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Main Feature List as core success criteria of organizing Requirements Elicitation

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Innovation process and innovation output is positively affected by adequate reference models and supporting means. For this reason, a New V-Model for Engineering Mechatronic and Smart Systems is being worked out by the Technical Committee VDI GMA 4.10 "Interdisciplinary Product Creation". Thus, the directive VDI 2206 "Development methodology for mechatronic systems" from the year 2004 (VDI 2206 2004) is being revised and adapted to the actual trend towards digital transformation of technical systems, business models and ecosystems. The core of the guideline is the V-Model describing mechatronic engineering (VDI 2206 2004). One core success criterium of organizing Requirements Elicitation is the established main feature list first published by Pahl and Beitz (Pahl et al. 1996). Based on this, a new Main Feature List enhanced for the usage in requirements elicitation of mechatronic and smart products is proposed. This Enhanced Main Feature List comprises additional requirements such as sampling rate, bus system, big data usage and fosters result quality and efficiency of requirements elicitation. This was proven and validated by applying it to Inline spectral measurement systems in the printing industry. The proposed Enhanced Main Feature List establishes new fundamentals in research and theory.

1. Introduction and Motivation

Today's engineering applications are characterized by high interdisciplinarity, networking, complexity and heterogeneity. So-called Smart Systems network with each other and with the Internet of Things and Services (IoT) to flexibly adapt their system behaviour to changing boundary conditions, operational situations and user preferences. Furthermore, they detect and correct errors independently. For this, cross-disciplinary system architectures and a model-based engineering approach are needed. (Graessler 2017) Moreover, the technological change towards digitization and networking is enabling new Digital Business Models. Digital Business Models enrich the value proposition of material core products with additional data-based services. An example of this is the business model “Power by the Hour” by Rolls-Royce (new name: “Total Care”). While previously the purchase of aircraft engines, the maintenance and repair as well as the risk of default was borne by the airline, the airline now pays per hour of flight. By renting the thrust, the airline only pays for the actual engine power it calls and avoids consequential and downtime costs due to unscheduled maintenance. An important technological prerequisite for this is transmitting and processing mass data of engines during the flight. (Graessler 2018)

In order to meet these challenges, there is a need for new basic scientific methods that build the framework for innovation and engineering. Due to this need, the Technical Committee VDI GMA 4.10 (TC) “Interdisciplinary Product Creation” of the Association of German Engineers (VDI) was founded in March 2016. Its goal is to update the VDI Guideline 2206 which incorporates the V-Model for mechatronic engineering. In order to achieve excellent applicability of the New V-Model in industrial practice, the Technical Committee was constituted by as many industrial as academic members. As the academic part was represented by scientific employees working on their phD thesis and their instructing professors, fast results were incorporated by deep discussions (Graessler 2017). Present needs for revisions of the VDI 2206 guideline were deduced from analysis of the contemporary version of the V-Model (Graessler and Hentze 2015a), (Graessler et al. 2016) and a comparison with existing V-Model variants (Graessler and Hentze 2015b), (Graessler et al. 2018) and built up the basis for discussion in the TC VDI GMA 4.10. Moreover, experiences in applying the V-Model in industrial practice as well as present research areas were considered.

2. New V-Model for Engineering Smart Systems

Based on the identified need for revision (Graessler and Hentze 2015a), (Graessler and Hentze 2015b), (Graessler et al. 2016), (Graessler et al. 2018), an enhanced V-Model was proposed in (Graessler 2017) and (Graessler 2018). The current state of work was discussed and validated in a facilitated workshop held at the 15th International DESIGN Conference with 25 practitioners from industry and high-ranking researchers from academia. The aim of the workshop was to discover improvement potentials and further implications for the revision of VDI Guideline 2206. The resulting state of the New V-Model is illustrated in figure 1.

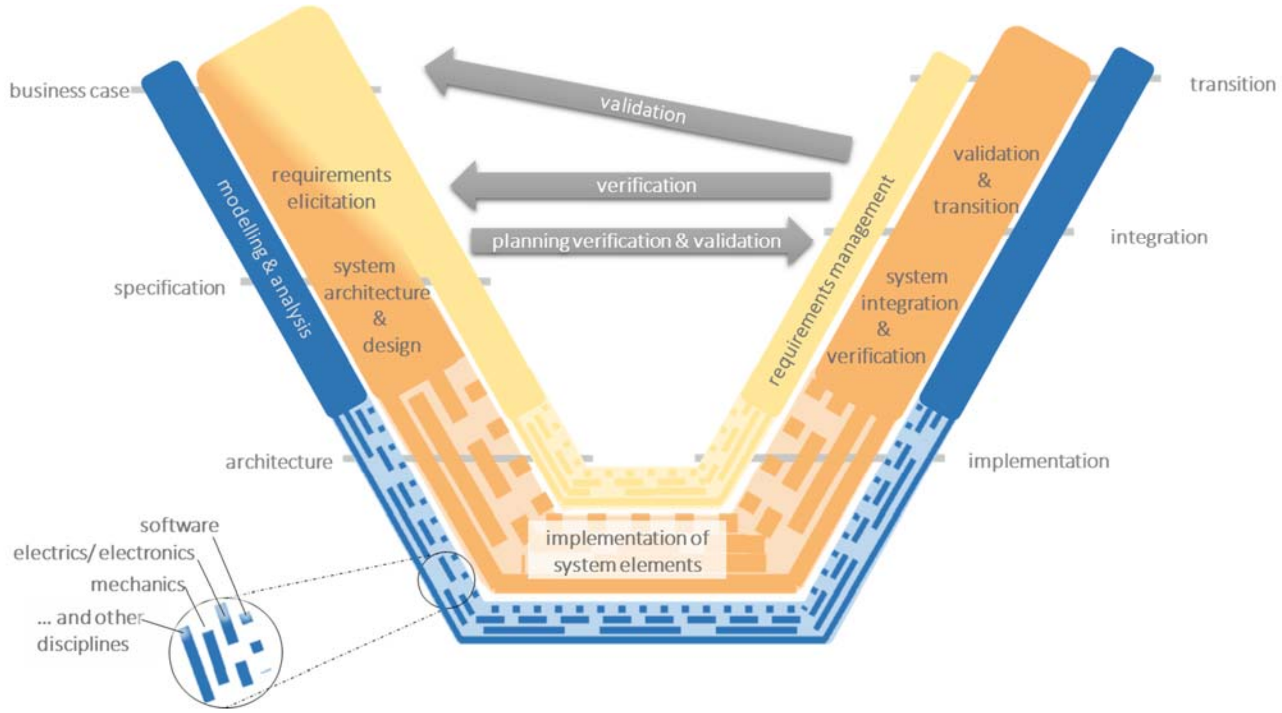


Figure 1. Validated New V-Model

The "V" lays the foundation in the logical sequence of tasks. From time to time, V-Models are misunderstood as sequence models and associated with a stepwise consecutive procedure. That is not correct. Instead, the "V" represents the inherent Concern Logic of tasks. It illustrates logical relationships between tasks without specifying the sequence of process steps. This emphasizes the content-related, factual networking of the tasks. Thus, the model is independent of the selected project organization.

