62nd General Assembly of CIRP
62ème Assemblée Générale du CIRP
62. Mitgliederversammlung des CIRP

Hong Kong, P.R. China – August 19–25, 2012
Table of Contents

Session on Life Cycle Engineering and Assembly (A)

A1 - Production of large-area lithium-ion cells – Preconditioning, cell stacking and quality assurance
J. Kurfer, M. Westermeier, C. Tammer, G. Reinhart (1) ........................................... 1

A2 - Process development for the assembly of microsystems with hot melt adhesives
A. Raatz, S. Rathmann, J. Hesselbach (2) ................................................................. 5

A3 - Force generation during friction stir welding of AA2024-T3
D. Trimble, J. Monaghan, G.E. O'Donnell / J. Jedrzejewski (1) ............................. 9

A4 - The influence of spot weld position variation on geometrical quality
R. Söderberg (2), K. Wärmefjord, L. Lindkvist, R. Berlin ..................................... 13

A5 - Determination of extended availability and productivity for assembly systems using existing database
M. Putz (3), T. Langer / A. Fischer (1) ............................................................... 17

A6 - Reconfiguration management of remanufactured products for responding to varied user needs
T. Sakai, S. Takata (1) ................................................................. 21

A7 - Investigation of a multiple trigger active disassembly element
H.-C. Zhang (1), J. Carrell, S. Wang, D. Tate, S. Imam ........................................... 27

A8 - Hollow structure snap-fit design embedded with shape memory polymer sheet
H. Li, K. Jin, B. He, Y. Chen / R. Teti (1) ......................................................... 31

A9 - A novel separation process for recycling of post-consumer products
M.J. Lee, S. Rahimifard (2) ................................................................................. 35

A10 - A three dimensional system approach for environmentally sustainable manufacturing
C. Yuan, G. Zhai, D. Dornfeld (1) ................................................................. 39

A11 - Development of an energy consumption monitoring procedure for machine tools
T. Behrendt, A. Zein, S. Min (2) ................................................................. 43

A12 - Contribution to the environmental performance of the dry-vibratory drilling technology
H. Paris (2), M. Museau ................................................................................. 47

A13 - A value based evaluation method for Product/Service System using design information
T. Sakao, M. Lindahl / J.G. Persson (1) ......................................................... 51

A14 - Impact of green machining strategies on achieved surface quality
M. Helu, B. Behmann, H. Meier, D. Dornfeld (1), G. Lanza (2), V. Schulze ............................... 55

A15 - Eco-efficiency of manufacturing processes: A grinding case
W. Li, M. Winter, S. Kara (1), C. Herrmann ................................................ 59

A16 - Critical comparison of methods to determine the energy input for discrete manufacturing processes
J.R. Dufloc (2), K. Kellens, Renaldl, Y. Guo, W. Dewulf ..................................... 63

A17 - Quantifying the water inventory of machining processes
F. Zhao, J. Ogaldez, J.W. Sutherland (1) ......................................................... 67

Session on Cutting (C)

C1 - A new 3D multiphase FE model for micro cutting ferritic-pearlitic carbon steels
M. Abouridouane, F. Klocke (1), D. Lung, O. Adams ............................................. 71

C2 - Acoustic emission for controlling drill position in fiber-reinforced plastic and metal stacks

C3 - Ultra-precision cryogenic machining of viscoelastic polymers
Y. Kakinuma, S. Kidani, T. Aoyama (1) ......................................................... 79
Session on Design (Dn)

Dn1 - Abductive reasoning for design synthesis
S.C.-Y. Lu (1), A. Liu ........................................... 143

Dn2 - Semantic-based taxonomy for immersive product design using VR techniques
S. Makris, L. Rentzos, G. Pintzos, D. Mavrikios, G. Chryssolouris (1) .......................... 147

Dn3 - Improving design for recycling: Application to composites
N. Perry, A. Bernard (1), F. Laroche, S. Pompidou ....... 151

Dn4 - Designs that surpass imagination are born from discomfort outside the knowledge domain
M. Nakao (2), S. Nakagawa, K. Iino .................................. 155

Dn5 - An integrated computational support for design of system architecture and service
H. Komoto, N. Mashima, T. Tomiyama (1) ..................... 159

Dn6 - Integration of manufacturing-induced properties in product design

Dn7 - A dynamic feature information model for integrated manufacturing planning and optimization
Y. Li, X. Liu, J.X. Gao, P.G. Maropoulos (1) .............. 167

