Improvement of the Scheduling of Automotive Testing Processes Based on Production Scheduling Methods

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Abstract. Increasing challenges in the automotive industry are caused by shorter development times for products, greater diversity of variants and increasing cost pressure. Testing plays an elementary role within the product development process (PDP). There are already many publications that deal with the early phases of the PDP, but relatively few that address testing. Inefficient scheduling leads to suboptimal use of development and testing resources.

Automotive testing is characterized by high momentum and process complexity. The complexity of testing is determined, among other things, by the number of test rigs in a test field, the number and diversity of test objects, the type of testing and the preparatory setups. In addition, complex testing processes at the component and system level require a large number of human and material resources, whose time availability and sequence must be coordinated with the testing process. The sequence planning is subject to a high inherent dynamic because unexpected changes and disturbances of the process can occur during the testing. These changes require a rescheduling of the testing process. If done manually, the rescheduling results in high costs.

Based on known production planning methods, a solution approach is derived for improved utilization of test field resources for the automotive sector. The planning is optimized with a multitude of product - and process-related dependencies and restrictions using mixed-integer linear programming, a standardized method from operations research. The test field is simulated via a discrete event simulation. The proposed method considers the availability of essential resources.

Keywords: testing optimization · production scheduling · automotive testing · mixed-integer linear programming

1 Introduction

The well-known product development processes from industry and research are at the center of new advances in academia. Validation plays an essential role within product development [1]. Validation activities aim to compare the requirements and goals set for the product with the current status of the product as part of the product development

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process (PDP). To ensure operationally and functionally safe vehicles, the process steps of simulation (virtual validation), test rig testing (test rig validation) and real road tests (vehicle validation) are run through in the course of testing [2].

Due to shorter development times, increasing cost pressure and the higher number of product variants, a methodical approach in product development is indispensable to achieve reliable and reproducible development results. Research work to date in the area of electrified powertrains has increasingly focused on early phases of PDP, which is why rig testing must be given priority to ensure high efficiency and reliability [3].

Overall vehicle reliability and efficiency is essentially determined by the five categories of product, process, environment, method and people. Testing is a subset of the process category and a key factor along with research, development, simulation and design [4]. To ensure a methodical approach to testing, the V-model of system development can be used (see Fig. 1). The approach required for planning the testing processes is discussed. In particular, approaches to data-driven production optimization are applied in the derivation of a relevant method for the allocation of test rig fields [5, 6].

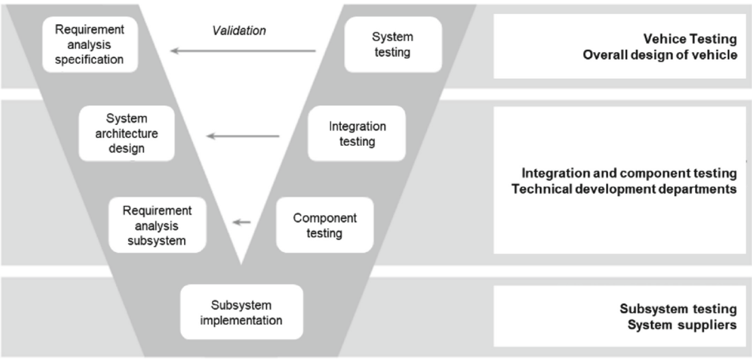

Fig. 1. V-model of system development [7]

In development phases, unforeseen interruptions and unavailable testing resources can negatively impact the testing processes. This has an impact on the time schedule. The proposed approach of simulating a virtual test field with a discrete event simulation in combination with a mathematical optimization model as a reference order generator is intended to counteract this problem in advance of testing so that critical time schedules can be identified. The simulation also enables an early estimation of critical testing processes with regard to completion times, considering disturbances that may occur.

2 State of the Art

The problem of interest with most industrial processes is to find the most efficient way to produce a set of products or services in a given time period using a limited set of resources. Due to the large potentials in resource savings, the scheduling of processes in industrial environments has attracted an increasing amount of attention from academia and industry.

The field of PDP is of interest for academia and industry because it is one of the main ways to achieve competitive advantage for a company. The performance of a product and its cost are defined in its development. The optimization of these two parameters is necessary for cost management [8, 9]. For many manufacturing companies, innovation, design and successful management of new product development often present major challenges [10, 11]. Long development times, prohibitive development and manufacturing costs, and poor quality have been common results for many of these organizations. The primary factor contributing to such unsuccessful results is the use of traditional sequential new product development by these organizations [12, 13]. Conversely, the literature over the past three decades clearly shows that, through their lean manufacturing practices, world class organizations, such as Toyota, have dominated competition not only in the area of manufacturing but also in the area of innovation, design, development and commercialization of new technologies [13–15]. Although the scheduling potential has been known for a long time, in recent years the substantial advances of related modeling and solution techniques, as well as the rapidly growing computational power have enabled new solutions for the existing problem [16].

