White paper: Digital simplicity.
New ways to increase productivity with “smart” systems

This white paper provides information on:

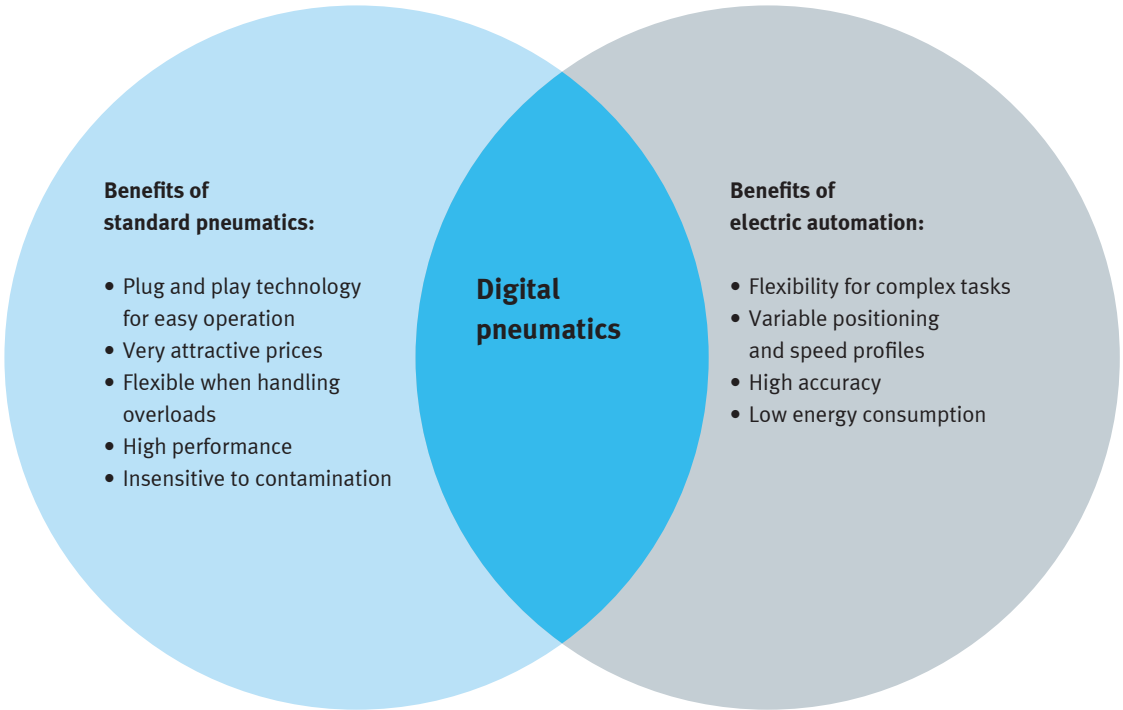
- The features and the current roles of conventional mechatronic systems and cyber-physical systems in automation.
- The benefits offered by CPS across the entire value chain and how they promise a quick return on investment thanks to digital simplicity.

Executive summary

The so-called “smart” cyber-physical systems (CPS) are completely new. They are set to increase production and make it much more flexible. And they are set to change traditional processes in the value chain by simplifying them – this is what is called digital simplicity. They are leading to autonomous production with self-regulating systems.

Cyber-physical systems like the Festo Motion Terminal are future-proofing new plants for machine and system builders as well as for operators. With its digital pneumatics, the Festo Motion Terminal combines maximum standardisation with a very high level of flexibility. It is also enabling Festo to propel pneumatics into the age of Industry 4.0.

The technology behind the Festo Motion Terminal unites the benefits of traditional pneumatics with those of controlled and complex electrical motion. Despite the simplicity, it integrates more functionalities than conventional technology.



Intelligent automation in the age of Industry 4.0

The trend in automation towards networked, decentralised and intelligent systems with optimum function integration is unstoppable because technical and economic requirements are constantly on the increase. The demand for additional features such as the interpretation of environmental information is also on the rise in the age of Industry 4.0. The new communication opportunities, including the ability of components to communicate with each other, are opening up completely new areas of activity. This not only permits more specific preventive maintenance, but also clears the way for autonomous production with self-regulating systems.

