories, is indeed similar to MES systems, i.e., to track and document the transformation of raw materials to finished goods, and SCADA systems, i.e., to manage and control real-time production processes, in manufacturing. And though almost all the required information is available somewhere in one of the various DevOps tools, the integrated overviews and aggregations are not easily accessible. This means that tracing specific parameters from various software parts to the deployed product instances requires in general manual effort in current state-of-the-art DevOps environments. Making this information instantly available is one of the goals of the proposed software manufacturing control system.

B. Software Architecture

The integrated software manufacturing control system artifact for the NSX software factory is implemented itself as a *Normalized Systems (NS)* application, allowing us to take advantage of the *NST* metaprogramming environment. Moreover, as NST was proposed to provide a theoretic foundation to build information systems that provide higher levels of evolvability [8] [10], NS applications are intrinsically suited for systems that need to integrate with various rapidly changing technologies and protocols. This should enable us to cope with the many, and rapidly changing, DevOps tools and technologies.

NS applications provide the main functionality of information systems through the instantiation of five detailed design patterns, termed *element structures* [8] [20]:

- Data elements to represent data or domain entities.
- Action elements to implement computing actions or tasks.
- Workflow elements to orchestrate flows or state machines.
- Connector elements to provide user or service interfaces.
- Trigger elements to trigger or activate tasks or flows.

At the core of every information system is its data model, consisting of the various domain entities and their relationships. A central part of the data model of our software manufacturing control system is represented in Figure 3. As every software artifact that is built resides in a *Repository*, we define an *AssemblyUnit* for every repository. For every assembly unit, automated *Pipelines* can be defined with different *PipelineVersions*. A first category of artifacts produced by assembly units are NS *Applications*, belonging to a *Domain*, and having different *ApplicationVersions* that can have various *ApplicationDeployments* themselves. The expansion of the NS applications is configured in *ExpansionResourceSettings*, and *ElementModelMeasures* and *CustomCodeMeasures* capture and track various measures of the application versions regarding both model and custom code. A second category of software artifacts are the expander bundles or *Expansion-Resources* and their different versions. While the concept of an *ExpansionResourceDependency* is used to represent their mutual dependencies, various characteristics of these versions are stored in *ExpanderBundleMeasures*. A third category of software artifacts are (versions of) *DeveloperTools*. As these tools, including the *μRadiant* and various plugins, exhibit less predefined structure, we are limited here to capturing traditional software measures like technical debt.

The action or task elements serve to import, collect, and or compute various types of data for the software factory control system. Indeed, the manual entering of data in such a system would not only be extremely time consuming, it would also lead to consistency problems. More specifically, types of data that has to be collected, or computed, include:

- Versions of applications and developer tools with the corresponding versions of their dependencies.
- Aggregated information measures on NS applications, like the number of model entities, or the number and size of custom source code extensions and insertions.
- Aggregated information measures on NS expansion resources, like the number of individual expanders, or the number and size of expander templates.
- Overviews of automated tasks that have been performed in build pipelines with their result status.
- Various quality measures that have been computed for the various applications, expansion resources, and tools.
- Aggregated values for the use of various technologies, libraries and expansion resources in applications.

C. Implementation Features

A system or artifact for the monitoring and control of software manufacturing processes should be able to track the various parameters and data sets over time. This means that we need to track data over time for most data entities, like sizes of models and custom code, success rates of build processes, or software quality parameters. Therefore, the *history or log tables* are a crucial part of the data model. In the NS metaprogramming environment, *expanders* or code generators exist to automatically add —and even populate— an history element for every data element. These history tables can then be represented in graphs and analyzed over time, looking for possible improvements in productivity and/or output quality.

A large part of the relevant data for the software manufacturing control system is already present or computed in one of the many external tools or technologies represented in Figure 1. This implies that the automated collection and or computation of software factory data in automated tasks needs to integrate with these tools and technologies, such as *Bitbucket* repositories, *Maven* dependency declarations, *Jenkins* build engines, *SonarQube* code quality assessment, and *Dependency-Track* vulnerability analysis. In accordance with NST, there is a decoupling between the functionality of the data collection in the task element, e.g., build engine results or quality measurements, and the actual implementation (class) of the task element, e.g., getting data from *Jenkins* or *SonarQube*. In this way, the software manufacturing control system is able to support additional versions or variants of these tools and technologies with limited impact.