Scheduling of automotive testing processes and production scheduling methods have many overlaps, mainly in the field of production planning. Manufacturing resources provide values for cost, quality, time and environmental impacts, which multiply with their usage within a manufacturing task for a specific part [17]. Accordingly, the planning of testing processes also aims to reduce the necessary resources (human resources, time, etc.) to conduct the testing task.

In most cases enterprise resource planning systems are used for production planning in combination with integrated manufacturing execution systems and advanced planning and scheduling systems. In production planning, especially in the scientific field, control algorithms are also taken into account in order to consider the constantly updated planning according to current production conditions [18, 19]. The production including the production control system is considered as a control loop, so that the current production status can be taken into account by data acquisition and if changes occur can be counteracted [20].

To enable the best possible planning, mathematical optimization algorithms are used, for instance mixed integer linear programming (MILP), which are mainly adapted to computational efficiency and the quality of results in terms of the minimization of setup and total flow time [21, 22]. Discrete event simulations can also be used to create a digital twin of a production environment to test, as well as validate the production control systems at hand with the virtual machine models [23, 24]. These simulation models are also used for production simulation in order to check and evaluate defined processes in production environments [25]. Similarly, the effects of alternative scenarios and different framework conditions on the production processes can be simulated to match the real system underlying the simulation model with the findings [26].

The scope of this paper is to transfer an approach from virtual testing of production environments, essentially consisting of virtual machines and a reference job generator, to a digital twin of a test field. Thus, the test field consists of virtual test rigs. The test field is also simulated as realistically as possible via a discrete-event simulation. The transfer will enable an estimation of temporal conditions and critical time schedules.

3 Test Field Modelling

3.1 Physical Test Field

The investigated test field consists of four component test rigs and one system test rig (see Fig. 2). The testing task, which is derived from a system context, is divided into subtasks at the component level and then assigned to the component test rigs. This enables simultaneous testing on several test rigs. It is also possible to substitute individual testing tasks, e.g. if a rush job is to be included in the test plan. Through the efficient combination of component and system test rigs, the test time can be reduced and the test rig utilization, through the more flexible use of the test rigs, can be significantly increased.

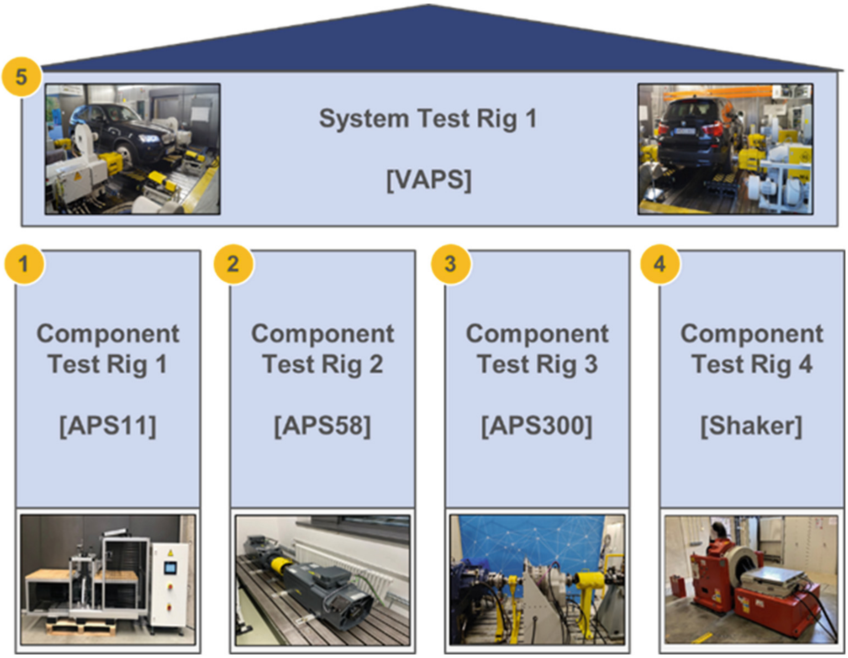

Fig. 2. Test field: component and system test rigs

3.2 Virtual Test Field

In modern test fields, accurate knowledge of test times and, above all, identification of critical time schedule is essential to ensure optimal testing in complex test fields. The dynamic fluctuations, which should be considered in real time if possible, pose further challenges. These problems can be addressed with a control system that allows an up-to-date consideration of the status and counteracts deviations from the schedule in combination with a virtual test field (see Fig. 3). The aim is therefore to replicate a real test field as realistically as possible and as detailed as necessary.