Dn8 - Encourage non-designer's design: Continuous value creation in manufacturing products and services
T. Hara, T. Arai (1) ........................................... 171

Dn9 - LC-CAD: A CAD system for life cycle design
Y. Umeda (2), S. Fujishige, E. Kunii, Y. Matsuyama .................................................. 175

Dn10 - Methods and tools that support a fast and efficient design-to-order process for parameterized product families
P. Schönsleben (2) ........................................... 179

Session on Electro-Physical & Chemical Processes (E)

E1 - Electrical discharge dressing and its influence on metal bonded diamond wheels
E. Weingärtner, R. Roth, F. Kuster (3), M. Boccadoro (3), F. Fiebelkorn / G. Levy (1) .......... 183

E2 - Comparison of energy and removal efficiencies between micro and macro EDM
M. Zahiruddin, M. Kunioka (1) ................................ 187

E3 - Enhanced surface integrity and dimensional accuracy by simultaneous micro-ED/EC milling
M.D. Nguyen, M. Rahman (1), Y.S. Wong .................. 191
E4 - Enhancement of mass transport in micro wire electrochemical machining
Y.-B. Zeng, C. Yu, S.-H. Wang, D. Zhu (1) 195

E5 - Machining of turbulated cooling channel holes in turbine blades
J. Pattavantich, S. Hinduja (1) 199

E6 - On the relationship between the dynamics of the power density and workpiece surface texture in pulsed laser ablation
M.C. Kong, C.B. Miron, D.A. Axinte (2), S. Davies, J. Kell 203

E7 - Process investigations of optical trap assisted direct-write microsphere near-field nanostructuring
K.-H. Leitz, U. Quentin, I. Alexeev, M. Schmidt (3) / L. Li (1) 207

E8 - Density improvement of alumina parts produced through selective laser sintering of alumina-polyamide composite powder
J. Deckers, J.-P. Kruth (1), K. Shahzad, J. Vliegerts 211

E9 - Laser patterning of thin film sensors on 3-D surfaces

E10 - Submicrometer thickness layer fabrication for layer-by-layer microstereolithography using evanescent light
S. Takahashi (2), Y. Kajihara, K. Takamasa 219

E11 - Freeze-form extrusion fabrication of functionally graded materials

E12 - Prediction of tool wear in micro USM
Z. Yu (2), C. Ma, C. An, J. Li, D. Guo 227

Session on Forming (F)

F1 - On the die design in AA6082 porthole extrusion
F. Gagliani, G. Ambrogio, L. Filice (2) 231

F2 - Multi billet extrusion technology for manufacturing bi-layered components
L. Madej (2), H. Paul, L. Trebacl, W. Wajda, M. Pietrzyk (1) 235

F3 - High quality extrudates from aluminum chips by new billet compaction and deformation routes
W.Z. Misiolek, M. Haase, N. Ben Khalifa, A.A. Tchekov (1), M. Kleinoir (1) 230

F4 - On the gas pressure forming of aluminium foam sandwich panels: Experiments and numerical simulations
H. Nassar, M. Albakri, H. Pan, M. Khraisheh (2) 243

F5 - Sheet forming process of carbon fiber reinforced plastics for lightweight parts
J. Yanagimoto (2), K. Ikeuchi 247

F6 - Accumulative-DSIF strategy for enhancing process capabilities in incremental forming
R. Mahotra, J. Cao (2), M. Beltran, D. Xu, J. Magargee, V. Kirdena, Z.C. Xia 251

F7 - Punching of small hole of de-quenched steel sheets using local resistance heating
K.-i. Mori (1), T. Maeno, Y. Maruo 255

F8 - Failure prediction for nonlinear strain paths in sheet metal forming
W. Volk, H. Hoffmann (2), J. Suh, J. Kim 259

F9 - Orbital forming of tailored blanks from sheet metal
M. Merklein (2), R. Plettke, S. Opel 263

F10 - Finite element analysis of the ring rolling process with integrated closed-loop control
V. Jenkouk, G. Hirt (2), M. Franzke, T. Zhang 267

F11 - Analysis of fluid lubrication mechanisms in metal forming at mesoscopic scale
L. Dubar, C. Hubert, P. Christiansen, N. Bay (1), A. Dubois 271

F12 - Cold joining of rotor shafts with whine by using plastic deformation
K. Kitamura, K. Hirot, Y. Ukai, K. Matsumaga, K. Osakada (1) 275

Session on Abrasive Process (G)

