Lecture Notes in Production Engineering

Konrad von Leipzig
Natasha Sacks
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Smart, Sustainable Manufacturing in an Ever-Changing World

Proceedings of International Conference on Competitive Manufacturing (COMA '22)

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About CIRP

CIRP was founded in 1951 with the aim to address scientifically, through international cooperation, issues related to modern production science and technology. The International Academy of Production Engineering takes its abbreviated name from the French acronym of College International pour la Recherche en Productique (CIRP) and includes some 600 members from 50 countries. The number of members is intentionally kept limited, so as to facilitate informal scientific information exchange and personal contacts.

CIRP aims, in general, at:

- Promoting scientific research, related to
  - manufacturing processes,
  - production equipment and automation,
  - manufacturing systems, and
  - product design and manufacturing
- Promoting cooperative research among the members of the academy and creating opportunities for informal contacts among CIRP members at large
- Promoting the industrial application of the fundamental research work and simultaneously receiving feedback from industry, related to industrial needs and their evolution.

CIRP has its headquarters in Paris, staffed by permanent personnel, and welcomes potential corporate members and interested parties in CIRP publication and activities in general.

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Foreword

Welcome to the eighth International Conference on Competitive Manufacturing hosted by the University of Stellenbosch and organized by the Department of Industrial Engineering.

The recent COVID pandemic yet again illustrated the interconnectedness of countries, companies, and individuals and also highlighted the dependencies on one another. In a small world where global trade is a given, international competitiveness stays a challenge. It requires high-quality products manufactured with state-of-the-art technologies at low cost under the assumption of highly efficient operations management as well as clear corporate goals and strategies. This in turn is facilitated by and dependent on improved engineering training, education, and relevant applied research, fueled by active interaction between academia and industry.

The main objective of COMA '22, the International Conference on Competitive Manufacturing, is to present recent developments, research results, and industrial experience accelerating improvement of competitiveness in the field of manufacturing. The close to 80 papers and presentations invited or selected to be delivered at the Conference deal with wide aspects related to product design and realization, production technologies and systems, operations management as well as enterprise design and integration. The worldwide participation and range of topics covered indicate that the Conference is truly a significant meeting of people striving for similar aims. The event is an additional opportunity for communication between paper authors and attendees, which undoubtedly will serve as a further step toward exciting developments in the future. It also provides ample opportunities to further exploit international research collaboration and collaboration between academia and practice. As in the past, we hope that the event will lead to tangible new outreach endeavors not only between existing collaborators, but also opening new opportunities to stimulate increased productivity and entrepreneurial ideas, so vital for an economy challenged by the COVID pandemic.

The chairmen and the organizing committee express heartfelt thanks and gratitude to the members of the international program committee, who have given their help and expertise in refereeing the papers and will chair the plenary and technical sessions during the Conference, as well as to the authors for participating and ensuring that the high standards required on an International Conference were maintained. These thanks and gratitude are extended to our highly regarded plenary speakers.

The chairmen convey sincere thanks to the conference sponsors for their generous support, which made this event possible.

The International Academy of Production Engineering (CIRP) is gratefully acknowledged for the scientific sponsorship given to the Conference.

Finally, the tremendous effort of the organizing committee is appreciated. Grateful thanks are due particularly to the Conference secretariat for ensuring the success of COMA '22.

We hope that you will find the Conference interesting and stimulating!

Stellenbosch, South Africa

Mr. K. H. von Leipzig
Conference Chair

Submission Review Process

A formal "Call for papers" for the 8th International Conference on Competitive Manufacturing (COMA '22) was issued in May 2021 to submit an 'Abstract' within the identified tracks/themes. Abstract submissions were subjected to an internal reviewing process, whereby successful submissions were notified and invited for presentation to the conference. Authors were subsequently invited to submit the 'Full Paper', which was published as a conference proceeding. Both the Abstracts and Full Papers were submitted online through the EasyChair submission page https://easychair.org/my/conference?conf=coma22 where acknowledgement of receipt was sent to authors. Authors were informed that a double-blind review process is applied to Full Paper submissions.