> Automation needs to be ever faster and more diverse, more flexible and more intelligent. This requires greater availability and flexibility along with productivity, energy efficiency and cost-effective just-in-time production down to batch size 1. This is where conventional mechatronic systems reach their limits.

Status quo: mechatronics as the basis

Conventional mechatronic systems bring together mechanical systems, electronics, control technology and information technology and enable them to interact in actual automation applications. They are the only way to ensure that pneumatics can be integrated in electromechanical applications and are essential for precise positioning of pneumatic drives, for example.

Modular mechatronic systems facilitate extensive function integration, i.e. greater system adaptability and standardisation. This not only results in system improvements but also in significant optimisations all along the value chain since fewer components have to be selected, procured, assembled and wired. Digital communication provides additional benefits, because for example the influence of EMC on analogue values and therefore system faults can be ruled out.

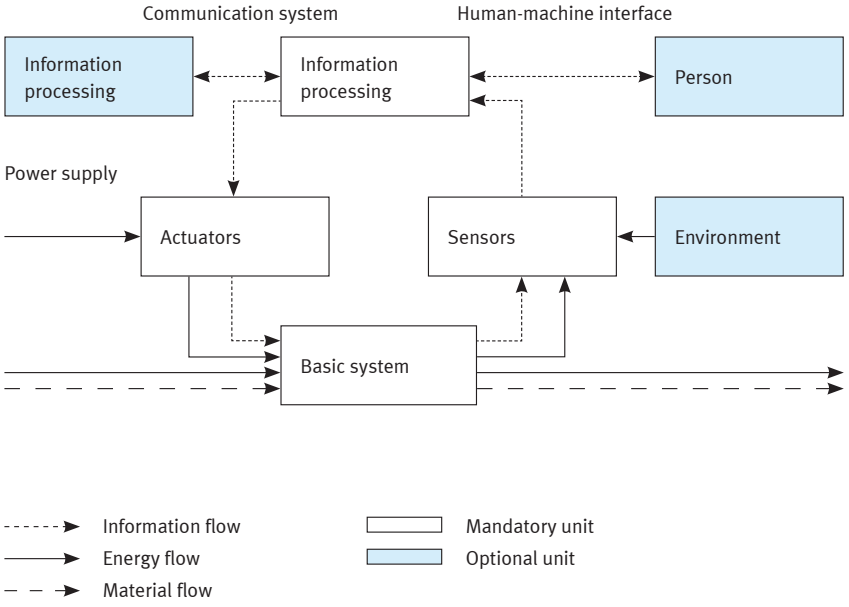


Figure 1: Basic structure of a mechatronic system[1]

[1] VDI 2206, 2004-06: Entwicklungsmethodik für mechatronische Systeme (Design methodology for mechatronic systems).

Mechatronics: a lack of flexibility drives up the costs of system adaptations

Despite all the benefits of modular mechatronic systems, there is still some room for improvement when it comes to flexibility. Retrofitting system adaptations during the design and engineering process or parameter changes required for format changes during operation are really only possible with costly and time-intensive modifications. A modular design offers a certain amount of flexibility, but only within the limits of the particular module. The general rule therefore is that any parameters that could possibly change, must already be taken into consideration at the design stage. After all, according to the rule of ten costs for subsequent adaptations increase by a factor of ten[2]. It makes no difference whether the changes are needed to adjust the sizing to a change in loads or to add new functions requested at a later date by the end customer.

> Conventional mechatronic systems offer benefits across the value chain through function integration. However, any subsequent changes required in the design or operation are time-consuming and costly. This is where CPS are much more flexible during the engineering process.