G1 - Dressing and truing of hybrid bonded CBN grinding tools using a short-pulsed fibre laser
C. Walter, M. Rabiey, M. Warhanek, N. Jochum, K. Wegener (3) / R. Züst (1) 279

G2 - Precision grinding of structured ceramic molds by diamond wheel true with alloy metal
H. Suzuki (2), M. Okada, Y. Yamagata, S. Morita, T. Higuchi 283

G3 - Development of fixed-abrasive tool with spiral groove for decreasing the loading
K. Tsuchiya, Y. Kamimura, Y. Tani, S. Lee / T. Matsuo (1) 287

G4 - Continuous generating grinding—Tooth root machining and use of CBN-tools
J. Köhler, A. Schindler, S. Woiwode / A. Ber (1) 291

G5 - Grinding performance and workpiece integrity when superabrasive edge routing carbon fibre reinforced plastic (CFRP) composites
G6 - Abrasive points for drill grinding of carbon fibre reinforced thermoset
D. Biermann (2), M. Feldhoff ........................................ 299

G7 - Dual mode control of the rotational grinding process
E. Ahearne (2), D. Logan, G. Byrne (1) ..................... 303

G8 - Prediction of bone grinding temperature in skull base neurosurgery
A.J. Shih, B.L. Tai, L. Zhang, S. Sullivan, S. Malkin .................. 307

G9 - Magnetic abrasive finishing of cutting tools for machining of titanium alloys
H. Yamaguchi, A.K. Srivastava (3), M.A. Tan, R.E. Riveros, F. Hashimoto (1) ...................... 311

G10 - Dynamic multiphase modeling and optimization of fluid jet polishing process
A. Beaucamp, Y. Namba, R. Freeman / J. Bryan (1) .................. 315

G11 - Macroscopic simulation of the honing process
B. Goeldel, M. El Mansori, D. Dumur (1) ...................... 319

G12 - Prevention of wheel clogging in creep feed grinding by efficient tool cleaning
C. Heinzel (2), G. Antsupov ...................................... 323

G13 - Study of tribo-chemical lubricant film formation during application of nano-lubricants in minimum quantity lubrication (MQL) grinding
P. Kalita, A.P. Malshe (2), K.P. Rajurkar (1) .................. 327

Session on Machines (M)

M1 - A novel tool path/posture optimization concept to avoid chatter vibration in machining – Proposed concept and its verification in turning
E. Shamoto (2), S. Fujimaki, B. Sonoo, N. Suzuki, T. Kato, R. Hino ......................................................... 331

M2 - Contour error control of CNC machine tools with vibration avoidance
Y. Altintas (1), M.R. Khoshdarregi .................................. 335

M3 - Prediction of workpiece dynamics and its effects on chatter stability in milling
E. Budak (1), L.T. Tunc, S. Alan, H.N. Özbudun .............. 339

M4 - Investigation of spindle bearing preload on dynamics and stability limit in milling
E. Ozturk, U. Kumar, S. Turner, T. Schmitz / M.A. Davles (1) ............................................................... 343

M5 - Design and control-concept for compliant machine tools based on controlled integrated models
E. Uhlmann (1), J. Eßmann, J.-H. Wintering ...................... 347

M6 - Improvement of feed drive dynamics by means of semi-active damping
A. Verl (2), S. Frey ................................................. 351

M7 - Integrated autonomous monitoring of ball screw drives
H.-C. Möhring, O. Bertram / B. Denkena (1) .............. 355

M8 - 6D direct-drive technology for planar motion stages
X. Lu, I.-u.-r. Usman / W. Tyler Estler (1) .................. 359

M9 - A newly developed ripple-free precision toroidal type motor
H. Yoshioka, Y. Kurisaki, H. Sawano, H. Shinno (1) ............. 363

M10 - Real-time monitoring of pressure distribution in microrolling through embedded capacitive sensing
Z. Fan, M.-K. Ng, R.X. Gao (2), J. Cao (2), E.F. Smith III ............................................................... 367

M11 - Ultra-precision finishing of micro-aspheric mold using a magnetostrictive vibrating polisher
J. Guo, S.-y. Morita, M. Hara, Y. Yamagata, T. Higuchi / T. Hoshi (1) .................................................. 371

M12 - Mechanism of surface modification using machine hammer peening technology
F. Breich, C. Lechner, C. Habersohn, E. Kozeschnik, B. Adjasscho, H. Kaminski / G. Pritschow (1) .................. 375