The following dates were set by the organising committee:

- Call for papers (1st May 2021)
- Submission of abstracts (12th July 2021)
- Notification of acceptance of abstracts (16th July 2021)
- Submission of full papers (28th January 2022)
- Feedback on paper reviews (8th February 2022)
- Revised paper submissions (15th February 2022)

Abstracts were required to be a maximum length of 400 words. Full Papers were required to be a maximum length of 6 pages, but leniency was given for the Author biographies and references. Full Paper submissions were required to adhere to a specific template and format which was placed on the conference site here: https://blogs.sun.ac.za/coma/callforpapers/.

A double-blind reviewing process was used for the Full Paper submissions. As such, both the reviewer and author identities are concealed from the reviewers, and vice versa, throughout the review process. Each Full Paper submission was sent to a minimum of two reviewers, with a third reviewer being requested in case of non-consensus between the first two reviewers. The reviews were completed by national and international academics, and experts in the respective field, listed on the International Programme Committee page.

A total of 45 reviewers participated in the review process, each reviewing between two and five papers. Reviewers were asked to review submissions according to the following criteria and were encouraged to provide recommendations and suggestions

- Does the title reflect the contents of the paper?
- Does the paper relate to what has already been written in the field?
- Do you deem the paper to be proof of thorough research and knowledge of the most recent literature in the field of study?
- Is the paper clearly structured, easy to read and with a logical flow of thought?
- Are the arguments employed valid and supported by the evidence presented?
- Are the conclusions clear and valid?
- Does the paper conform to accepted standards of language and style?
- Any other recommendation(s)?
- Select reviewer recommendation: ‘Accept Submission’, ‘Revision Required’, or ‘Decline Submission’

Reviewer feedback was saved on the submission system, where acceptance emails together with review comments were sent to the authors, allowing them to revise the submission. The authors were given between 2 and 4 weeks to incorporate changes, after which the final document was submitted for approval and publication as a conference proceeding.

Topics

Papers were invited in the following areas relevant to the conference themes:

Product Design and Realisation:
Design for manufacturing and assembly, reverse engineering, CAD/CAE, concurrent engineering, design for additive manufacturing, biologically inspired design approaches, virtual prototyping, networks in product development, open design.

Production Technologies:
Expert systems in manufacturing, CAD/CAM Systems, HSC, EDM, forming, additive manufacturing, casting, metrology, mechatronics, precision manufacturing, biomanufacturing, robotics, sensing, assembly, automation, intelligent manufacturing, biologically inspired manufacturing processes, non-conventional machining, environmental aspects, machining of materials, abrasive processes, hybrid processes, laser-based manufacturing, green manufacturing, coating technology.

Production Systems and Organisations:
Production planning and control, logistics, modelling and simulation, SW-applications, communication networks, 5G network applications, social manufacturing, learning factory, digital factory, biological transformation in production systems, cyber-physical approaches, big data, predictive maintenance,

asset management, human-machine collaboration, employee qualification, human resource management, IoT in manufacturing, manufacturing digitization challenges, augmented and virtual reality, lean manufacturing, sustainable manufacturing.

Enterprise Design and Integration:
Knowledge management, product life cycle, human interface, integrated design and manufacturing, technology and innovation management, total quality management, distributed control systems, socio- economic and environmental issues, artificial intelligence and machine learning, digitals twins, virtual setup, subscription vs selling.

Supply Chain Management:
Supply chain track and tracing; digital supply networks, blockchain in supply chains, circular economy, artificial intelligence for supply chains, biological transformation in supply chains.

COVID-19: Manufacturing and Supply Chain:
Post-pandemic business models, Supply chain localisation, manufacturing as a service, Rapid medical device manufacturing, Distributed manufacturing, Constrained supply chains, Resilient supply chains.

Materials and Manufacturing:
Smart materials, Recycling, Remanufacturing, Future materials, Biomaterials, Sustainable materials, Nanomaterials, Coatings, Metal matrix composites.

Acknowledgements

Sincere thanks to our distinguished supporters and sponsors, whose generosity made possible the success of this Conference.