V. Toward a Control Layer for Improvements of the Software Factory and Its Operations

As stated in Section I, by tracking and documenting the transformation of raw materials to finished goods, *MES* systems enable decision-makers to optimize conditions and improve production output. In the same way, a software manufacturing control system should provide an analysis platform and control layer to improve and optimize various aspects and characteristics of the software factory operations and output. In this section, we discuss some use cases and their added value, as they are being developed as part of the iterative case-based design process.

A. Monitoring Evolutions over Time

A first avenue to optimize and improve the output and quality of the software factory, is to monitor the evolution of certain parameters over time. As explained in [9], NS information systems distinguish between software skeletons, instantiations of element structures generated by modular code generators, termed expanders, and custom code being additional software artifacts or classes, i.e., *extensions*, or code snippets added to the generated artifacts or classes, i.e., *insertions*. From a quality and evolvability point of view, it is important to monitor the amount, size, and location of

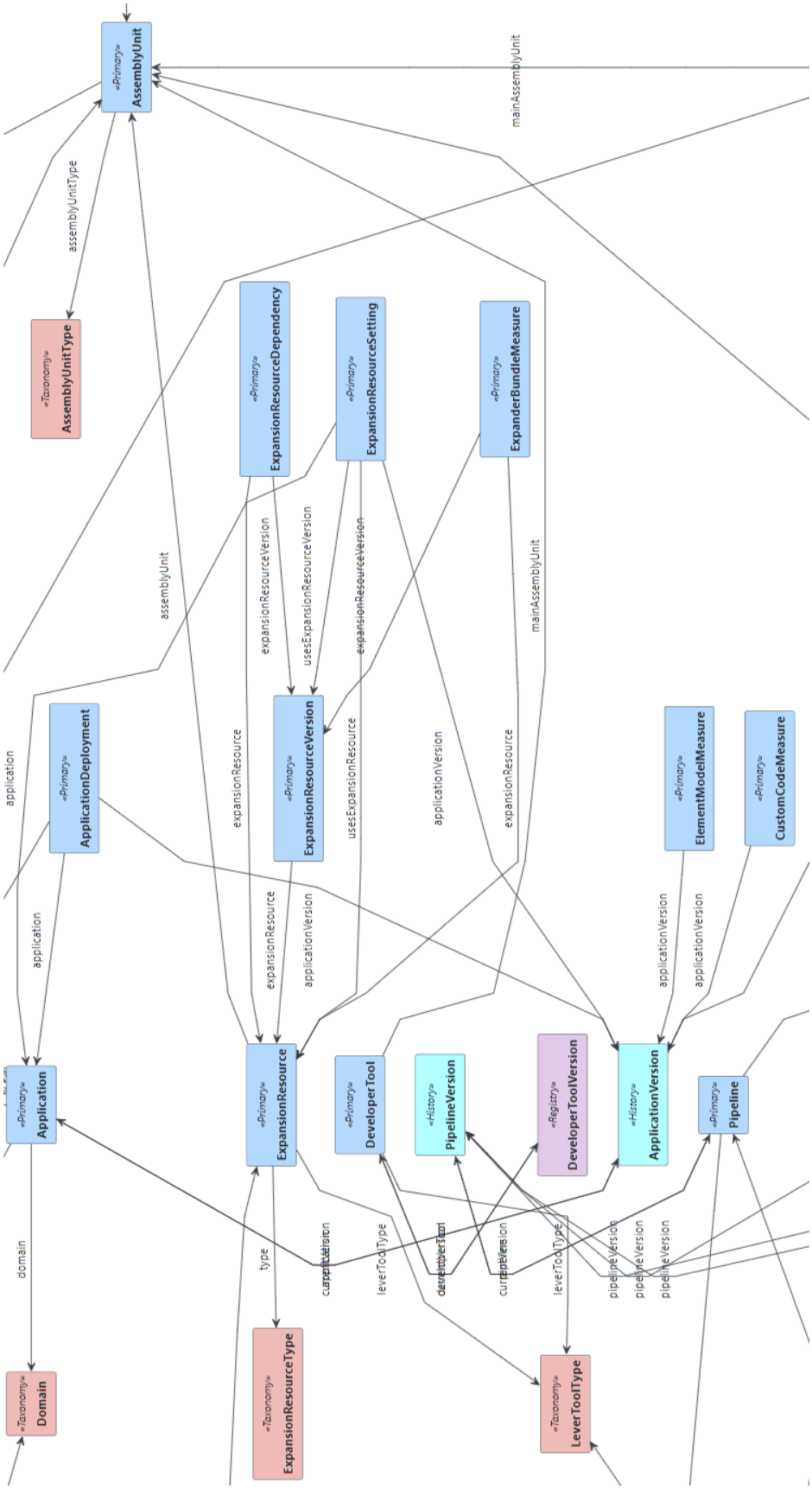

Figure 3. A representation of the data model of the integrated software manufacturing control system.