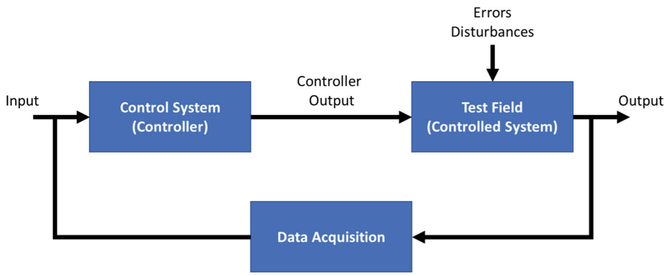

Fig. 3. Visualization of the structure of a control system to simulate virtual testing

The structure of the basic control loop is therefore transferred to a model for the simulation of testing processes and essentially consists of a reference order generator and virtual test rigs in a defined test field. Relevant data during the testing process can be recorded via test rig data (TRDA) and operating data (ODA) acquisition. The level of detail of the virtually represented test rigs corresponds to a very abstract level, because ultimately only higher-level variables, such as the test times, are relevant for a process planning. The reference order generator generates jobs for the virtual test rig. Based on defined testing scenarios a mathematical model is defined. In the following use case a MILP is used for a mathematical optimal order release. The reference order generator is connected via different communication processes with the virtual test rig. The virtual test rigs consist of a testing process simulation and an availability simulation, which are both dependent on the operating calendar of the test rigs. The availability simulation considers malfunctions, non-availability and operational reasons (e.g. personnel availability). The calendar, the testing process simulation as well as the availability simulation are connected via a simulation logic. The causes limit the availability and result in an average utilization rate. This is maintained by means of stochastic modeling averaged over a longer period of time (see Fig. 4).

4 Scheduling Results

In this section, the functionality of the developed model for simulating virtual testing processes and identifying critical time schedules during the process is presented. The virtual test field, which is affected by disturbances and unavailability, among other things, requires several reschedules during the process. The exemplary testing scenario visualized in Fig. 5 is composed of an initial state of testing orders and a variation, which in this use case represents a rush order, that the static testing process becomes a dynamic process with adjustments required. The initial state consists of test orders (A and B and C) for component testing and one order for system testing (ABC). System testing can only be started once the individual component tests have been completed. In the scenario, a total of four component test rigs and one system test rig are considered, as described in Sect. 3.1. The release of the test order (initial state) was on 30.05.2022 at 7.00 am. Different shift models (e.g. single-shift or three-shift) are considered for the test rigs, depending on the degree of automation.