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Contents

Production Systems and Organizations

Identification of Residual Development Efforts in Agile Ramp-Up Production

Thomas Bergs, Sebastian Apelt, Malte Becker, Alexander Beckers, and Sebastian Barth

Abstract Agile product development is increasingly finding its way into the development of physical products. The subsequent transfer of a planned and still unstable manufacturing process into stable series production after the design freeze is the goal of ramp-up production, but confronts manufacturing companies with different challenges. A currently high level of changes to the product geometry and the planned manufacturing sequence due to not achieved requirements in late phases of the ramp-up production (Residual Development Efforts—RDE) results in time-consuming and cost-intensive changes to the product and manufacturing sequence, which leads to failure to achieve ramp-up targets. The goal of current research is therefore to increase the agility of ramp-ups and to integrate the ramp-up production into the phase of agile product development. This offers the potential to use the increased dynamics of the product development process and the knowledge already generated for the validation and stabilization of the manufacturing process. However, due to the integration of ramp-up production into product development, there are additional far-reaching effects of product and technology uncertainties prevalent in agile product development on the design of agile ramp-up production. Additional uncertainties regarding the product geometry due to non-finalized designs and the resulting

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uncertainties regarding the probability of use and achievement of the requirements of the manufacturing technologies initially result in additional residual development efforts. Furthermore, the interactions between the manufacturing technologies in the manufacturing sequence are thus subject to additional uncertainties, which also leads to increased RDEs. To meet this challenge, it is necessary to analyze prevailing uncertainties and predict their impact on potential changes in agile ramp-up production. Therefore, a methodology is presented, which enables the analysis of product and technology uncertainties and thus the identification of product and process-related changes (RDE) in agile ramp-up production.

Keywords Agile ramp-up production · Technology planning · Uncertainties · Residual development efforts · Manufacturing sequence

1 Introduction

In the course of globalization, manufacturing companies are confronted with various challenges in a dynamic competitive environment. These challenges include shorter product life cycles, changing customer requirements and increasing product variety [1]. In order to meet these challenges, an optimized product development process and a controlled transition from product development to series production, which is referred to as ramp-up production, are necessary [2]. The design freeze describes the point at which no more changes to the developed product are allowed and at which the release for the ramp-up production is set [3]. In conventional ramp-up production, which follows the design freeze, ramp-up targets are often not achieved. This means, for example, that the time-to-market and time-to-volume as well as the ramp-up budget are exceeded [4]. The non-achievement is due to instabilities in the manufacturing sequence, which are caused by fluctuating employee and technology capabilities on the one hand [5]. On the other hand, the instabilities are caused by residual development efforts in the ramp-up production. Residual development efforts are necessary subsequent developments to the product or to the technologies of a manufacturing sequence, which are based on insufficient product and technology maturity [2] as well as on an insufficient coordination between product development, technology planning and ramp-up management [3]. Manufacturing sequences describe the combination of value-adding process steps and handling technologies for the manufacture of a component [6]. It is difficult to address these challenges in the planning phase because manufacturing technologies are not physically connected to generate a manufacturing sequence until ramp-up production. Only through this connection previously unknown interactions between technology and product, but also between the technologies themselves, become visible [4].

Residual development efforts (RDEs) in ramp-up production are similar to constantly changing customer requirements in product development. Since the concept of agile product development is finding its way into product development to meet this challenge, current research focuses on the adaptation of agile methods to the ramp-up production [4]. In agile product development, the scrum approach is widespread, which divides a development project into short development cycles, referred to as sprints [7]. The increase in agility and the integration of ramp-up production into agile product development is referred to as agile ramp-up production. On the one hand, the integration aims to enable improved coordination between product development, technology planning and ramp-up management. On the other hand, the ramp-up production should become more agile through agile product development, so that problems (like RDEs or instabilities of the manufacturing sequence) can be identified earlier to be counteracted. Due to the integration, the ramp-up production no longer starts after the design freeze. Therefore, uncertainties regarding the product are present in the agile ramp-up production [4]. Since the technologies for the manufacturing sequence are planned in parallel with product development, there are technology uncertainties as well. The challenge for technology planning in agile ramp-up production is to validate a manufacturing sequence planned under uncertainty based on uncertain information. As a consequence of agile ramp-up production, the existing uncertainties have to be analyzed to avoid additional residual development efforts.