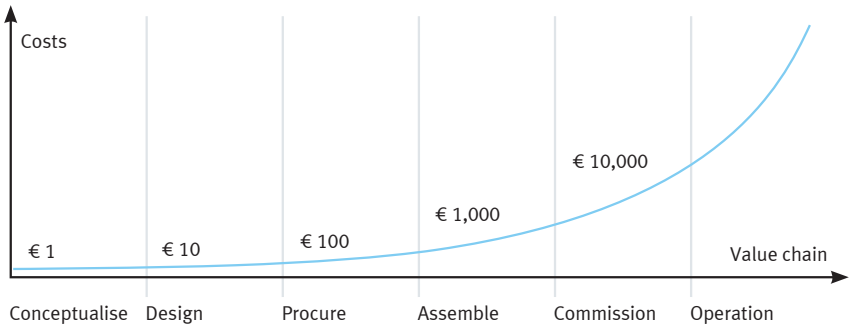


Figure 2: Rule of ten for subsequent system adaptations

There is much to be said for breaking entirely new ground: cyber-physical systems increase flexibility and networking

Although the literature contains numerous definitions for CPS, there is no one commonly accepted, precise definition.[3] However, what is certain is that cyber-physical systems will play a pivotal role in Industry 4.0 applications.[4]

In terms of their basic structure, CPS are mechatronic systems. In addition, they also have integrated smart sensors and greater software intelligence. One possible application is to predetermine external influences using data recorded internally without the need for additional sensors, and then sharing this information internally and externally with other systems via suitable communication interfaces. The benefits are that systems can be adapted without the need for new or additional hardware because the functional adaptations are executed using software and apps, or the system auto-tunes itself or via an instruction from the control system.

[2] Robert Schmitt, Tilo Pfeifer, Masing Handbuch Qualitätsmanagement (Masing Quality Management Manual), 5th edition 2007.
[3] VDI/VDE Society of Measurement and Automation Engineering, Cyber-physical Systems: Chancen und Nutzen aus Sicht der Automation (Cyber-physical Systems: Opportunities and Benefits from the Viewpoint of Automation), April 2013.
[4] Fraunhofer Institute for Production Technology and Automation IPA, structural study “INDUSTRIE 4.0 FÜR BADEN-WÜRTTEMBERG” (INDUSTRY 4.0 FOR BADEN-WÜRTTEMBERG), 2014.

Implementation of the requirements for Industry 4.0 such as system-wide data usage depends on the system and the product, and can be limited. The reason for this is simple: the data recorded in the device by sensors is not shared with other stations because there is no data interface. For example, the temperature data measured in proportional valves is only processed in the valve itself. No other diagnostic functions are carried out, even though this would provide the means to determine whether there is a defective fan in a control cabinet, for instance.

In summary, it can be said that for the factory of the future the industry needs products with integrated sensors and an Industry 4.0 interface. It is essential that this interface meets international standards for data management and communication. The software interface standard OPC UA, published as part of the IEC 62541 series of standards, is a good example of such a standard.

The Festo Motion Terminal VTEM: new, flexible technologies are making Industry 4.0 possible

The actuators used in the pneumatic parts of the Festo Motion Terminal, which are in the form of a bridge circuit, are one of the new technologies driving Industry 4.0 forward. The four 2/2-way piezo pilot and diaphragm poppet valves with integrated smart sensors offer huge flexibility. In contrast to conventional mechatronic systems, these smart sensors are embedded directly in the Festo Motion Terminal VTEM. This means that the pressure measurement sensors are no longer a separate module that needs to be selected via the configurator. The range of tasks is also expanded as the pressure measurement sensors can be used for various tasks, such as diagnostic functions.

> The Festo Motion Terminal can be used to digitally define and query a large number of process parameters. This provides numerous options for controlling and analysing related processes. Since “smart” sensors work autonomously, the reproducibility of the processes is also improved. This contributes to better and more consistent quality.

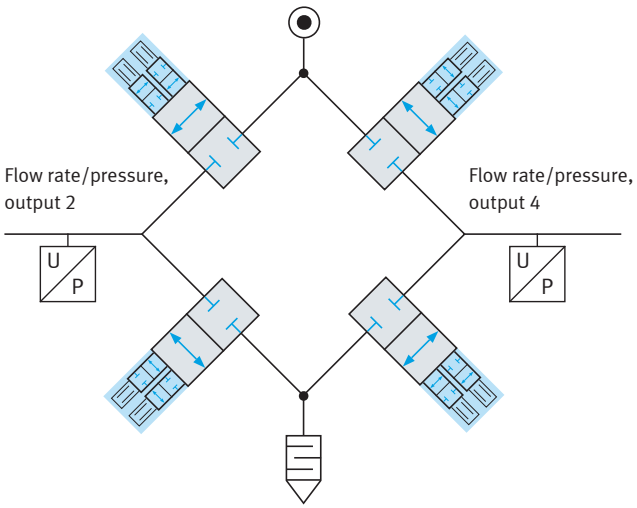


Figure 3: The actuator in the Festo Motion Terminal VTEM is a digital control piston. It can take on the functions of a wide range of mechanical control pistons found in common directional control valves. The control piston consists of a bridge circuit with piezo pilot and diaphragm poppet valves.