M13 - Sacrificial structure preforms for thin part machining
S. Smith (1), R. Wilhelm (2), B. Dutterer, H. Cherukuri, G. Goel .......................................................... 379

M14 - Raw part characterisation and automated alignment by means of a photogrammetric approach
M. Zatarain (1), A. Mendikute, I. Inziarte ....................... 383

Session on Production Systems and Organizations (O)

O1 - A risk management-based approach for inventory planning of engineering-to-order production
A.M. Radke, M.M. Tseng (1) ......................................... 387

O2 - Categorization and mechanism of platform-type product-service systems in manufacturing
N. Nishinc, S. Wang, N. Tsuji, K. Kageyama, K. Ueda (1) ................................................................. 391

O3 - Integrated capacity planning over highly volatile horizons
G. Lanza (2), S. Peters ............................................. 395

O4 - Method for energy and resource balancing demonstrated as an example of the hot sheet metal production process
A. Göschel (3), F. Schlieck, J. Schönblatt / R. Neugebauer (1) ............................................................... 399

O5 - Simulation based comparison of safety-stocking calculation methods
M. Schmidt, W. Hartmann, P. Nyhuis (2) .................. 403
O6 - Versatile autonomous transportation vehicle for highly flexible use in industrial applications
J. Franke, F. Lütteke / K. Feldmann (1) .......................... 407

O7 - Decision support systems for effective maintenance operations
J. Ni, X. Jin / Y. Koren (1) ........................................... 411

O8 - A method for determining a functional unit to measure environmental performance in manufacturing systems
J. Plehn, R. Züst (1), F. Kimura (1), A. Sproedt, P. Schönfelden (2) .................................................. 415

O9 - Using probabilistic relational models for knowledge representation of production systems: A new approach to assessing maintenance strategies
B. Jung (2), G. Medina-Oliva, P. Weber, E. Levrat .......................................................... 419

O10 - Discovering autonomous structures within complex networks of work systems
R. Vrabič, D. Huseinagic, P. Butala (2) ........................................ 423

O11 - A multi-criteria evaluation of centralized and decentralized production networks in a highly customer-driven environment
D. Mourtzis (2), M. Doukas, F. Psarommatis ........................................... 427

O12 - Cost innovations by integrative product and production development
A. Kampker, G. Schuh (1), P. Burggraf, C. Nowecki, M. Swist .................................................. 431

O13 - Modeling of machine tools using smart interlocking software blocks
A. Nassehi, S.T. Newman (2) ........................................... 435

O14 - Design and assessment of control loops for stable business processes
R. Schmitt (2), L. Monostori (1), H. Glöckner, Z.J. Viharos .................................................. 439

O15 - Combination of planning methods in a comprehensive production planning approach for sequenced production lines
K. Matyas, S. Auer / H.-J. Warnecke (1) ........................................... 445

O16 - Scheduling with alternative routings in CNC workshops
Y. Nonaka (3), G. Erdös, T. Kis, T. Nakano (3), J. Vánca (1) ........................................... 449

O17 - Integrated quality, production logistics and maintenance analysis of multi-stage asynchronous manufacturing systems with degrading machines
M. Colledani, T. Tolo (1) ........................................... 455

O18 - Energy-aware scheduling for improving manufacturing process sustainability: A mathematical model for flexible flow shops
A.A. Gruzzzone (1), D. Anghinolfi, M. Paolucci, F. Tonelli ............................................... 459

O19 - Integrating sustainability within the factory planning process
D. Chen, S. Heyer, G. Seliger (1), T. Kjellberg (1) ........................................... 463

O20 - A proposal on optimized scheduling methodology and its application to an actual-scale semiconductor manufacturing problem
T. Kihara (2), S. Kurose, N. Fujii ........................................... 467

Session on Precision Engineering and Metrology (P)

P1 - A noncontact scanning electrostatic force microscope for surface profile measurement
W. Gao (2), S. Goto, K. Hosobuchi, S. Ito, Y. Shimizu .................................................. 471

P2 - Improvements and experimental validation of a 3D-probing system for micro-components
T. Liebrich, W. Knapp (1) .................................................. 475

P3 - Dimensional measurement of micromoulding components using a high-aspect ratio high-quality control system
Y. Takaya (2), M. Michihata, T. Hayashi, T. Washitani .................................................. 479

P4 - Optical measurement for the estimation of contact pressure and stress
J. Solle, A.-M. Linares (2), I.-M. Sprael, E. Mermoz (3) .................................................. 483