In order to invent new value propositions, engineers must closely work together with sales and marketing people, as engineers are the ones who keep the knowledge of emerging cross-cutting product and production technologies. In addition, engineers must understand the way the user applies the product to gain impulses for product innovations. For this reason, upstream and downstream tasks have to be taken into account when applying the V-Model. Therefore, the New V-Model is coupled with the Holistic Product Life Cycle Model, which has been worked out by the VDI TC 702 "System House" and will be published soon in the VDI 2000 guideline (Figure 2). Within the HPLC Model, human beings are represented besides organizational approaches, information and communication technologies (ICT). Points of transfer are shaped by the checkpoint "business case" in upstream direction and the checkpoint "transition" to downstream realization/ producing, product usage and product end of life. Thus, engineers are provided with a clear orientation and enabled to act as drivers in the design of Digital Business Models.

In the V-Model version of 2004 (VDI 2206 2004), disciplines are limited to mechanics and electrics and information technology. In order to demonstrate that the new approach relates to interdisciplinary product creation, reference is made to the possibility of further disciplines, such as hydraulics, pneumatics or even production engineering.

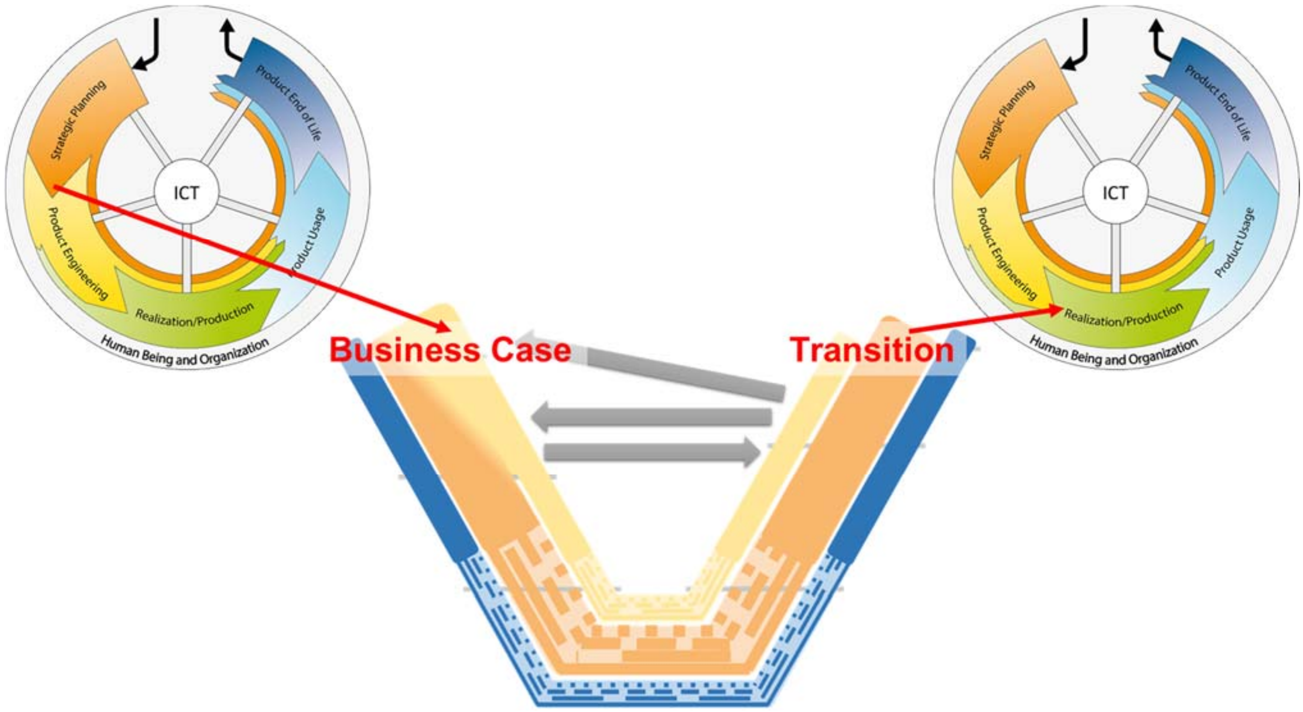


Figure 2. Coupling the New V-Model with Holistic Product Life Cycle Model [created by TC VDI 702]

The cross-disciplinary system architecture approach is represented within the left thigh of the "V". Here a cross-disciplinary overall solution structure is developed. The term "system architecture" refers to the cross-disciplinary overall solution structure and behaviour of a product. Based on the functional structure and the underlying principles of operation, the system architecture in a mechanical sense includes the building structure. In an electronic understanding, the system architecture comprises signal flow structures. From the perspective of software, the system architecture structures a program into its modules and components including the respective connection conditions. The system architecture thus embodies elements, relationships, necessary principles and the system behaviour for the design and development of a system (Walden et al. 2015).

A core revision aspect consists in representing a comprehensive modelling and analysis. In the VDI Guideline 2206 of the year 2004, graphical representation of modelling started only in the middle of the system concept and ran only up to the middle of integration and verification. This representation is corrected and replaced by a complete strand, which incidentally is also based on consistent product data modelling. Models are formed in order to be able to predict system properties during development and to use this as a reference for property verification and validation. Since models always represent a reduced image of reality, this underlines the need to fully understand the product's principles of action.

The arrows in the V-Model version of year 2004 give the impression that activities of property assurance only have to be performed on the right thigh of the "V". However, verification and validation have to be planned in advance. Requirements must be extracted and formulated verifiably. In addition, the established distinction between verification and validation is introduced and graphically represented in the New V-Model. This distinction already exists in various System Engineering approaches, e.g. (Walden et al. 2015).