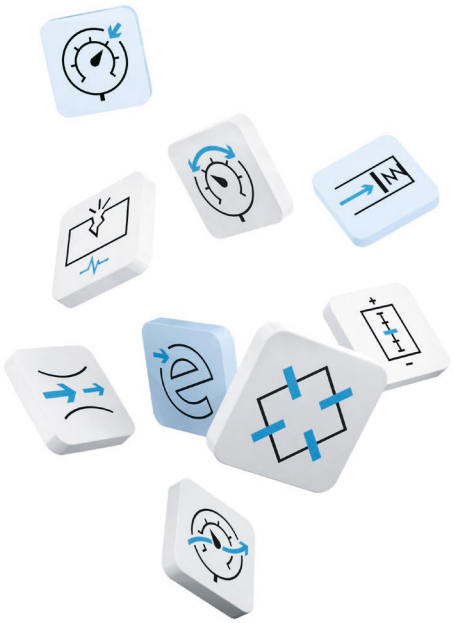
Motion apps as the natural replacement for hardware

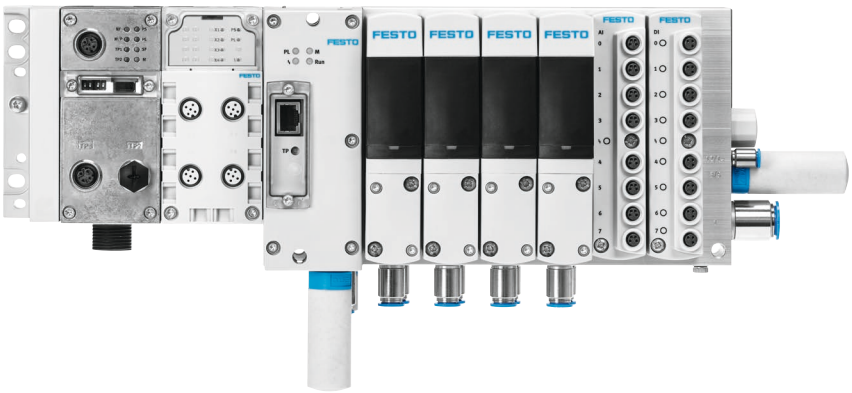
Thanks to its motion apps, the Festo Motion Terminal offers the traditional valve functions of 2/2-way, 3/2-way, 4/2-way or 4/3-way valves as well as proportional technology and servo-pneumatic functions in one device. Other functions include presetting of travel time, ECO drive and leakage diagnostics. All these functions can be implemented in a cyber-physical system like the Festo Motion Terminal using motion apps. What is special about this, is that it can all be done with a single valve that always has the same design.

This valve combines the benefits of pneumatic and electric automation technology. The Festo Motion Terminal integrates complex movements, variable positioning, condition monitoring and many other functionalities into one single component – and consumes less energy.

The flexibility, the implementation speed and the overall economic benefits compared with “hardwired” conventional systems are many times greater. Since changing parameters in systems such as the Festo Motion terminal doesn't necessarily mean the hardware needs to be adapted, the rule of ten no longer applies. Adaptation costs are kept within tight margins, even if changes are made during phases well after the design phase.

> Motion apps enable many functions with just one hardware device. Using the apps, functional changes can be realised at a later stage via the controller without any problems and at little cost.





