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Perspectives for Process Systems Engineering – a Personal View from Academia and Industry

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Abstract

Process systems engineering (PSE) has been an active research field for almost 50 years. Modeling, simulation and optimization technologies have been developed to a mature state. These technologies have been penetrating all fields of chemical engineering in academia as well as in industrial practice. Systems thinking has been established in industrial practice largely through powerful commercial process simulation software and through mandatory courses in most chemical engineering programs. This contribution reflects on the past, present and future of PSE. Special emphasis will be on the perspectives of this field from an academic and industrial point of view.

Keywords: Review, critical assessment, emerging fields, modeling, design, optimization, control, operations, numerical algorithms, software.

1. Introduction

Process systems engineering (PSE) is a largely mature and well-established discipline of chemical engineering with roots dating back to the 1950s [1]. The systems approach [2,3,4] has been successfully adapted and refined to address the needs of designing, controlling and operating chemical process systems in a holistic manner. PSE has been evolving into a specialized field at the interface between chemical engineering, applied mathematics and computer science with specific model-based methods and tools as its core competencies to deal with the inherent complexity of chemical processes and the multi-objective nature of decision making during the lifecycle of the manufacturing process. PSE has been successfully implemented as a discipline in its own right in academia, industrial practice as well as in chemical engineering education.

This paper is supposed to assess the status and the future perspectives of PSE from an academic as well as from an industrial point of view. It is not aiming at a comprehensive review of the numerous scientific achievements. Rather, it aims at an assessment (i) of the overall progress made with respect to the formation of a self-contained and independent scientific discipline and (ii) of the concrete contributions and impact in industrial problem solving.

The paper is organized as follows. Section 2 gives an introduction into the nature of PSE. The academic achievements and their impact on industrial practice are discussed in Section 3 to prepare for a look into the future. Both, clearly visible emerging trends as well as some desirable extensions of the scope of PSE are identified in Section 4. Only the main theses can be formulated due to space limitations of this proceedings paper. An in-depth discussion with many illustrating examples and suggestions for further reading will be covered in an extended version of this paper to be published elsewhere.

2. The nature of process systems engineering

General systems theory has been created as a scientific discipline in the 1930s by L. v. Bertalanffy, a biologist, aiming at a set of generic problem solving methods and tools to represent, analyze and synthesize complex systems in general regardless of the context they occur in [2]. The creation of such a meta-science was intended to overcome the progressing segmentation of the sciences on the one and to efficiently deal with systems complexity on the other hand [3]. Obviously, this motivation still holds today given the explosion of the scientific literature, the continuously progressing specialization in science and engineering and the increasing complexity of socio-technical systems. While general systems theory established the systems paradigm conceptually on an abstract level [4], *systems engineering* addresses all practical aspects of a multi-disciplinary structured development process that proceeds from concept to realization to operation [5]. Multiple business and technical objectives are considered to generate alternative solutions, to assess their performance and to finally provide a quality product meeting the users' needs. Formal problem representation and algorithmic problem solving capabilities implemented by means of computers have been expected to possibly automate or at least support human problem solving processes. General systems theory and to some extent also systems engineering provide generic problem solving principles to be applied in any kind of technological domain. These methodologies are powerful instruments to deal with complexity on a conceptual level but are necessarily weak when it comes to concrete problem solving in a specific domain. The generic principles have to be refined and enriched by specific domain knowledge on the scientific foundation and the engineering paradigms of a given technological field to be successful.

In this sense, PSE largely follows the systems engineering paradigm [5] but targets at (chemical) process systems. Its objectives have been defined by T. Takamatsu as follows [6]: *PSE is an academic and technological field related to methodologies for chemical engineering decisions. Such methodologies should be responsible for indicating how to plan, how to design, how to operate, how to control any kind of unit operation, chemical and other production process or chemical industry itself.* Hence, PSE is all about the systematic and model-based solution of systems problems in chemical engineering [7]. Grossmann and Westerberg [8], more recently emphasized the role of PSE as a means to support decision-making for the creation and operation of the chemical supply chain constituting of the discovery, design, manufacturing and distribution of chemical products. Hence, PSE is more than *computer-aided process engineering* (CAPE) since its core business is not merely the use of computers to assist problem solving but to address the inherent complexity in process systems by means of systems engineering principles and tools in a holistic approach and to establish systems thinking in the chemical engineering profession.

The field of PSE has been rapidly developing since the 1950s reflecting the tremendous growth of the chemical industry and its increasing economical and societal impact. Though, the roots of this field can be traced back to the UK and to the US [1,9], it has also been picked up very early on in the eastern part of Germany with a first book publication in German language in 1976 [10]. The PSE series of conferences has been established in 1982 with a first event in Tokyo (J) and follow-up conferences in Cambridge (UK, 1985), Sydney (AUS, 1988), Montebello (CA, 1991), Kyong-ju (Korea, 1994), Trondheim (N, 1997), Keystone (USA, 2000), Kunming (China, 2003) and Garmisch-Partenkirchen (D, 2006).