The term Requirements Engineering summarizes requirements elicitation and requirements management. The exact collection, analysis and further processing of requirements forms a core success factor of development projects and product quality. Empirical studies show that this is one of the rout courses of project success. In order to raise this constantly into the consciousness of product engineers, in the New V-Model a separate strand with the inscription "requirements elicitation and management" is provided.

The New V-Model for Engineering Mechatronic and Smart Systems contains the Checkpoints "Business case", "Specification", "Architecture", "Implementation", "Integration" and "Transition". In contrast to milestones or gates known e.g. from the stage gate process [Cooper 2008], the defined checkpoints have no temporal reference. They are only defined by their contents in relation to the associated task in the V-Model. The Checkpoints contain all relevant artefacts related to the particular engineering task and serve as a checklist for reviews. Thus, they give hints for carrying out the engineering process. As an example, checkpoint "specification" is illustrated in Figure 3.

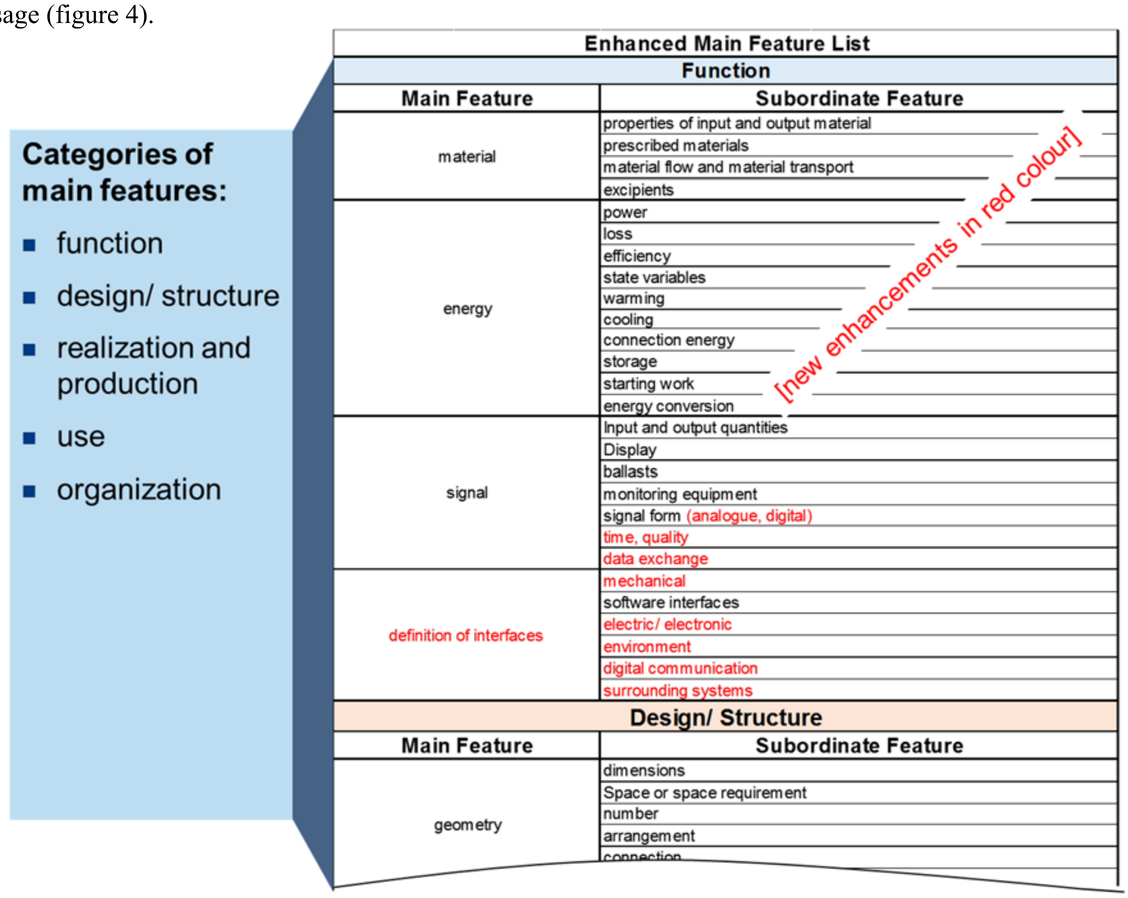
Specification

- Have all relevant requirements been derived from the Enhanced Main Feature List? Are all secondary features recorded or checked?
- Is the specification comprehensible, meaningful and clear?
- Is it solution-neutral?
- Are the requirements as independent among each other as possible?
- Does the specification have a structure?
- Are its contents sufficiently documented?
- Is there a possibility to make changes in the specification? Has a process been agreed for this?
- Can the specified requirements be verified?
- Are the required specifications realistic?
- Are the requirements clearly formulated and/ or measurable?
- Distinction between "shall" and "must" (wishes or optimization goals and demands)

Figure 3. Control Questions at the Checkpoint "Specification"

3. Main Feature List for Mechatronic and Smart Systems

One core success criterium of organizing requirements elicitation is the established Main Feature List first published by Pahl and Beitz (Pahl et al. 1996). This Main Feature List was enhanced for the usage in requirements elicitation of Mechatronic and Smart systems and now comprises additional requirements such as sampling rate, bus system and Big Data usage (figure 4).



Enhanced Main Feature List	
Function	
Main Feature	**Subordinate Feature**
material	properties of input and output material
	prescribed materials
	material flow and material transport
	excipients
energy	power
	loss
	efficiency
	state variables
	warming
	cooling
	connection energy
	storage
	starting work
	energy conversion
signal	Input and output quantities
	Display
	ballasts
	monitoring equipment
	signal form (analogue, digital)
	time, quality
	data exchange
definition of interfaces	mechanical
	software interfaces
	electric/ electronic
	environment
	digital communication
	surrounding systems
Design/ Structure	
Main Feature	**Subordinate Feature**
geometry	dimensions
	Space or space requirement
	number
	arrangement
	connection

Figure 4. Extract of Enhanced Main Feature List, based on (Pahl et al. 1996), with new enhancements in red colour

This list was proven and validated by applying it to several industrial sample products, e.g. inline spectral measurement in the printing industry (Chapters 4 and 5) and electronic devices such as inverters and actuators. The Enhanced Main Feature List is referenced by the Checkpoint "Specification" and thus ensures complete requirements elicitation related to the respective state of development. Thus, it fosters result quality and efficiency of requirements elicitation. The proposed Enhanced Main Feature List is of immense practical value in mastering the forthcoming changes due to digital transformation. Further, it establishes new fundamentals in mechatronic research and theory.