To address this challenge, the state of the art regarding existing methods for ramp-up production and product development is analyzed and the objective of the developed methodology is presented. Subsequently, the methodology is explained in detail and validated in a case study.

2 State of the Art

For agile ramp-up production, it is necessary that both product development and ramp-up production are considered. In addition, the manufacturing sequence and residual development efforts must be taken into account. Due to the integration of ramp-up production into product development, uncertainties are present in agile ramp-up production, which must also be taken into account. In the scientific literature, a variety of approaches exist which address either the ramp-up production or the product development. Most of the analyzed approaches addressing ramp-up production describe it from an organizational and socio-technical point of view and neglect the manufacturing sequence and residual development efforts, such as the approaches of Laick [8], Winkler [9], Dyckhoff et al. [10]. The approaches of Lanza and Stauder consider manufacturing technologies as a part of a manufacturing sequences but handling technologies and residual development efforts are not sufficiently addressed [3, 5]. It is concluded that existing approaches regarding ramp-up production do not allow a comprehensive consideration of residual development efforts.

The following section analyzes approaches from product development and their transferability to agile ramp-up production. Examples of such approaches are Cooper et al. and Sommer et al. However, these approaches describe product development from an organizational and socio-technical perspective [11, 12]. Rey's dissertation deals with the combination of technology planning and product development. Handling technologies and instabilities during ramp-up production are not considered [13]. Summed up, the ramp-up production is not considered in any of these approaches.

In addition to the described approaches, first approaches which consider both product development and ramp-up production exist, e.g. from Basse and De Lange. However, manufacturing sequences, modeling of uncertainties, and the identification of residual development efforts are not or insufficiently discussed [14, 15].

Conclusively, existing approaches do not allow a cross-phase consideration of product and technology uncertainties as well as a consideration of residual development efforts in agile ramp-up production. Furthermore, existing approaches neglect handling technologies in the manufacturing sequence. Therefore, a methodology is needed that considers the manufacturing sequence, product and technology uncertainties and the residual development efforts in the ramp-up production. This requires modeling product and technology uncertainties as well as predicting and evaluating residual development efforts in ramp-up production. The developed methodology is described in detail below.

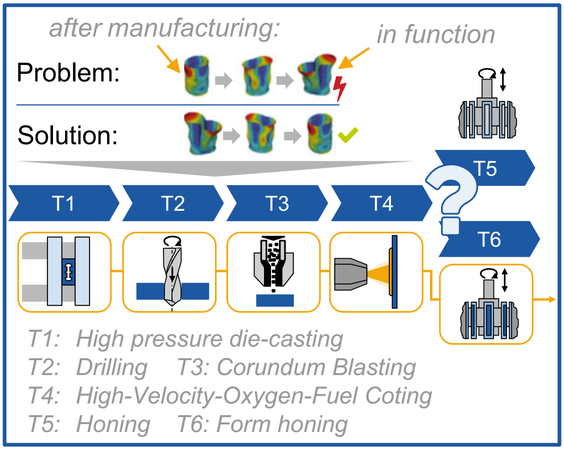
3 Objective

The objectives of the methodology presented are to increase the agility of ramp-up productions and to enable users to systematically model existing uncertainties for the identification of residual development efforts under consideration of planned manufacturing sequences. For this purpose, uncertainties resulting from the integration of ramp-up production into product development must be taken into account in order not to additionally threaten ramp-up targets. The methodology enables the identification of problems at an early stage in the ramp-up production and the initiation of targeted measures to eliminate the problems. This improves target achievement during the ramp-up production and reduces the development time to series maturity.