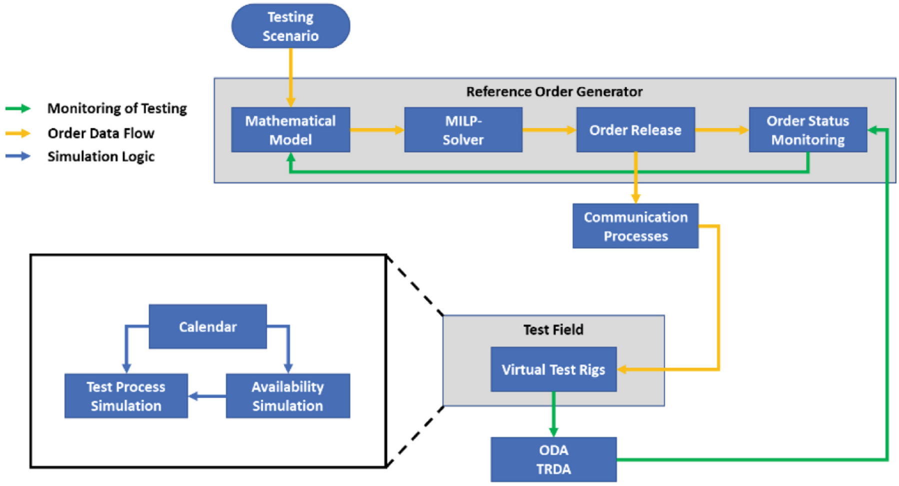

Fig. 4. Structure of the model for the simulation of virtual test procedures

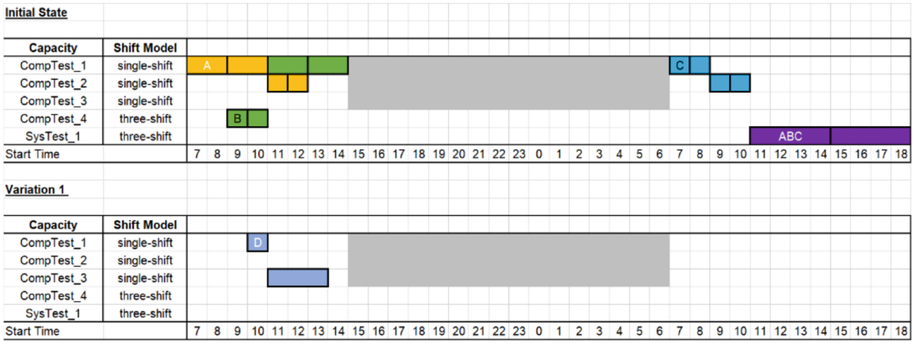

Fig. 5. Exemplary testing scenario with the defined test field

Due to delays in ongoing testing processes caused by disruptions and personnel absences, as well as the rush order, an update of the planning is essential to represent the current situation. The control process is performed with the MILP solver. The control strategy underlying the simulation model aims to complete all test orders as early as possible. So, the interval between the planned completion time and the latest permitted completion time is maximized. Several test specimens can be tested at the individual test rigs. Each individual test specimen can be passed on separately to the next test step. Product changes in the meantime are not permitted, so that the setup time that has to be considered for a change is minimized as far as possible. In the model, a degree of utilization that may have an impact on the actual test time can be considered for the test rigs.

Figure 6 below represents the results of the simulated planning scenario with multiple readjustments. In each case, the planned completion dates are shown as a function of the rescheduling steps. The necessary regulations during the testing process and the resulting new schedule can be clearly seen in the individual figures. Adjustments at a single testing step also have a significant impact, here especially on system testing.

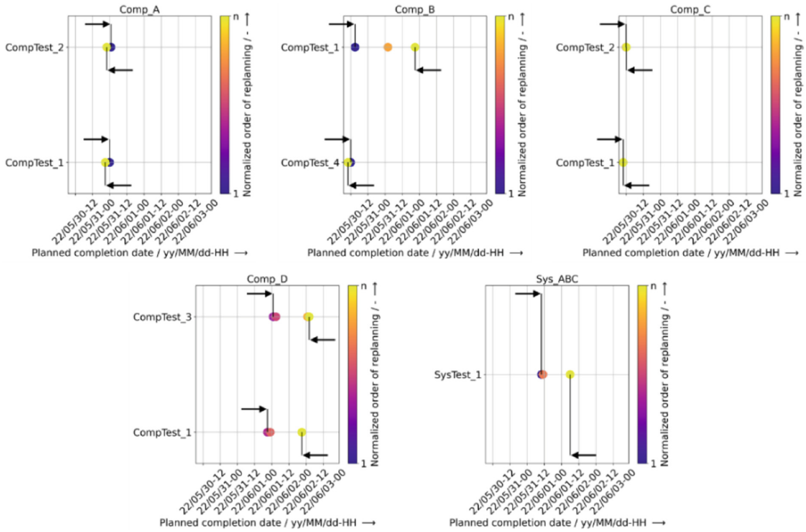

Fig. 6. Results of the simulated testing scenario

5 Conclusion and Outlook

In the context of this publication, it is shown that a simulation model for the virtual representation of test rigs enables an estimation and identification of critical time schedules with regard to the completion date, considering disturbances and personnel unavailability. Scheduling is based on MILP rule algorithms, so that an early completion of all test jobs is targeted. The component and system test rigs of the Institute of Drive Technology Aalen provided a sufficient reference environment to demonstrate the behavior and interaction of the individual test rigs with regard to the required replanning. The influence on each other and the influence of disturbances and unavailability can be seen, so that an improvement of the resulting test schedule is demonstrated when using the simulation model and MILP algorithm compared to basic planning methods.

The shown research results also demonstrated the advantages of the MILP algorithm with regards to the inclusion of rush orders into an existing order management scheme. The uncertainty of an upcoming rush order did not interfere with the completion end-date for the previously integrated orders. The implications for practice suggest high degree of flexibility in the order management planning of testing processes, adjusting to the rapidly changing incoming orders and substitution effects in the daily business of testing facilities.

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