4. Industrial Case Study

Quality assurance in the web processing industry is particularly based on high dynamic mechatronic systems. Depending on the actual application, web speeds of up to 1000 m/min are possible. A running web at this speed cannot be monitored and controlled sufficiently with the bare eye. Therefore, e.g. the motive on a packaging-surface needs to be monitored during the printing process by utilizing high-speed cameras and accordingly powerful image analysis algorithms (BST eltromat 2018).

Exemplarily, faulty packages must be identified and discharged in downstream process steps, if a medication packaging shows "1 0g" as the maximum medication dose instead of "1.0g", due to an accidently not printed decimal point.

Furthermore, web guiding camera systems, embedded in image processing regulatory systems, ensure a stable run of a web through a production system by automated web edge detection (BST eltromat 2018). Related systems, including e.g. moisture and spectral colour measurement sensors, are mostly self-sufficient systems and generate huge amounts of data. Interlinking of these systems provides the highest benefit for customers due to extensive communication along the whole value chain (Dattner and Bohn 2017, 258-269).

With focus on packaging-printing in the paper and foil processing industry (cf. figure 5), the inline spectral colour measurement system is described representatively for a great number of mechatronic systems in this context of application solutions. Due to the upcoming increase in digitization, the need for communication interfaces and data analysis becomes more and more relevant. Especially the holistic approach concerning system interfaces, currently considering also more explicit software related aspects, shows the need for using the updated V-model and the new Main Feature List for developing Smart Systems like this.

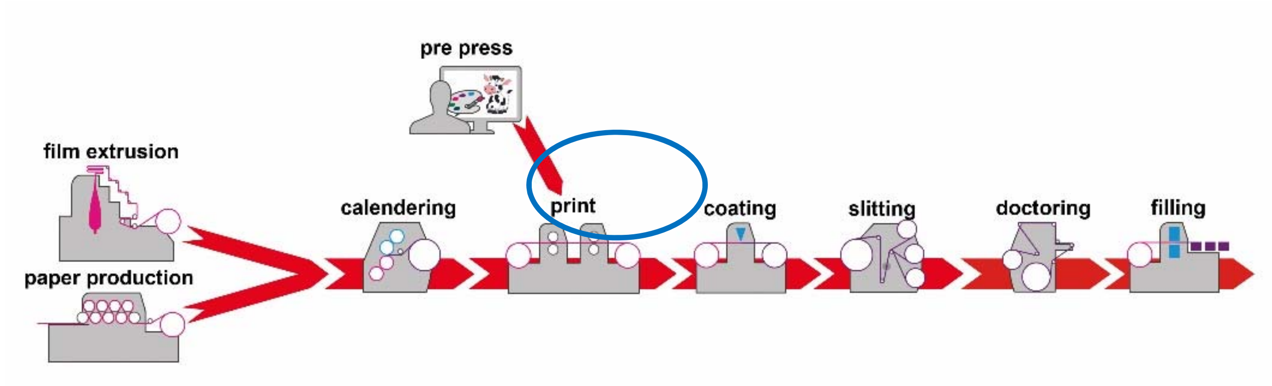


Figure 5. The value chain "packaging" (Dattner and Bohn 2017, pp. 258-269)

Figure 6 shows a printing press concept, where unprinted paper is printed with the desired design image by applicating colour out of 8 ink decks subsequent before rewinding again the printed result at the end of the printing machine.

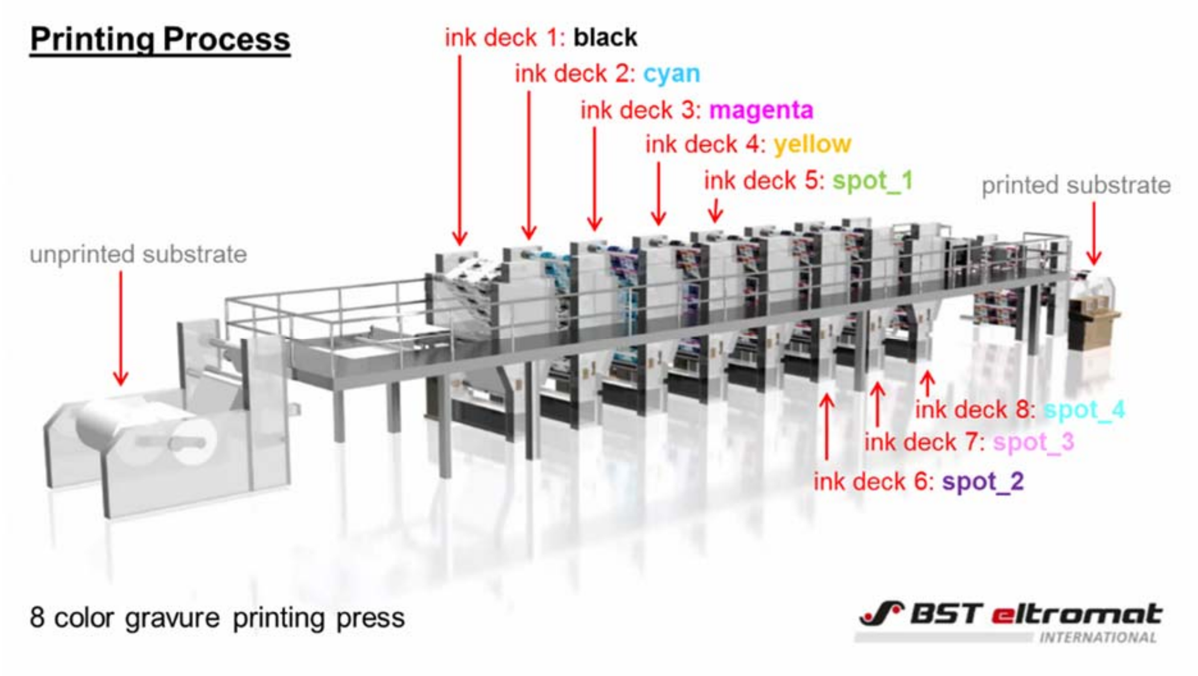


Figure 6. Eight colour gravure printing press

Figure 7 shows a typical sub set of quality assurance systems that are integrated in a (flexographic) printing machine, to ensure a reliable production process with a quality protocol included for subsequent process steps in the packaging value chain.