4 Case Study

For a better understanding of the methodology, the details are given by means of a case study from industrial practice. As a consequence of the increasing demand for vehicles with low CO_2 emissions, legal regulations for the reduction of CO_2 emissions as well the high importance of a successful ramp-up production in the automotive industry, the validation of the developed methodology is carried out on the basis of a cylinder crankcase for an engine. One solution to the problem of reducing exhaust emissions and fuel consumption is to reduce friction. There is potential in optimizing the tribological system between the cylinder bore and the piston ring. The friction

Fig. 1 Case study [16]



is largely dependent on the contour of the cylinder bore surface [16]. The aim is to manufacture the cylinder bore surface of the cylinder crankcase with a containment contour, see Fig. 1.

The development of the cylinder crankcase is conducted agile. Uncertainties exist with regard to the general use of a containment contour, the exact contour dimensions and shape, position and dimensional tolerances. In the case study, the containment contour could be realized by form honing (T6). However, there are uncertainties with regard to the tool life and the handling step that transfers the cylinder crankcases to the form honing technology. In order to achieve the shortest possible time to market, the ramp-up production is carried out in parallel with agile product development.

5 Methodology

In this section, the developed methodology is described. Uncertain manufacturing sequences and product characteristics represent the input of the methodology. The conceptual design of the methodology consists of two steps (see Fig. 2). In the first step, the uncertainty situation is modeled by collecting single information, which are afterwards combined to aggregated information. In the second step, RDEs are identified based on the modeled uncertainties, which are finally evaluated for the prioritization for the execution of prototype tests and validation in the ramp-up production. The output of the methodology are prioritized potential residual development efforts for which countermeasures have to be determined. The determination of countermeasures is not part of this paper. In the following, both steps are presented in detail.

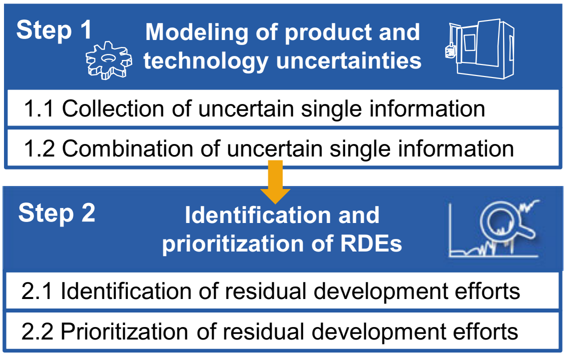


Fig. 2 Conceptual design of the methodology

5.1 Modeling of Uncertainties

The understanding of uncertainty in this approach is based on the generalized information theory, in which the terms information and uncertainty are linked with each other. According to this theory, uncertainties are information deficits, which can be reduced by appropriate additional information [17]. Furthermore, in this approach, uncertainties are divided into product and technology uncertainties. Product uncertainties result from uncertain product characteristics. Technology uncertainties are information gaps for the manufacturing of product characteristics as well as for handling. This step serves to quantify existing uncertainties regarding the developing product and the manufacturing sequence. This step is modeled based on the methodology of Rey, which allows the combination of various individual pieces of information into product requirement and technology capability profiles [13].

5.1.1 Collection of Uncertain Single Information

The first step of the methodology is to collect information regarding product requirements and technological capabilities of the planned manufacturing and handling technologies. A single Information (A) can be acquired from various sources such as standards, journals, technical books or expert statements. The certainty of single information (CI) describes how certain an information source is when providing a single information. A certainty of 100% corresponds to the highest certainty of an information source regarding a single information, whereas a certainty of 0% corresponds to the lowest certainty. Furthermore, the user of the methodology determines the reliability of a single information (RI), see Fig. 3.

The reliability of a single information describes the percentage of trustworthiness of an information source. This is relevant, because different sources of information have different credibility [13]. Subsequently, the collected information is modeled using the evidence theory from Dempster [18] and Shafer [19].