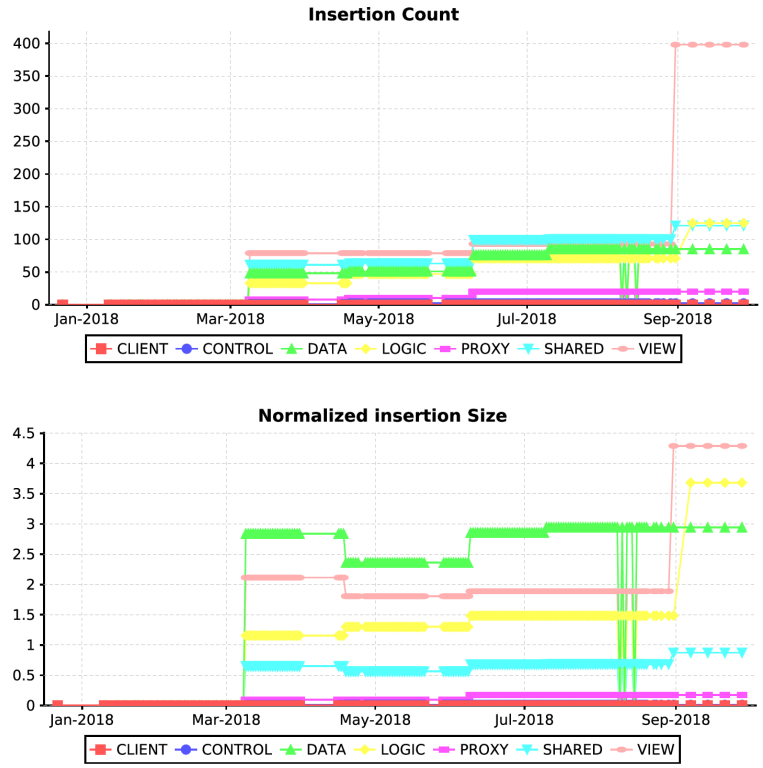

Figure 4. Sample graphs monitoring the amount of custom insertions and the normalized total size of insertions.

these extensions and insertions. As an example, some sample graphs are shown in Figure 4. They represent, for a specific information system, the evolution of the total amount of insertion snippets, and the total size of those insertion snippets. As shown in the second graph, these values can be made relative with respect to the evolving size of the model, i.e., the number of element structures. Different graph colors represent the various *layers* of the multi-tier web information systems. Higher levels of custom code can be specifically related to certain applications, but can also point to structural needs to provide additional expansion features in a specific layer.

This type of monitoring, based on automated data collection from the source code repositories, has been performed for quite some time in the NSX software factory. It has provided valuable insights into the actual project phases when such custom code typically grew fast, and the software layers where such custom snippets where needed the most. This last parameter provided an indication in which layer the development of the code generators should be prioritized to provide more out of the box functionality. Of course, other types of software systems and factories, without the typical NS distinction between element structures and custom code, should monitor other structural measures to improve software structure and productivity.

While this monitoring of custom code has been performed for some time, its integration in the overall software manufacturing control system provides additional added value. It will enable for instance a faster and broader analysis across multiple applications, comparisons between time periods and teams, and correlations with versions of expansion resources. Moreover, the monitoring over time is not limited to the source code repositories. History tables are also being created for success rates of build pipelines, quality measures of the custom source code, test overage percentages and numbers of failed tests, numbers of live system deployments, etc. Of course, this implies the integration with various DevOps tools and technologies, either through REST interfaces or reporting files.