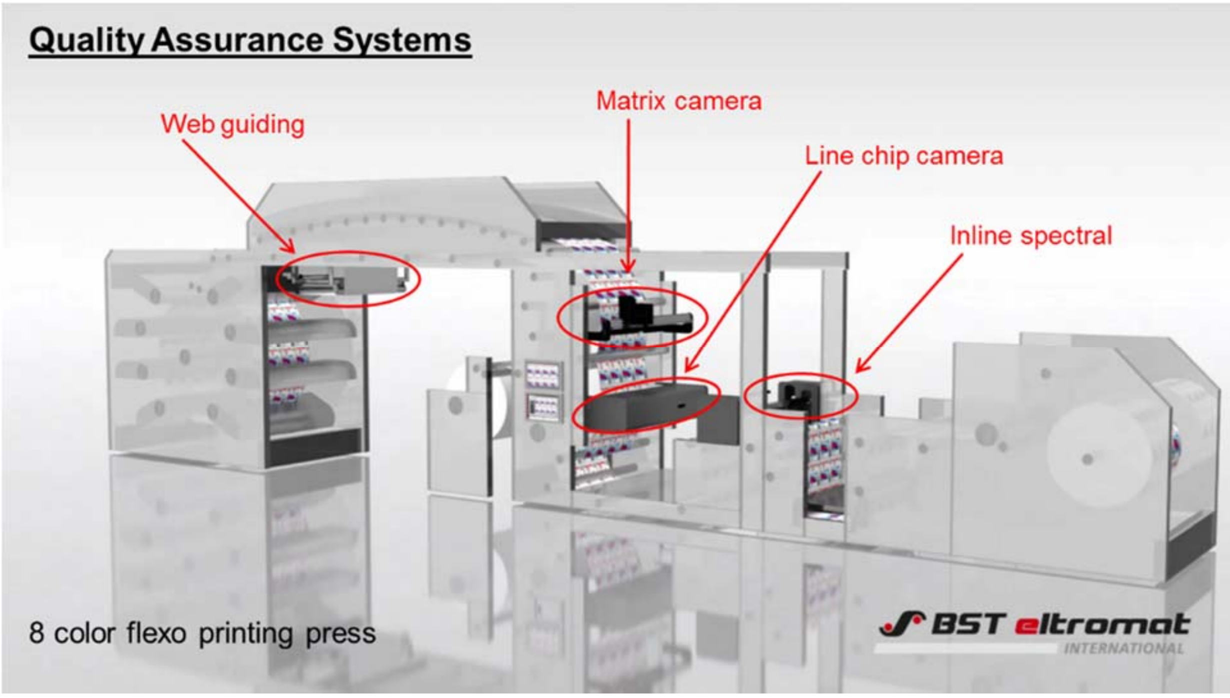


Figure 7. Quality assurance systems in 8 colour flexographic printing press

Relevant components of the inline spectral colour measurement system are shown in figure 8, where the mechatronic character of the sensor device becomes clear: Next to controlling the web path for valid measurement results, the sensor must be synchronized with the running web. This synchronization is realized by combining digital information of several included subsystems like e.g. incremental encoder and contrast sensor for the sensor triggering in web running direction completed by a magnetic way measurement system with a very high resolution for positioning the traversing spectral sensor at the right position across the web width.

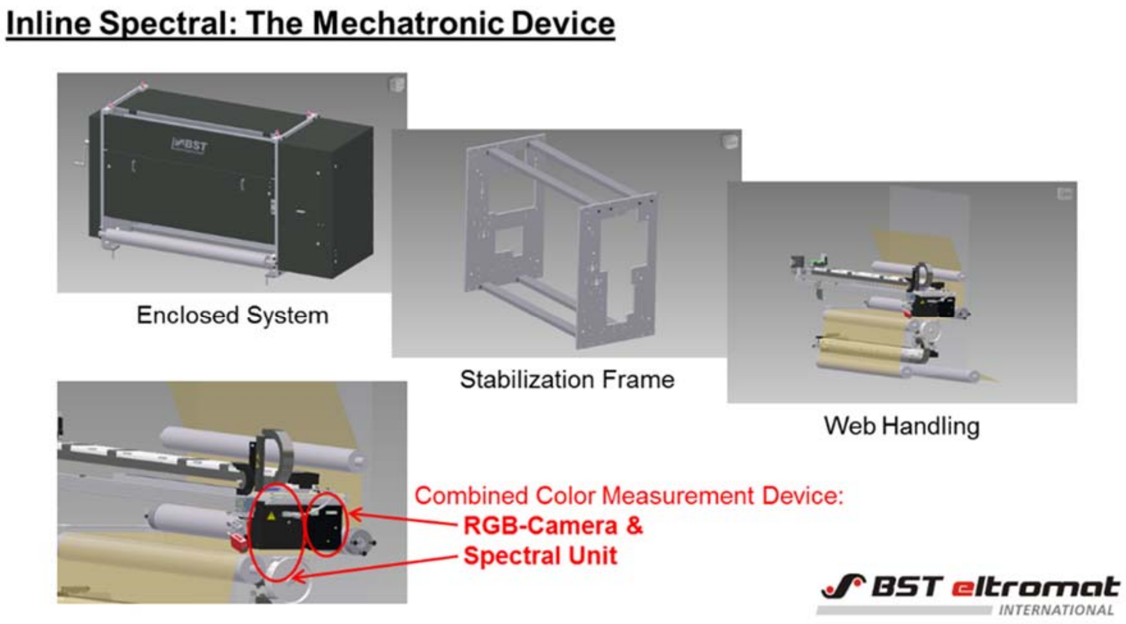


Figure 8. Components of the inline spectral measurement system

The background for this necessary synchronisation is visualized in figure 9: To generate spectral data for homogeneous areas in the printed design for process control and quality assurance tasks, it must be ensured that the measurement takes place at the right position within the moving web. Spectral data related to non-homogeneous areas is not relevant and must not be used for quality interpretation or process control. Smallest deviations (+/- 0.7 mm) in this positioning task lead to inconsistent measurement results and must be avoided.
Validating the system performance concerning these high requirements, the spectral sensor is equipped with an additional RGB camera, which takes an image of the position at the same time as the measurement takes place. Image analysis provides repositioning possibilities, if a mispositioning can be identified within the validation image. Derived offsets are considered fully automatically for the subsequent positioning of the spectral sensor.