P5 - Universal high precision reference spheres for multisensor coordinate measuring machines
C.P. Keferstein (3), M. Marxer, R. Götti, R. Thalmann, T. Jordi, M. Andrä, J. Becker / L. de Chiffre (1) .................................................. 487

P6 - Accuracy of industrial computed tomography measurements: Experimental results from an international comparison
S. Carmignato / L. De Chiffre (1) .................................................. 491

P7 - Sense and non-sense of beam hardening correction in CT metrology
W. Dewulf, Y. Tan, K. Kiekens / P. Vanherck (1) .................................................. 495

P8 - Three-dimensional holistic approximation of measured points combined with an automatic separation algorithm
K. Lübke, Z. Sun, G. Goch (1) .................................................. 499

P9 - A methodology for the quantification of value-adding by manufacturing technology
E. Savio (2) .................................................. 503

P10 - Integrating the continuous improvement of measurement systems into the statistical quality control of manufacturing processes: A novel link
M. Villeta, E.M. Rubio (3), J.L. Valencia, M.A. Sebastián (3) / R. Bueno (1) .................................................. 507

P11 - Nano fabrication of star structures for precision metrology developed by focused ion beam direct writing
Z. Xu, F. Fang (1), H. Gao, Y. Zhu, W. Wu, A. Weckenmann (1) .................................................. 511
P12 - Five-axis machine tool calibration by probing a scale enriched reconfigurable uncalibrated master balls artefact
J.R.R. Mayer / M. Balazinski (1) ............................................. 515

P13 - Machining of optical freeform prisms by rotating tools turning
X. Zhang, H. Gao, Y. Guo, G.X. Zhang (1) ......................... 519

P14 - Multivariate sensing and wireless data communication for process monitoring in RF-shielded environment
R.X. Gao (2), D.O. Kazmer .................................................. 523

Session on Surfaces (S)

S1 - Generalized form characterization of ultra-precision freeform surfaces
C.F. Cheung, L. Kong, M. Ren, D. Whitehouse (1), S. To ................................................................. 527

S2 - Automated surface inspection of cold-formed micro-parts
B. Scholz-Reiter (1), D. Weimer, H. Thamer ....................... 531

S3 - Surface wear of TiN coated nickel tool during the injection moulding of polymer micro Fresnel lenses
G. Tosello (2), H.N. Hansen (1), S. Gasparin, J.A. Albajez, J.I. Esmoris ........................................... 535

S4 - Influence of rapid mold temperature variation on surface topography replication and appearance of injection-molded parts
G. Lucchetta, M. Fiorotto, P.F. Bariani (1) ......................... 539

S5 - Cryogenic deep rolling – An energy based approach for enhanced cold surface hardening
D. Mayer / E. Brinksmeyer (1) ........................................... 543

S6 - Prediction of machining induced residual stresses in turning of titanium and nickel based alloys with experiments and finite element simulations
T. Özal (2), D. Uluslan ......................................................... 547

S7 - Evaluation of process causes and influences of residual stress on gear distortion
R. Husson, J.-Y. Dantan (2), C. Baudouin, S. Silvani (3), T. Scheer, R. Bigot ........................................... 551

S8 - The influence of process vibrations on precision polishing metrics
B. Mullany (3), M. Mainuddin / C. Evans (1) ...................... 555

S9 - Alternative strategies in finishing cylinder running surfaces
B. Karpuschewski (1), H.-J. Pieper, F. Welzel, K. Risser ............................................................... 559

S10 - Manufacture of functional surfaces through combined application of tool manufacturing processes and Robot Assisted Polishing
R.S. Eriksen, M. Arendt (2), J. Grønbæk, N. Bay (1) .......................................................... 563

S11 - A study on the quality of micro-machined surfaces on tungsten carbide generated by PCD micro end-milling
K. Nakamoto, K. Katahira, H. Ohmori (2), K. Yamazaki (1), T. Aoyama (1) ........................................... 567

S12 - Highly wear-resistant cutting tools with textured surfaces in steel cutting
T. Enomoto (2), T. Sugihara, S. Yukinaga, K. Hirose, U. Satake ......................................................... 571

S13 - Laser-assisted nano particle deposition system and its application for dye sensitized solar cell fabrication

S14 - Influence of surface properties on bioactivity and pull-out torque in cold thread rolled Ti rod—Development of bioactive metal-forming technology
Y. Yoshida, K. Kuroda, R. Ichino, N. Hayashi, N. Ogihara, Y. Nonaka / Y. Tozawa (1) ........................................... 579