B. Aggregating over Manufacturing Chains

It is often considered to be a crucial characteristic of software factories and software product lines that software artifacts should only be created when their reuse is predicted in one or more products [5]. And for instance in the NSX software factory, a typical JEE application uses various other software artifacts produced by the factory, such as:

- Several *runtime libraries* providing various utilities like file handling or protocol adapters.
- Several *reusable components* supporting more generic functionality like workflows or notifications, and/or providing more domain-specific building blocks, such as components for project planning or employee benefits.
- Several *expander bundles* that are used during the expansion of the application, such as the expanders to generate the instances of the NST element structures, or extensions such as the *Relational State Transfer (REST)* interfaces.

These artifacts are in general stored in other repositories and built in other CICD pipelines. And while the dependency on the code generation modules may be specific to NS applications, the dependencies on various runtime libraries and domain components are valid for nearly every software factory.

While parameters related to, for instance test coverage and code quality, can be monitored for every individual software artifact that is created in the factory, it seems quite relevant to offer instant overviews and aggregations of these parameters for all artifacts that are part of a specific aggregated artifact, such as a JEE application. While such integrated quality measures across a *Software Bill of Materials (SBOM)* are clearly relevant to the customers using or licensing such an application, this could also enable the optimization and improvement of the overall quality of the software factory itself [21]. Indeed, it would allow to identify the relatively weak or low quality parts in such aggregated artifacts, and to prioritize these software artifacts for improvements.

C. Tracking Technology Use Across Projects

Software applications are in general dependent on multiple *external* artifacts and technologies, e.g., libraries and plugins, that are build outside the software factory by commercial software vendors, or within open source projects. To address transparency around software applications, these components should also be part of a software inventory or SBOM. While these dependencies are available in configuration files, it is important to surface overviews and aggregations of these dependencies. Such overviews and their added value include:

- immediate overviews of the impacted applications when a vulnerability is detected in a library or technology.
- straightforward assessments of the impact when retiring a certain (version of a) technology.
- regular evaluations of the usage and adoption rate of libraries or expander bundles from the factory itself.

Obviously, such integrated information would also support decisions concerning internal resource allocation, both for supporting internal and external technologies.

VI. Preliminary Results of the Control System

The proposed software manufacturing control system aims to provide a transparent and traceable overview on the software factory, and to enable its steady improvement through a control layer. Though optimizations based on such a control layer takes time, we can already describe some basic results and findings from the initial implementation and data import.

A. On Software Applications

As mentioned in the previous section, the (versions of) NS software applications in this software factory have been analyzed on a continuous basis monitoring both the size of the models, i.e., data, task and flow elements, and the custom code, i.e., number and size of extensions and insertions. Therefore, it was pretty straightforward to import this data in the software manufacturing control system for the dozens of applications of the factory, corresponding to thousands of data elements.

Importing the expansion settings was relatively easy as well, and has already given insightful information, not just on the use of the various expansion resources, but also on the various versions that are being used at a specific point in time. This will clearly support the process of streamlining versions.

Constructing the SBOM or software inventory for external runtime libraries and technologies has proven to be less straightforward. As dependencies in *Maven POM (Project Object Model)* files are defined in a recursive way, we are currently investigating the integration of a suitable SBOM tool to flatten the resource and library dependencies.

B. On DevOps Infrastructure

Implementing the data import, we have observed a clear need for more structure and consistency across repositories and CI/CD pipelines. While some software applications were based on a single repository, others had one or multiple additional repositories, separating for instance authentication mechanisms, project-specific expanders, testing, master data, et cetera. This lack of consistency was also present in the definition of the pipelines in the various application repositories. Though other software factories may exhibit a superior consistency in the organization of the repositories and pipelines, consistent structure is something that typically arises during process automation. Therefore, it is quite possible that a structural improvement of this consistency could be a specific added value of a software manufacturing control system.

The integration of information from DevOps technologies like Jenkins and SonarQube needs to be performed carefully. As calling REST services to retrieve information from these tools could open up a path from the web-based manufacturing control system to those mission-critical servers, files are currently used to share information, and we are considering a callback architecture, where REST services on the control system are called from scripts in the external technologies.

C. On Expansion Resources

In the same way that model and custom code data have been imported for NS applications, retrieving data from (versions of) expander bundles or *expansion resources* has been integrated in the control system. Figure 5 presents for a number of expansion resources a schematic overview of the amount of expanders, i.e., the modular NS code generators, of expander features, i.e., feature modules within the expanders, and the total size of the templates (in bytes). Currently, the software manufacturing control system has imported (versions of) 66 different expansion resources. Besides showing that some expansion resources contain many heterogeneous expanders and need to be further modularized, this has also made clear that some additional streamlining and taxonomy is needed for the expansion resources.