CPS using the example of the Festo Motion Terminal: greater speed and flexibility along the entire value chain

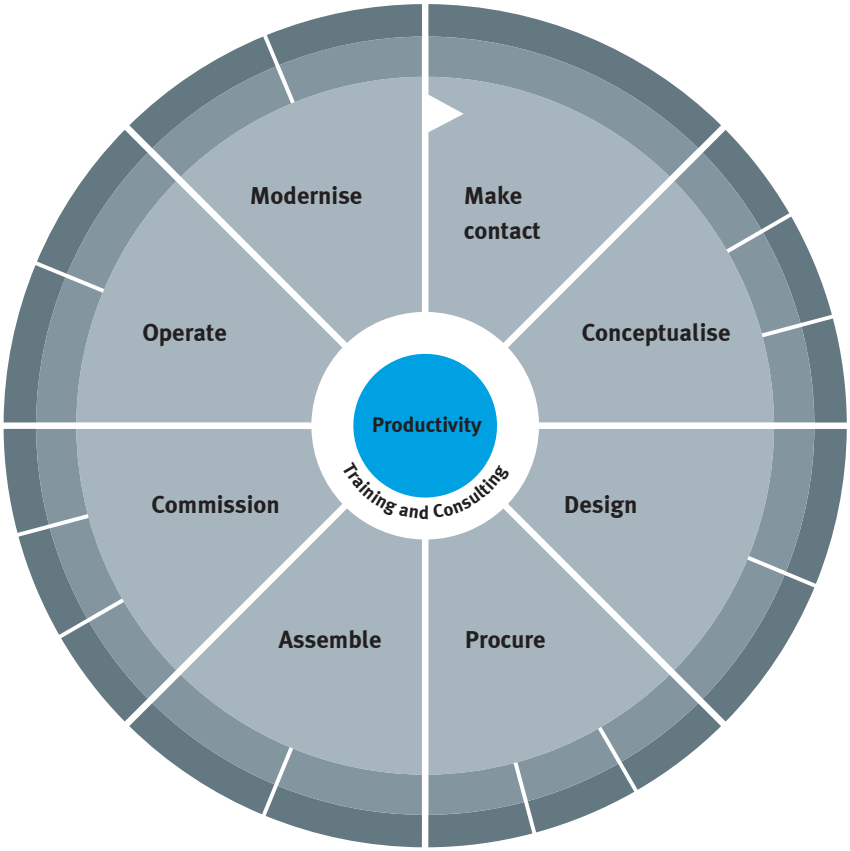


Figure 3: Complete value chain modelled on the Festo productivity circle

Faster to market, faster return on investment, increased productivity

Cyber-physical systems (CPS) are characterised by maximum flexibility. Functions and movements in the system can be adapted via the software, even during operation, without major changes to the hardware. Improved or new functions can be realised quickly and easily via software updates. As a result the system is always up to date. A standardised platform can therefore also be used for several applications – once again without the need to replace any of the hardware. As can be seen below, this streamlines and simplifies all phases of the lifecycle of a system.

Phase: Make contact
Innovative action with the right partner

In many companies, the decision in favour of "smart" solutions is heavily influenced by the company's business model and capacity for innovation. This also affects the requirements for suppliers as they need to be ambitious and capable. If they are, other questions that need to be asked are: does the supplier operate globally? And even more importantly: can they be expected to deliver successful further developments in the future? After all, end customers will only invest in a new technology if it offers potential for the future.

> A very high level of flexibility with maximum standardisation, reduced energy costs, preventive maintenance and more streamlined processes are important selling points for OEMs and end users. CPS also offer added values in the value chain that are not easy to quantify (e.g. knowledge protection), since these functions are not visible from the outside.

Phase: Conceptualise
Give the green light right from the start

During the conception phase, designers create the foundation for the plant or system. “Smart systems” – like the Festo Motion Terminal, for example – greatly help to standardise the hardware of system modules, while still permitting a fast and flexible response to any changes. All the functional adaptations are easily realised via a motion app, without the need to change the existing hardware.

Assigning updates and new tasks is quick and easy
Making changes at a later stage is particularly easy and cost-effective with CPS. The time and costs for tests are also noticeably reduced, as the ongoing process to achieve the optimum customer solution is done digitally instead of manually changing the hardware.