S15 - Significant improvement of corrosion resistance of biodegradable metallic implants processed by laser shock peening
Y. Guo, M.P. Sealy, C. Guo (2) ........................................... 583
Combination of planning methods in a comprehensive production planning approach for sequenced production lines

Kurt Matyas a,*, Stefan Auer b

a Institute of Management Science, Vienna University of Technology, Theresienstraße 27, 1040 Vienna, Austria
b Fraunhofer Austria Research GmbH, Division of Production and Logistics Management, Theresienstrasse 7, 1040 Vienna, Austria

Submitted by: Hans-Juergen Warnecke (1) Stuttgart, Germany

1. Introduction

In the European automotive and mechanical engineering industry an effective management of order processing, in particular regarding data processing and information exchange will be an increasing success factor [1]. In these industrial sectors various systems for sales planning, purchasing, production and supply chain management are employed, which are often poorly synchronized or even incompatible [2].

That entails, it is common to plan the different steps in a chain sequentially while at the same time, in the whole planning process, a broad variety of types and combinations of options have to be considered. One of the planning requirements is a high accuracy concerning i.e. workstations, human resources and material. Currently planning, especially in the automotive sector, but in different industries as well, is conducted in cascades. This poses the problem of a lack of coordination and feedback between the planning steps, which may cause contradictions in the production programs. As a result, short-term troubleshooting has to take place and additional or different resources must be procured [2].

The aim of this paper is to describe a method of achieving a harmonized planning process for sequenced production lines through the combination of planning methods and the timely consideration of constraints of a cascading planning. The solution presented herein represents a tool with which different domains can communicate with each other. The tracking of bottlenecks and timely detection of problems will be ensured, enabling a proper reaction.

Therefore Section 2 summarizes the relevant planning processes for order driven production in sequenced production lines. The gap of existing solutions and the reason for the development of the method are depicted. In Section 3 the principles of existing solving algorithms are described and possibilities of an integration of sequencing rules in program planning are shown. Section 4 describes how the planning processes and the combination of program planning and sequencing steps will be executed. Section 5 summarizes the results and gives an outlook to further activities.

2. Planning process for sequenced production lines

In customer order driven production processes the key target of planning is to align market requirements with available production factors. Production restrictions in long- and mid-term planning are fixed and production factors are limited according to context-related restrictions [3].

In Fig. 1 a planning cascade of a synchronized production line is described, where several production factors have to be taken into account on different levels of aggregation [4]. Depending on the planning horizon, the planning process starts from rough estimations and ends with the manufacturing or the assembly process. Tasks and restrictions have to be adjusted to avoid conflicts such as bottlenecks or under-utilization of the production factors.

The planning process starts with a market analysis. After that follows an annual budget planning that results in sales forecasts, which are continuously updated. This step is succeeded by the generation of a rough production plan allocating, for example, production orders to order pools. Finally in the short term planning horizon a detailed order sequence has to be defined.

The planning gradually gets more detailed with each step. For example, in the very beginning (program planning) dummy orders are assumed, based on various sales prognosis etc. gradually being replaced by real orders, the further the planning proceeds [5]. Simultaneously, the constraints for the planning process become tighter with the production date approaching.

The development of an integrated planning approach as the basis of a software tool that harmonizes the planning tasks over the different planning horizons is subject of an ongoing research project called HarnoPlan. This paper presents the application of the new developed integrated planning approach that is based on a
classification of the origins of planning constraints. The resulting software tool is to bridge the usually employed planning cascade.

This can be achieved by shifting later occurring constraints to an earlier planning stage. Therefore, the so called Constraint Manager is required. This newly developed tool combines necessary constraints in a standardized format and even enables tracing the originator of each of these constraints. The application of filters winnows irrelevant constraints, leaving the focus on the important ones. The constraint Manager even indicates the necessity for preplanning by searching for a reason as soon as a constraint is ignored or exceeded [3].

3. Solving algorithms

In the following, typical algorithms and solving solutions are presented, which are used for dealing with problems in program planning and sequencing. After that a possibility to draw restrictions from sequencing to the earlier stages of program planning is introduced. This systematic approach simplifies the basic approach to the planning problem. Subsequently, the paper focuses on the description of how the single planning tasks in the planning system have to be integrated to be used operatively. That means how the restrictions have to be defined so that they can be executed in both planning problems.