Based on their configuration, the system also imports the dependencies between the (versions of) expansion resources.

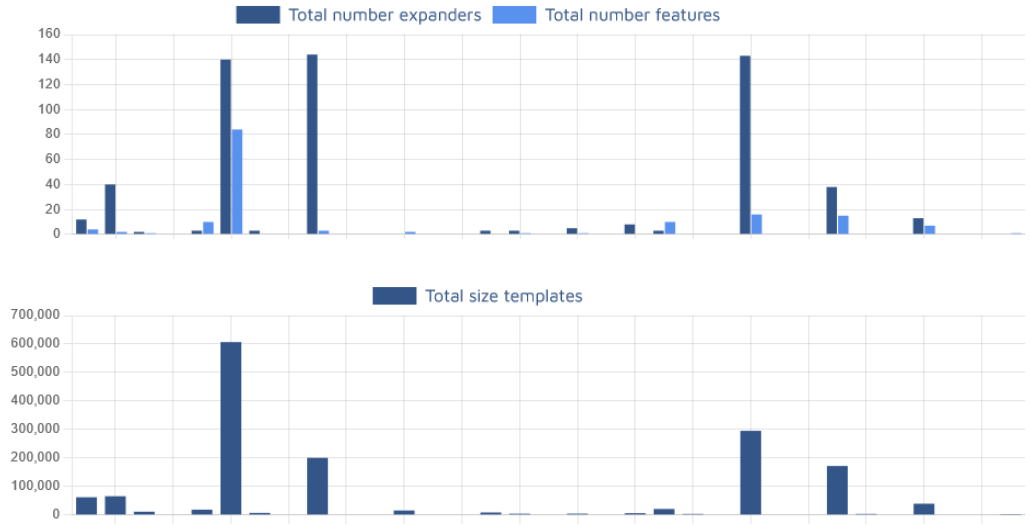

Figure 5. Sample graphs monitoring the amount of expanders and features and the total template size (bytes) of expansion resources.

As we represent and track these dependencies ourselves, the flattening of these dependencies to construct a SBOM has already been implemented.

VII. Conclusion

For many years, software engineers have strived to produce and/or assemble software in a more industrial way. In today's software factories, building and assembling software systems is mainly controlled using a methodology called *DevOps*. These *DevOps* environments are quite advanced and highly automated, but are in general based on many different technologies and tools. As previously experienced in the automation of business processes and traditional manufacturing, this often leads to a need for more integrated systems. In this contribution, we have investigated the creation of an integrated software manufacturing control system, similar to SCADA or MES systems in traditional manufacturing.

As part of a case-based design science approach, we have presented a functional scope and overall architecture for such a software manufacturing control system, and have described the design and prototype implementation of the artifact for the case of a specific software factory. This software manufacturing control system prototype does not provide fundamentally new information, but collects, aggregates and integrates information over time, across various repositories and build pipelines, and from different DevOps tools and technologies. Therefore, this control system does not provide new possibilities per se to optimize processes and improve output in software factories, as this can be done today by analyzing in detail the data produced by the various tools. However, aggregating and providing this information with short latency times, offers the opportunity to fundamentally reduce the lag times for such optimizations and improvements. Though the design as a search process is still ongoing, we have presented some use cases where the added value was validated in the case study. We have also discussed some preliminary findings and results of the implementation in the target software factory.

Investigating the creation of such a software manufacturing control system is believed to make some contributions. First, we have identified and validated a need for integrated control in today's state of the art automated DevOps environments. Second, we have designed an architecture that enables the rather straightforward creation of such integrated software manufacturing control systems in most contemporary software factories. Third, we have described and validated a number of detailed scenarios that can leverage such an integrated control system to improve the output of such software factories. Fourth, we have empirically shown that the implementation of such a control system can improve the consistency and structure across a state-of-the-art DevOps infrastructure.

Next to these contributions, it is clear that this investigation is also subject to a number of limitations. First, the case-based approach means that the integrated system has been created for a single software factory, though this factory does include for instance code generators. Second, the major part of the added value through optimizations and improvements, enabled by the drastic reduction of the lag times in the control processes, has yet to be confirmed empirically. However, its design has been validated by some key actors in our case study, and we have already verified empirically improvements in structure and consistency across the factory infrastructure, such as streamlining expansion settings and DevOps configurations across application projects.

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