Easier engineering with standardised platform concepts
With a single valve slice providing the functionality of over 50 individual components, a CPS like the Festo Motion Terminal is opening the door to standardised platform concepts for systems and system modules. This also considerably reduces the pneumatic control chain as the number of different components that have to be defined and stocked as spare parts by the customer can be greatly reduced. For example, there is no stacked valve assembly for pressure control, the valve variety is reduced to one, the pressure sensor and flow control valves are integrated, and silencers are superfluous. These are just some examples. By focusing on a flexible CPS platform right from the start, even the planning stage with its search for suitable products and suppliers and initial meetings can be shortened.

Integrated knowledge protection thanks to apps
Function configuration via apps will stop unauthorised parties being able to quickly analyse and identify future functionalities and system designs. This is precisely what a CPS offers, as all the functions are realised using software modules, apps and basic technology offering flexible control.

> CPS such as the Festo Motion Terminal are already replacing up to 50 individual components. This speeds up the planning phase, reduces complexity and minimises follow-up costs for any subsequent changes and innovations.
>
> **Potential for change and savings during the conceptualisation phase: high**

Phase: Design and program
Getting up and running quickly

The design phase is one of the biggest cost items in the value chain in machine and system building, where it accounts for approx. 25 to 30%.[5] CPS like the Festo Motion Terminal enable significant time gains and savings compared with a conventional valve terminal platform, despite higher expenditure for parameterisation and integration in the control system. In some cases, the time saving compared with designing and parameterising a modular valve terminal and additional individual components is up to 70%.

While a solution with modular valve terminals requires several individual steps, a solution with CPS gets you to your goal faster. The adaptations are implemented digitally on the product itself, so there is no need to reconfigure the valve terminal, download and create the CAD model or adapt the hole pattern and assembly drawing including parts list. Last but not least, this also speeds up the creation of electrical circuit diagrams, the documentation (spare and wearing parts lists) and the approval process in the PLM system.

[5] Festo AG & Co. KG, Costs? Reduced! – Consistent use of Festo products and services enabled a reduction of approx. 50% in the total cost of ownership, October 2016 (www.festo.com/net/SupportPortal/Files/9496/BioPharma_TCO_de.pdf).

Other benefits of standardisation
How the standardisation potential of a pneumatic solution is assessed depends on the application and company processes. The VDMA study "Modularisation and Standardisation in Large Industrial Plant Manufacturing – Myth or Reality" estimates it at about 10 to 20% in terms of the overall business result.[6] Design changes and therefore changes to parts lists, drawings, circuit or fluid diagrams are for the most part no longer required, because the adaptation is carried out by software updates. This means fewer components are needed and thus fewer components need to be ordered and stocked for maintenance or machine breakdowns. While integrating, say, an additional proportional valve used to take weeks from when it was planned, bought to being installed, it now takes just a few mouse clicks. There is no doubt that this has a welcome side effect: since fewer components are required and, for example, one valve can cover two proportional pressure applications, the space needed is halved.

System costs are more than just product costs
Engineers start to consider the product costs no later than during the design phase. However, the total cost of ownership (TCO) should play a more important role in order to have a clear calculation – and to sell the benefits to end customers. That is why a CPS must always be analysed in its entirety across all phases of the value chain, rather than only comparing the individual hardware costs.

Take for example the Festo Motion Terminal and its motion app "Supply and exhaust air flow control". You cannot just focus on eliminating the flow control valve, which only costs a few euros; you need to look at the big picture. For example, there is no need for time-consuming settings during commissioning, and the cylinder speeds (e.g. in a series system) are completely identical. Process disruptions caused by readjusting the flow control valves are avoided and optimisations are carried out digitally without having to be near the system. In addition, new pneumatic processes are possible, for example digital speed control with slow start-up and subsequent acceleration.

> CPS speed up the design process, since fewer components and therefore fewer part numbers are required. They reduce system complexity and improve standardisation. Subsequent changes can be quickly and easily implemented via apps as no design modifications are needed.
>
> **Potential for change and savings during the design phase: very high**

Phase: Procure
Lower costs for data management, logistics and warehousing

During the procurement phase a lot of data is processed, such as delivery dates, prices, supplier details, internal stock locations, etc., and then entered and maintained in the ERP system. From a cost point of view, this complex task is often included as part of the overheads, which means that these costs are not directly visible.