3.1. Program planning

Usually, short-, mid- and long-term production planning are being distinguished in planning. While long- and mid-term planning most notably are determined in a qualitative way, the short term planning determines the production program quantitatively (quantity per time).

In the relevant literature several approaches and algorithms for the planning tasks can be found. The following basic mixed-integer programming model for master scheduling, suggested by Boysen et al. [6] is proposed to minimize deviation costs.

The objective function (1) considers deviation costs for all orders assigned to period $t (x_t \neq 1)$. The variables in the equation are the number of product orders $N$ and the planning periods $T (t = 1, \ldots, T)$.

Minimize $z = \sum_{t=1}^{T} \sum_{i=1}^{N} c_{iP} x_{tP}$

(1)

$\sum_{t=1}^{T} x_{iP} = 1 \quad \forall i = 1, \ldots, N$

(2)

$\sum_{t=1}^{T} x_{iP} \leq P \quad \forall t = 1, \ldots, T$

(3)

Eq. (3) simply states, that a limited amount of production period $P$ must not be exceeded.

First, $B_{iq}$ from Eq. (4) deals with the availability of components. It stands for the number of available components which states a maximum. The coefficient of demand $d_{iq}$ states, that if a certain component is a part of an order, it can either be 0 or bigger. $Q$ stands for the sum of all relevant components of a product whilst $i$ is one specific component [6].

$\sum_{t=1}^{T} b_{iq} \times x_{iP} \leq B_{iq} \quad \forall q \in Q; t = 1, \ldots, T$

(4)

$x_{iP} \in \{0, 1\} \quad \forall i = 1, \ldots, N; \; t = 1, \ldots, T$

(5)

3.2. Sequencing

For solving the sequencing problem, three different solutions are described in the literature.

Level scheduling - based on the principles of the Toyota-Production-System - is a method that aims to achieve a smooth distribution of the material demand [7]. Another sequencing method is the so called mixed-model sequencing that reduces overloads of resources in the system. In an exact schedule of each type and station, under consideration of the type specific work content, is calculated [8-12].

Within the research project HarmoPlan a constraint programming approach for the car sequencing problem is used. The restrictions for the car sequencing are on the one side that an order is connected to a certain type $v (v = 1, \ldots, V)$ in the cycle $t (t = 1, \ldots, T)$ which is expressed by $x_{vt}$ and can take the value 0 or 1. On the other side it has to be assured, that in each cycle exactly one option is being produced. If a constraint is added, that assures, that only one type $v$ products in a series of $N_v$ products have the same option $o$, the result is a model for the sequential arrangement [13].

$\sum_{i=1}^{V} \sum_{o=1}^{V} x_{iPo} \times a_{io} \leq H_0 \quad \forall o = 1, \ldots, O; \; t = 1, \ldots, T - N_v + 1$

(6)

Here $a_{io}$ is the demand of option $o$ in type $v$. It has to be noted, that one type can have different options $o (o = 1, \ldots, O)$ [6].

3.3. Possibilities of an Integration of Sequencing rules in program planning

To integrate sequencing rules into the program planning, following condition is suggested as a basis for integrated planning [8]:

$\sum_{i=1}^{V} x_{iPo} \leq \alpha \times H_0 \times P \quad \forall o = 1, \ldots, T$

(7)

$d_{Po}$ is the demand factor; $\alpha = \text{scaling factor}$.

Eq. (7) however represents only a reasonable and not a necessary condition for a solvable sequencing problem. Nonetheless, the knowledge about the single approaches for the solution is just the first step for the development of a comprehensive production planning approach. It is essential to fill up these algorithms with suitable inputs such as defining capacity constraints as well as other planning restrictions.

4. Applicable comprehensive planning approach

This part describes how the planning processes and the combination of program planning and sequencing steps will be executed. Therefore the overall planning approach is presented. The most challenging task for the comprehensive planning approach is to make planning restrictions of one planning task available in the other planning tasks. This mapping of constraints is also described in the following part.

4.1. Planning approach

The overall goal of the research project HarmoPlan is to define and develop a planning system that supports comprehensive
planning throughout the different levels. This approach has to take into account shifting responsibilities and different levels of abstraction along the planning cascade (e.g., sales planning on the level of car volumes in order to meet market requirements, production planning is dealing with planning objects such as specific car configurations or bills of materials to optimally utilize production capacities). Due to the high complexity of the planning problem for a tool that covers all planning processes from long- to short-term planning, current systems do not integrate planning constraints throughout the whole planning cascade. Therefore the presented approach is meant to introduce a realizable solution to convert planning constraints for consideration in each planning task [4].