The paradigms of PSE are various. Modelling, simulation and optimization (MSO) of large-scale systems is a core technology to deal with the complexity of chemical processes and their products on multiple scales [8,11]. These technologies have to be implemented into easy-to-use software systems to render them accessible to problem solving practitioners. The systematic (explicit or implicit) generation and evaluation of a comprehensive set of design alternatives is considered to be a key to success. Integration of different problem formulations in the lifecycle and across multiple scales of chemical, spatial and temporal resolution is desirable to drive a design to a true optimum [12]. This attempt for integration tightly links PSE with a traditional focus on complete plants to both, *process intensification* [13] which exploits meso-scale kinetic phenomena to develop compact, highly efficient and multi-functional equipment, and to *chemical product design* [14] which exploits micro-scale molecular phenomena to tailor chemicals, materials, fuels and the like to display desired properties in some context of application. Model-based process control and operation support as well as enterprise and supply chain optimization together with their links to information technology, to operations research and management complement the various research tracks of PSE.

3. The past and present – academic achievements and industrial practice

The early years of academic research in the 1950s have been largely focused on mathematical modeling, simulation and optimization to design unit operations. These early works have been exemplarily exploring the potential of computers to deal with complexity and to assist in problem solving. Emphasis has been on individual unit operations like distillation and on chemical reactors. First results on modeling, simulation-based analysis and optimization have been reported to demonstrate the opportunities of applying mathematical concepts and algorithm to chemical engineering problem solving.

Research has been developing along many lines. Most importantly, methods at the interface to mathematics and computer science have been (further) developed and tailored to satisfy the needs of process systems problem solving. Mathematical modeling, problem formulations in design, control and operations relying on these models, numerical algorithms for their solution and software tools to empower the practitioner have been the major objectives. Scalability of all these methods, algorithms and tools to large-scale process systems has always been an important issue since the quality of a design crucially depends on the choice of the system boundary. This choice has to be controlled by the degree of interaction between subsystems rather than by the capabilities of methods and tools in dealing with problem complexity.

In the first phase of research, the scope of a unit operation has been widened to whole processes, later the site and even the supply chain have been covered in addition. The scope has not only been widened to cover larger spatial and coarser temporal scales, but also to cover an increasingly higher phenomenological resolution which opens up the spatial and temporal scales towards meso-scale and molecular micro-scale phenomena. Furthermore, the type of problems studied has been steadily evolving from steady-state and spatially lumped to dynamic and spatially distributed modeling and simulation, from an analysis of some design to systematic methods for process synthesis, from simple monitoring and control to model-based control and real-time optimization, supply chain management and logistics. Accordingly, problem formulations have been getting more and more integrated. Examples include control-integrated design, integrated product-process design, green designs accounting for all aspects of sustainability and last but not least complete life-cycle assessment.

These attempts towards increased scope of integration also opened up the interfaces to the natural sciences to encompass the molecular level phenomena and to economics and management sciences to address the process as part of its supply chain and even of the global market.

The most important achievements of the PSE research community are related to the development and deployment of mature and reliable methods and tools for steady-state and dynamic simulation and optimization of processes described by strongly nonlinear large-scale process models. Nowadays, there is no serious process design and development activity in industry not heavily relying on modeling and simulation technology. Despite these significant achievements some limitations still exist from the practitioner's point of view. For example, we still have no adequate methods and tools to deal with solids and biotechnological processes, to properly link models to lab- or pilot-scale experiments or to the production process, to efficiently formulate very large-scale models and design problems, or to document, maintain and reuse models across the lifecycle of the plant.

Significant progress has also been made in control and operations. Plant wide control structure synthesis has progressed, model-based control and real-time optimization has reached a reasonable level of maturity. Production planning and management including the coverage of complex logistics is in an advanced state of development. However, there are many more open issues in control and operations than in design.

IT methods and tools to better deal with multi-disciplinary, cross-institutional and geographically distributed design processes have obtained surprisingly little attention in academia despite the enormous potential for cost reduction and quality improvement.

Furthermore, current research and development concentrates on application areas with high profitability, in particular on large-scale, continuous production processes. The extension to small-scale and often multi-purpose production facilities has yet not been successfully established.