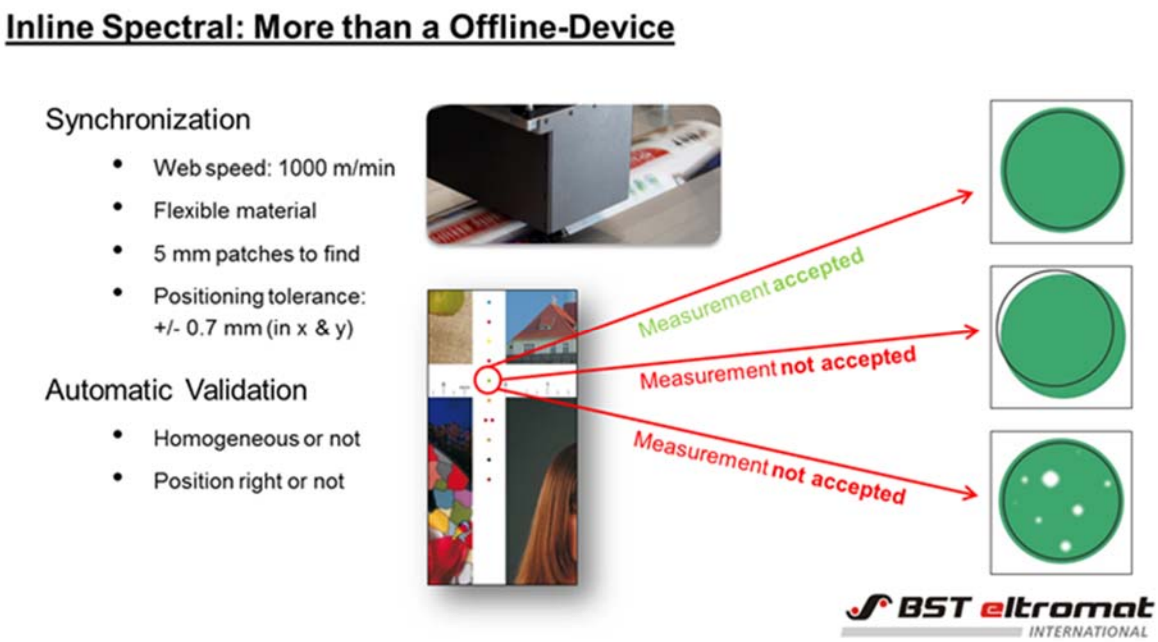


Figure 9. Synchronisation between the running web and the inline spectral measurement system

Interfaces to communicate measurement positions, reference values und system settings for a fast system setup are completed by data export interfaces and formats for a consistent colour communication within the complete packaging value chain.

5. Application and Validation of the Enhanced Main Feature List

As mentioned before, the Enhanced Main Feature List was used in Requirements Elicitation of the introduced Smart System for inline spectral colour measurements. Table 1 contains the complete Enhanced Main Feature List with enhancements in red colour and related case study information in an extra column. Case study information in green highlights important topics, where the list improved the process by sensing for non-obvious subjects. Five topics are discussed here to show how to interpret the table below.

5.1 Prescribed materials

In the Enhanced Main Feature List, “Function / material / prescribed materials” is a pretty clear topic if the focus lies on system functionality. But if the application scenario in which the system shall be used is ignored, no one realises that all materials and excipients must confirm the related and often very special requirements in the food industry, for example, which can be avoided by using the Enhanced Main Feature List.

5.2 Established communication standards

In the Enhanced Main Feature List, “Function / signal / time, quality” is an added topic that can be interpreted as a desired quality of an output signal. Every sensor generates large amounts of data in a short time. In case of a smart system, many internal and external interfaces are tailored to the individual requirements, which is common practice. But in the context of big data and derived added value for customer, it is necessary to handle all the data with sufficient meta data. The requirement “quality” in the Enhanced Main Feature List helps to think about a semantic description of a system combined with e.g. timestamp related data. This is the basis for a valid data analysis and data interpretation. Furthermore: for an open communication across industries or at least between process steps in a value chain, this data must be stored compliantly with established communication standards, which is implicitly also related to many other adjustments of the original Main Feature List.

5.3 Space requirements

In the Enhanced Main Feature List at “Design & structure / geometry / space requirements” it becomes clear that the related system-dimension (one item above in the list) may not be sufficient in case of positioning a system within a machine design. In the industrial case study, the required space exceeds the original dimension by 600 mm in length and width due to needed space for service-doors to be opened for maintenance activities.

5.4 Testability

In the Enhanced Main Feature List at “Design & structure / software / testability” the digital twin for interface tests and internal tests without hardware is one promising option to ensure a sufficient working system. One related additional opportunity is to include (internal or external) customer very early in the development process, which can be initiated by using the Main Feature List.

5.5 Customer needs

In the Enhanced Main Feature List at “Organization / market / customer behaviour and needs” not only the question must be answered, which added value can be provided to the customer by the system, but also how the customer will operate the system. One key question is how much (additional) time is the operator willing to spend for a system setup. At the end of the day, a system setup must be as comfortable as possible (one-bottom system setup by using big data for smart and automated parameter pre-settings), otherwise the customer denies the usage. Dealing with this item of the list, helps to tailor the system to the actual needs of the customer and to theoretically thrilling possibilities of a new technology.

5.6 Enhanced Main Feature List with related case study information

Enhanced Main Feature List		
Function		
Main Feature	**Subordinate Feature**	**Industrial Case Study**
material	properties of input and output material	no producing system, BUT: paper dust and ink dust need to be considered
	prescribed materials	Due to usage in the food industry all materials must confirm all related requirements.
	material flow and material transport	--
	excipients	Due to usage in the food industry all excipients must confirm related requirements.
energy	power	--
	loss	--
	efficiency	--
	state variables	--
	warming	sensor temperature increasement must be considered in the context of generating consistent data (temperature shift), but is not relevant for the production process or machine
	cooling	--
	connection energy	230 V, 10 A
	storage	Integrated flash capacitor
	starting work	--
	energy conversion	--
signal	input and output measures	spectral colour data for colour communication
	other input and output sizes	Meta-data for the spectral data like type of measurement-geometry & illumination, other measurement-conditions like surrounding- & web-temperature, Safety-shut down, WatchDog, …
	display style	Display of a HMI
	components	Machine integrated system, HMI & PC with standard interfaces
	monitoring equipment	--
	signal from (analogue, digital)	digital
	time, quality	signal types: real time signals, signals with deterministic delay, others
	data exchange	Many internal & external interfaces are tailored to the individual requirements and the data must be stored conform to established communication standards.
definition of interfaces	mechanical	System must be integrated into the printing machine without vibration.
	Software interfaces	- TCP-IP (Databases & Communication) - The system can be completely remote controlled or used in semi-automated modus.