A modular system like a valve terminal would already generate huge savings, because several components can be ordered with one part number. But a CPS makes data management, logistics and warehousing even simpler. The savings potential is quickly achieved when you consider the above-mentioned processes for a single part number and then also include invoice management, goods in, goods in inspection, system postings as well as storage. Experts estimate the annual administration costs per data record to be around EUR 1,000 or higher.[7]

Shorter parts lists, fewer mistakes
Since a lot of the components needed for many functions are eliminated, the risk of mistakes is also reduced. In the case of the Festo Motion Terminal, one valve slice can already replace up to 50 individual components. This goes all the way from the valves for supply and exhaust air flow control, to shock absorbers and additional pressure sensors.

> CPS, thanks to having many fewer components, minimise the process steps required for logistics and warehousing. And they reduce the cost of data management and maintenance. With the Festo Motion Terminal, integrating new functions just means purchasing the relevant motion app licences.
>
> **Potential for change and savings during the procurement phase: low to medium (without material savings)**

[6] Stecken Olaf; Modularisierung und Standardisierung im Anlagenbau (Modularisation and Standardisation in Plant Manufacturing); 16.07.2015, VDMA
[7] Andrè Guldi, Alexander Hoffmann, Alexander Mahl, Stefan Sander, Hans-Eckard Scholz, Paul Thierse, Jörg Weißkopf; Unternehmensspezifisches Klassifikationssystem zur effizienten Datenverwaltung (Company-specific Classification System for Efficient Data Management) (with practical application scenarios, 2005).

Competitive advantage thanks to short delivery times
CPS will also open the door to entirely new business models and delivery times in the future. Users of the Festo Motion Terminal will only need to buy the appropriate motion app licence to have the functionality they need immediately available. Shorter time to market, higher OEE with fewer disruptions and easier optimisation of the system for the end customer are important benefits that this ready-made availability has to offer.

Phase: Assemble
Greater reliability and reduced effort thanks to standardisation

Reducing system complexity is becoming more and more important given that "human error is increasingly being identified as the cause of system failures".[8] Solutions with intelligent function integration and fewer interfaces are therefore ideal for achieving maximum efficiency. This reduces assembly work as well as possible errors and any queries that may arise. Having just one standardised component optimises process sequences for a wide range of functions.

> CPS with their standardised design for a wide range of tasks require less assembly and wiring and prevent incorrect installation. This speeds up assembly and commissioning and reduces costs.
>
> **Potential for change and savings during the assembly phase: high**

Phase: Commission
Easier replication of pneumatic systems

Coordinating individual process steps, such as setting the travel speeds of cylinders, is often a time-intensive process in conventional mechatronic systems. CPS solutions generally do not involve complex manual setting processes for components that may sometimes be hard to reach, and they are also self-regulating and self-optimising in terms of energy consumption. These are clear benefits for series machine builders. The travel speed of each individual cylinder can be defined with just a few clicks via the app's parameter records; this also rules out tampering. This saves between 3 and 4 minutes of setting time per flow control valve. Looking at the annual production of a series machine builder, this offers huge savings potential – and the big advantage that all system configurations are completely identical.

Configuration and parameterisation of complex solutions
Parameterisation should be as fast as possible. Up until now, if you wanted to precisely and quickly control the pressure in order to compensate a pressure drop caused by friction in the compressed air line, you needed to determine the parameters empirically, i.e. a higher setpoint value and the time that the pressure stays at this value before it drops back down again to the target value. Thanks to the sensor intelligence and software modules in cyber-physical systems these tasks are superfluous. The Festo Motion Terminal VTEM has a "Model-based proportional pressure regulation" app for this process. It can also actively and autonomously respond to changing parameters, such as fluctuations in the input pressure.

> CPS eliminate the need for time-consuming manual settings. Once configured, the settings are very easy to duplicate. They have self-regulating apps (e.g. for defining travel times) as well as autonomous intelligence.
>
> **Potential for change and savings during the commissioning phase: high to very high**

[8] Hermann Himmelbauer, Albert Treytl; Fehlerbaumanalyse (Fault Tree Analyses (FTA)), 1996.