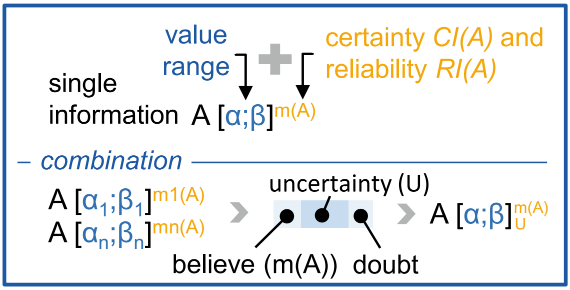


Fig. 3 Modeling on Uncertainties

In this theory of plausible reasoning, evidence describes an immediate insightfulness of findings and unprovable statements, for which the correctness can only be determined by their occurrence, or non-occurrence [20]. Evidence (also called base dimension) results from the certainty and reliability of the occurrence of a single piece of information (A). To do this, the certainty and reliability of a single information are multiplied, see formula (1) [13].

$$m(A) = CI(A) \cdot RI(A) \tag{1}$$

For example, an evidence of 100% results if an expert provides a single information with a certainty of 100% and the user of the methodology fully trusts this expert. In the case study introduced, one of the uncertainties is the tool life of the honing stones used in the manufacture of the cylinder crankcase. For this purpose, information is obtained from the design and technology planning departments, which differ in their credibility and in the specified interval range.

5.1.2 Combination of Uncertain Single Information

By combining different information from different sources, it is possible to generate an aggregate information considering the reliability of each source of information [20]. Thereby, fixed single values as well as value ranges can be specified by the information sources. By combining this single information (in the form of value ranges or single information), aggregated value ranges are evaluated with an uncertainty (based on the evidence). The uncertainty thus provides information about the certainty with which the final expression lies within the aggregated value (Interval). For this purpose, the combination rule of Yager [21] is used. This combination rule is a derivative of the combination rule according to Dempster [18], which is also suitable for processing contradictory information [21]. The result of the step is a combined information with a total certainty and uncertainty (U) [13]. Based on the case study, the information regarding the tool life from design and technology planning are combined. The result is a value range with a specified uncertainty that the actual tool life is assigned to. By acquiring more information, the range of values can be narrowed or the uncertainty can be reduced.

5.2 Identification an Periodization of Residual Development Efforts

In the second step of this methodology, residual development efforts are identified based on the previously modeled uncertainties. For this step, structural models are presented below, which allow the systematic identification of RDEs based on modeled uncertainties. The structural models offer the user a first point of reference for assistance and must be adapted to the considered manufacturing task. Subsequently, the identified residual development efforts are prioritized.

5.2.1 Identification of Residual Development Efforts

To identify RDEs, a fundamental distinction is made between product- and technology-driven uncertainties. Both structural models (product and technology) are analogous to a tree structure. The first level represents uncertainty classes to which the present uncertainties are assigned. Uncertainty classes based on product uncertainties are, for example, uncertainties regarding functionality fulfillment or geometric uncertainties. Regarding the use case, product uncertainty classes are differentiated into mechanical, hydraulic, pneumatic, electrical and magnetic, optical-physical, medical-biological, acoustic, optical-physical [22] and tribological [23] functionalities as well as geometrical uncertainties. Examples for classes of technology uncertainties are uncertain manufacturability, uncertain handling and uncertain process design (see Fig. 4).

The uncertainty classes are subdivided into subgroups (uncertain elementary function) on a second level, if possible. An elementary function is the smallest unit of a

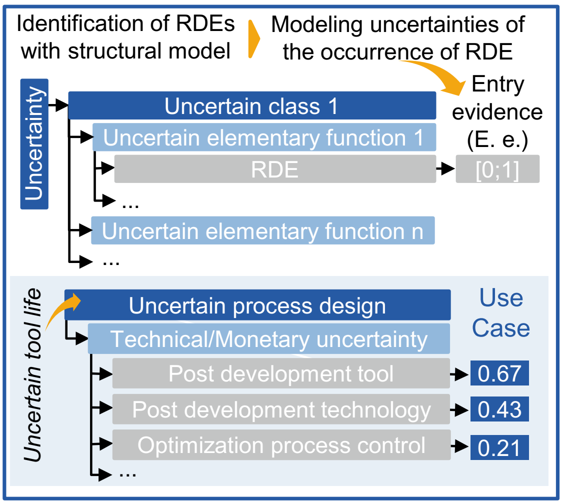


Fig. 4 Structural models for the identification of RDEs