	Electric / electronic		Control signals: 24V emergency stop & reel change System supply: 230V 50Hz connection in the control cabinet, Integration in machine emergency stop concept Traverse drives must be able to be de-energized independently of the overall system for reasons of safety (for example: motor stop when the housing is open)
	environment		Not suitable for the EX-area and behind the drying- and cooling-units.
	Digital communication		Communication is related to: measurement results, system parameters, measurement positions, reference values, warning thresholds, special functions (backing check, calibration, parking position due to reel change, ...), …
	surrounding systems		BSTe portfolio, machine control, customer databases, ...
Design / Structure			
Main Feature	**Subordinate Feature**		**Industrial Case Study**
geometry	dimensions		1600mm x 800mm x (web width + 400mm)
	space requirements		Required space is 1600mm x (800mm + 600mm) x (web width + 400mm + 600mm) for side-doors to be opened for service
	number		1 machine integrated system & HMI
	arrangement		System must be behind the drying and cooling units in the printing press; Distance between sensor and web must be 20mmm +/- 1mm; Orientation of the sensor 90° +/- 1°to the substrate surface; System orientation top down (0°) +/-90°
	connection		System must be individually integrated in many different printing machines
	extension		additional options in illumination, validation, sensor-module & -type, housing, ...
mechanics	prescribed materials		--
	forces	weight	< 500kg
		load (external forces)	depending on the orientation of the system integration this value will change
		force direction and size	gravity / traversing energy must only be considered internally, there is no relevant impact on the machine
		force frequency	--
	heat	friction	--
		thermal stress	Combining aluminium linear axis and steel traverses with length of up to 3m must be considered.
	strength	stability	mechanical tolerances: max +/- 0,5 mm in X,Y,Z & max +/- 0,5 ° in orientation for consistent spectral data with high measurement reproducibility

		surface quality	relevant at the mechanical integration interface to the machine, black for reduced light scattering, robust against paper- & ink-dust, easy to clean
		deformation	cf. "mechanical stability"
		stiffness	cf. "mechanical stability"
	kinematics	movement type and direction	linear, horizontal
		speed	1 m/s
		acceleration	4 m/s²
	kinetics	spring stiffness	--
		damping	--
		resonances	must be avoided cf. "mechanical stability"
electrics / electronics	nominal voltage		230 V
	rated currents		10 A
	power supply fluctuations		<10%
	fuse		10A
	lubrication		very relevant for internal cables
	filtering		--
	EMC		yes
	connection		in the cabinet
	wiring		mainly in the cabinet including labelling
	isolation		relevant
	air- / creepage distance		relevant
	plug		in case of specific hybrid cables robust versions, IP54 if necessary
	modular order		--
	function groups		relevant
	component availability		relevant: at least 5 years availability
	accessibility		relevant for maintenance
	exchange		sensor must be easy changeable by the customer, other components only by service technicians
software	integration		relevant
	interfaces		many internal & external interfaces tailored to the individual requirements but conform to established standards
	updates		possible per remote and at place
	hardware		multi-processor computing
	testability		digital twin for interface tests and internal tests without hardware
	Operating modes		Operating modes are: emergency, automatic, user-defined
	development environment		according to BSTe-standards
	versioning		relevant and with remarks concerning made changings
	selection of programming languages		according to BSTe-standards
	documentation		according to BSTe-standards
	filing of documents		according to BSTe-standards
	maintainability of the code		according to BSTe-standards
	real-time requirements		in case of triggering
	planning		sprint
	Is my output "B" under all circumstances when I've fed "A"?		relevant
safety / security	immediate safety technology		power down of the traversing motors if safety-doors have been opened
	indirect safety technology		in case of a strong heating in the spectral-sensor or the motors, the system must shut down

	indicative safety technology		in the user manual
	operational safety		No usage in explosive areas permitted (e.g. in gravure printing machine before the drying unit)
	occupational safety		in the user manual
	environmental safety		conform to standards
	risk potential		conform to standards
	border risk		--
	risk assessment		basis for CE certification
	radiation		--
	data protection		becomes relevant in the combined use with the data-communication-module.
	Protection against unauthorized access to the system		password protection
regulation	operating principles		--
	hardware		--
	structure		
	algorithms		--
	virtual sensors		--
	commissioning / parameterization		first parametrisation before delivery, fine tuning at customer
ergonomics	man-machine interaction	value	same level as other combinable BSTe-modules
		logical operation	The system can be completely remotely controlled, semi-automated and completely manually operated via an HMI.
		audible and tactile oscillations (NVH)	oscillations must be avoided, haptic response in the HMI is a future topic
		collaborative work (safety)	relevant
	display and controls	operating	The system can be completely remotely controlled, semi-automated and completely manually operated via an HMI.
		Operating mode	via touch display
		clarity	most important for a satisfied customer usage
		lighting	--
	forces	operating forces	--
	shape design	anthropometric dimensions	--
		tactile coding	--
		haptics	--
industrial design	importance		highly relevant
	aesthetic functions		according to corporate design
	visualization functions		according to corporate design
	symbol functions		according to corporate design
	product recognition		highly relevant
	colouring		same level as other combinable BSTe-modules
	sinus-milieu		--
Realization and Production			
Main Feature	**Subordinate Feature**		**Industrial Case Study**
purchase	make-or-buy strategy		- buy-strategy for spectral-sensor: due to cooperation with the market leader at spectral measurement handhelds - make-strategy for integration: due to core know-how in web synchronization at BSTe