Phase: Operate
Combining maximum productivity with energy efficiency

High overall equipment effectiveness (OEE) with short downtimes during maintenance or repairs are an obvious goal for end customers who keep an eye on efficiency. When it comes to costs, sustainability as well as ever more stringent legal regulations, the spotlight is increasingly on energy efficiency. The Festo Motion Terminal combines all these issues together.

The "ECO drive" app of the Festo Motion Terminal can already generate significant savings. For example, approx. EUR 400 can be saved on annual energy costs with just 4 cylinders.[9] Productivity is increased at the same time because the variety of spare parts, storage and procurement are simplified. Each stock item that is not needed saves space and money. Experts estimate the annual storage costs for a single component at over EUR 30.[10] Having identical components also greatly reduces the time required for maintenance and repairs.

Fewer production faults and stoppages thanks to smart apps
Stoppages or production errors can be identified at an early stage in a CPS and maintenance can be planned with the help of diagnostic functions like leakage detection. The reduction in the number of hardware components also has a positive effect.

The wealth of information available in a CPS like the VTEM means that one day it might even be possible to make statements about the cylinder status.

The "Soft Stop" motion app dramatically improves productivity: cycle times can be reduced by up to 70% through process optimisation. The gentle retraction of the actuators almost entirely prevents vibrations (e.g. during high-speed opening and closing of pneumatic tool change doors) and therefore does away with the need for wear-prone shock absorbers. The different ways in which energy consumption can be reduced together with the diagnostic capability contribute to very economical operation and a fast return on investment.

Shorter setup times and adjustment at the touch of a button
Format changeovers usually involve changing components such as grippers. This in turn involves adapting pressures or flow rates and travel speeds or entire functions. The Festo Motion Terminal eliminates many manual procedures – and thus also sources of error. Reconfiguration and adjustments are done via the app or automatically via the PLC, which means that the performance and/or processes of all machines during format changes or in series machines can be improved at the touch of a button.

> CPS make system operation very productive, energy-efficient and cost-effective. Reconfiguration and adjustments are carried out using software. Diagnostics and intelligent apps prevent stoppages and production errors and also contribute to a fast return on investment.
>
> **Potential for change and savings during the operation phase: very high**

Phase: Modernise
Easier, cheaper and faster adjustments

Modernisation may serve several purposes, for example to increase system output, to expand the range of products which are produced or to reduce operating costs. As already described for the previous phases, CPS save energy, improve processes through fewer manual procedures and allow the easy adjustment of entire series machines. The high flexibility of CPS also means that existing solutions can be recycled and used in future systems, although that is a topic which is not explored in detail in this paper.

> CPS increase the scope for all kinds of modernisations through simplified conversion and easy adjustment of entire systems. This means that they are up to date and always ready for any new requirements the future might bring.
>
> **Potential for change and savings during the modernisation phase: high**

[9] Calculated on the following basis: DSBC 32x100 cylinders from Festo, a weight of 0.5 kg to be moved, a cycle rate of 2–3 seconds, two-shift operation and 250 working days.
[10] Annual storage costs per component: € 0.08/day x 365 days = € 30. With a storage rate of 15% and an average overall purchasing price of € 200.

Ready for new dimensions in automation

Digitisation will profoundly alter the world of production. For the first time, cyber-physical systems are enabling solutions that combine mechanical systems, electronics and software and also get systems ready for Industry 4.0 applications, including in the area of pneumatics. Compared with modular mechatronic systems, they offer an impressive combination of maximum standardisation and a very high level of flexibility. Since the Festo Motion Terminal is uncoupling pneumatic functions from the mechanical hardware for the first time and making them available via apps, a wide range of pneumatic motion tasks can be performed with just a single valve type. This offers many measurable benefits along the entire value chain.

The Festo Motion Terminal as a CPS solution not only enables complex movements like gentle retraction into the end position as well as various speed profiles or positioning tasks that were formerly only possible with servo-pneumatics or electrical automation; it also makes it easy to realise a wide range of functions, condition monitoring, preventive maintenance and it reduces energy consumption. Any higher purchase costs for CPS for OEMs and end customers are quickly compensated by hugely simplified processes, increased productivity and process reliability, as a look at the individual phase descriptions shows.

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