As every single planning step is dealing with various input data depending on the planning horizon, the planned quantities are presented as monthly, weekly and daily volumes or order pools in long- and mid-term or as order sequences in short-term planning.

In order to align the existing capacities with the customer requirements and to identify bottlenecks as early as possible, constraints of subsequent planning tasks need to be available for each planning step and in each required configuration. Therefore, the constraints caused by the earlier described originators are stored within the already developed so called constraint manager, a database that collects the constraints and stores them in a standardized format [3].

When a planning task has to be executed all relevant planning constraints can be taken into account.

Due to a higher number of constraints than in the original planning task it is possible that the planning problem is too complex and no solution fulfilling all constraints exists. Therefore the constraints have an attribute that classifies whether the constraint is “hard” or “soft”. First the used planning algorithms try to find a solution considering hard and soft constraints. If no solution can be derived, the planning problem is relaxed and only hard constraints will be considered. Planning constraints of following planning steps will usually be classified as soft constraints. In order to evaluate different planning results, each constraint owns an attribute that defines a penalty in case of a violation. More important constraints have a higher penalty rate than others.

After the execution of the planning task the planner has an overview of all violations. So, if a constraint cannot be fulfilled, the planner is able to identify the reason and can set possible countermeasures to widen the bottleneck – or to solve the problem by a re-planning, considering a different constraint setting. Fig. 2 shows the concept of the planning workflow that will be covered within one planning tool.

One task of the research project was to identify, which of the constraints should be available in other planning steps. During the project it turned out that if valid order pools are passed to the next planning step, constraints do not need to be considered again. If major changes are necessary the previous planning step has to be executed again.

4.2. Creation and handling of planning constraints

The following part about the creation and handling of constraints will focus on the combination of program planning and sequencing. The topic of the research project also covers the integration of sales planning. The procedure for integrating sales planning is analogous to the approach described within this paper.

The described classification of constraints in Fig. 2 gives an overview on possible restriction types. However, so far there is no categorization, on which restrictions have to be taken into account in which planning step.

Within the program planning capacity constraints are usually taken into account. On the one hand this can include capacity restrictions according to factory calendars, working hours and cycle times. On the other hand the part availability is important and also covered by capacity restrictions. In some cases also staff sizing problems can be included within the program planning algorithm [5].

There are also a high number of possible sequencing rules. In order to show how the conversion of constraints works, three constraint types are described in detail:

- **Distance constraint**: This constraint type defines a minimal or maximal distance for two vehicles with the same value (e.g., a vehicle with a sunroof cannot be followed by another vehicle with sun roof).
- **Block constraint**: Such constraints aim at building blocks of vehicles with special values within the sequence. This rule can be useful for planning a color sequence in the paint shop or to build blocks of vehicles where extra personnel is required on a special assembly station.
- **Distance constraints for different options**: define the distance of two vehicles in the assembly sequence with different values (e.g., a car with a sun roof cannot be followed by a convertible car).

Other sequencing rules can aim on an even distribution of options, can limit the amount of options per day or shift, or can define a sequence position for vehicles with a special option, etc.

For the definition of rules that have to be considered in both, program planning and sequencing, a whole bunch of attributes is crucial. A list and classification of those attributes is given in the following. This classification tries to describe the different types of rules is a uniform mode, so that they can be featured in a database. As listing all attributes would exceed this paper; only the above mentioned constraints are described herein. The research project however dealt with a far broader range of restrictions.

The database is structured in common attributes, sales planning attributes, program planning attributes and attributes concerning sequencing.

If a restriction is created, it is the restriction type has to be selected. With this choice, it is only necessary to enter attributes that are relevant for that certain type. Furthermore, the conversion logics are being activated and additional fields of the restriction are being complemented automatically.

- **General attributes**: These attributes are required for every constraint within the system and allow for an identification of the constraint. Typical attributes are name or constraint ID, textual description, constraint type, affected assembly plant, sales region, vehicle type, validity period and value.
- **Program planning attributes**: For the described capacity constraints, minimum and maximum values are required. Furthermore, a classification (hard or soft constraint) and a penalty for rule violation need to be defined.
- **Sequencing attributes**: For sequencing also minimum and maximum values, classification and penalty are necessary attributes. In order to fully specify the previously described constraints, also block length, block distance and a second value are compulsory attributes.