	A supplier	Preferred supplier may change due to: - cooperation with market leader for spectral measurement handhelds - very special mechanical requirements with linear axis → only one suitable supplier - very special optical requirements with contrast sensor → solution only due to cooperation with one supplier
	local-content	--
	catalogue assemblies	--
	operational/strategic purchasing; specification of the components to be purchased	requirements engineering is a key factor because: - cooperation with market leader for spectral measurement handhelds - very special mechanical requirements with linear axis → only one supplier - very special optical requirements with contrast sensor → cooperation with one supplier
	data exchange	--
manufacturing	restrictions by production facility	Due to the high system weight in combination with the very low mechanical tolerances special manufacturing conditions are necessary
	largest manufacturable dimensions	5 x 5 x 2 m^3
	preferred manufacturing method	--
	manufacturing equipment	--
	possible quality and unavoidable tolerances	--
control	measurement and testing capability	Distance and angle measurement systems to validate the mechanical requirements
	special provisions	electrical interfaces are critical and must be validated intensively
assembly	special mounting instructions	according to the very detailed installation instructions
	pre-assembly	combining subsystems according to the detailed installation instructions
	installation	depending on position of integration (ground level or in 2 m height) the mechanical interfaces must be prepared before starting installation
	site assembly	--
	foundation	--
	tools	no extra equipment necessary
	excipients	--
	safety data sheets	safety data sheets are prepared by the development are provided with the system
SW-deployment	How to transfer (e.g. flashing)	A complete PC-hard-drive-image is prepared for first installation, updates can be done for every module separately by remote control
	frequency	Releases are launched every 3 to 6 months
	versioning	Release numbers #.#.#: are interpretable as follows: new-hardware. New function. Minor changing and bucks
maintenance	compatibility with hardware of the product	over at least 5 years

Main Feature	Subordinate Feature	Industrial Case Study
	maintenance-free or number and time required for maintenance	Sensor-recertification once a year
	inspection	--
	replacement and repair	customer / service technician
	software update	by remote control
	availability of components in the life cycle (spare parts strategy)	at least 5 years
	feature enhancement in the life cycle	by remote control
	diagnosis	by remote control
	cleaning	according to the cleaning manual
	lubrication	according to the cleaning manual
	location	10°-40°C, 10-90% humidity
	versioning	Release numbers as follows: new-hardware. New-function. Minor changings and bucks
	Use / Recycling	
Main Feature	**Subordinate Feature**	**Industrial Case Study**
usage	area of application and sales	printing industry for colour control and communication
	location	within the printing machine in printing plants
	moisture	usable between 10 & 90%
	commissioning (learning process)	--
	comfort	comfortable replacement of handheld devices for colour control at the printing machine; easy to use due to interfaces to previous production steps where system setup information can be stored for a very fast "one bottom set up".
	Service	--
	reliability	Due to calibrating concept of the sensor, the customer will have a lifetime working system; software & hardware are chosen to last at least 10 years.
	Availability	24-7
recycling	reuse	99%
	recycling	50%
	disposal	only metal, plastic and electronic components
	final disposal	--
	clearance	--
	harmful and hazardous substances	light bulbs
	recycling-critical substances	--
	accessibility	easy
	solubility	no
transport	limitation by hoists	500 kg
	track profile	--
	transport routes by size and weight	--
	shipping method and conditions	plane, train, transporter
	delivery time	12 weeks after technical clarification

Organization

Main Feature	Subordinate Feature		Industrial Case Study
planning	cost	target costs	--
		cost for manufacturing	10.000 €
		tool costs	42.000 to 60.000 €
		investment	1.500.000 €
		amortization	10 years
		penalties	market acceptance

	time and date	end of development	release 1.0 after 3 years
		available resources	4 to 8 developers
		date of delivery	drupa 2012 for the first delivery
		SOP (start of production)	September 2012
		customer milestones, sampling levels	--
	laws, contracts, patents	standards, guidelines (product liability → SdT)	ISO 13655
		customer standards	--
		certifications	XRGA
		company know-how (in particular: non-patented ideas)	concept for triggering and spectral data transformation for additional measurement conditions
		CE certification	yes
sustainability	ecological balance		Very good because of the dramatically reduction of waste during production, if the system is integrated.
	energy efficiency		as good as possible
	system costs		costs for electricity and sensor recalibration
social acceptance	ecology		--
	economy		--
	compliance		yes
	sustainability (resource utilization)		yes
market	competitors		at least 5 with less performing systems
	customer segment		roll to roll printer in the packaging industry
	benchmarking		best available product for absolute spectral inline measurements
	customer behaviour and needs		System setup must be as comfortable as possible (one-bottom system setup by using big data), otherwise customer prefer handheld devices.
	market standard		the market standard is set by this system
	sales figures		30 systems / year (planned)

Table 1: Enhanced Main Feature List with new entries in red colour and related case study information in an extra column with highlights in green

6. Summary and Outlook

Innovation process and innovation output are positively affected by adequate reference models and supporting means. Today's engineering applications are characterized by high interdisciplinarity, networking, complexity and heterogeneity. This technological change towards digitization and networking is enabling new Digital Business Models. In order to meet these challenges, there is a need for new basic scientific methods that build the framework for innovation and engineering. Based on discussions within the Technical Committee VDI GMA 4.10 "Interdisciplinary Product Creation", a New V-Model for Engineering Mechatronic and Smart Systems has been proposed in (Graessler 2017) and (Graessler 2018) and was validated in a facilitated workshop held at the 15th International DESIGN Conference. The resulting state of the New V-Model has been proposed in this contribution (figures 2 and 3) and unique characteristics such as cross-disciplinary system architectures and a model-based engineering approach were outlined.

One core element of the New V-Model is the adequate representation of requirements elicitation and management as an own strand of the "V" and its interlinkage with the checkpoint "specification". Based on the established main feature list first published by Pahl and Beitz (Pahl et al. 1996), in this contribution a new Main Feature List enhanced for the usage in requirements elicitation of Mechatronic and Smart Systems was proposed. This Enhanced Main Feature List comprises additional requirements such as sampling rate, bus system, big data usage. Applicability and specific advantages of the Enhanced Main Feature List were proven and validated by several industrial application cases. In this contribution we gave an insight into the industrial case study of an Inline spectral measurement system in the printing industry and pointed out the specific advantages.

The proposed Enhanced Main Feature List establishes new fundamentals in research and theory and fosters result quality and efficiency of Requirements Elicitation and Management. Our further proceeding will consist in publishing the revision of the guideline VDI 2206 "Development methodology for mechatronic systems" from the year 2004 (VDI 2206 2004) as a so-called "VDI Gründruck". Collecting feedback and taking the gained response into account, the final guideline will be published in 2019.

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