Model-based PSE methods and tools are indispensable in today's industrial practice. They have proven to be profitable and reliable in a very broad range of applications [15]. This includes process synthesis and design, process performance monitoring and optimization, operator training simulation, soft sensoring, production planning and supply chain optimization, and advanced model predictive control, just to mention a few but very important topics. However, it is still a challenge in many cases to realize economically attractive projects with model-based applications using currently available methods and tools, which have to offer short pay-out times to successfully compete with other projects. For example, the application of mixed-integer programming in process synthesis or nonlinear model-predictive control in process automation can be found only rarely in industrial practice, if at all. Obviously, the main driver for industrial application is not the mere existence of a certain problem solving method in academia, but also the availability of these technologies in robust software tools and more importantly its profitability in routine industrial problem solving. Hence, it might be concluded that the profitability of those methods is at least not widely recognized in today's industrial practice for whatever reasons.

4. The future

There are a number of emerging fields in PSE which are already under investigation in a number of research groups and which are considered to be of high future relevance. We first focus on new methodologies and then move on to challenging and rewarding fields of application.

4.1. PSE Methodologies

Linking experiments to models. Modeling does not only involve the formulation and solution of the set of model equations but also the identification of the model structure and the model parameters from experiments either on the plant, pilot or lab scale. The modeling of the measuring instrument for improved calibration to transform the measured data into physically meaningful quantities has to be addressed in particular in the context of high resolution measurements aiming at the discovery and discrimination of competing mechanistic models. Systems engineering methods can be favorably applied to obtain valid models at minimum experimental effort [16].
Multiscale and lifecycle modeling. While MSO technology has been focusing traditionally on the scale of the unit and above, the integration of process, equipment and product design requires a unifying modeling approach spanning all the scales from the molecular micro-scale to the mega-scale of a site [8, 17]. The idea of multiscale modeling is the computation of some desired information on a finer scale to pass it to a coarser scale or vice versa. By traversing the scales, not only the number and type of degrees of freedom typically change but also a switch in the modeling paradigm – most notably from the continuum to some molecular paradigm – is typically involved. The documentation and reuse of models along the lifecycle of the plant is a closely related issue [12].
Equipment synthesis and design. Multi-functional units, micro-reactors and plants can benefit from MSO technologies applied to the meso-scale to achieve process intensification. Partial differential equation models dominate these scales and contribute to complexity. A prominent example is the analysis of mixing processes by means of computational fluid dynamics. The design and synthesis of such multi-functional units lead to demanding optimization problems with PDE constraints. Besides the usual operational degrees of freedom the arrangement of subunits and their geometric design are subject to optimization.
Process synthesis. Process synthesis, though a classical topic of PSE, has not received sufficient attention in an industrial environment. Educated guesses and intensive simulation studies still dominate industrial practice. Easy to use model-based process synthesis methodologies not only for large-scale

continuous plants but also for small-scale batch plants, could make a tremendous difference in lifecycle cost. Such methods not only have to support the generation and evaluation of an enormous number of alternative process structures but should also facilitate the integration of engineering experience, the support of multi-objective decision making, and the systematic management of risk and uncertainty. A gradual refinement of the design specification to reflect the increasing level of confidence in the prior knowledge would be highly desirable.

Process operations and management. In industry, there is a distinct shift in focus from controlling a process plant in isolation towards an agile management of a process plant as an integral part of the supply chain comprising a number of enterprises in different geographical locations. While process control aims at attenuating disturbances and maintaining the plant at its desired steady-state, future process operations will have to exploit the dynamics of the environment – most notably caused by changing market conditions – by means of model-based optimization techniques. They have to integrate vertically across the automation hierarchy of a single process plant and horizontally along the supply chain connecting various plants by material and information flows. The objective of plant operation is hence moving from controlling the plant at its setpoint to maximizing its economics in real-time subject to equipment, safety and product related constraints [18]. Obviously, such a forward looking understanding of process operations sheds new light on the integration of process and control (or in more general terms operational support) system design which – together with the operating personnel – has to guarantee a fully functional process plant in nominal as well as exceptional operating regimes [19]

IT support of engineering design and development processes. Understanding and managing design processes is at the heart of systems engineering research and practice [20]. Despite the fact that this topic has been brought up in PSE quite some time ago [21], only little activity has been observed in academia despite the tremendous opportunities and enormous potential for cost reduction and quality improvement in industrial design processes. An integrated view on the design process in the various lifecycle phases together with IT methods and tools for its support have been the focus of the IMPROVE project at RWTH Aachen [22]. The focus of this research has been on the modeling of creative, multi-disciplinary, organizationally and geographically distributed work processes in chemical engineering and the development of novel, work-process centered support functionality which integrates existing engineering design tools in an a-posteriori fashion. A new generation of technologies is required to come up with cost-effective and tailor-made solutions which reflect the culture and the specific work processes of an enterprise. Semantic technologies seem to offer an attractive platform for knowledge capturing, information management and work process guidance.

4.2. Emerging application domains

While the research in PSE has been focusing on novel methods and tools, there are challenging emerging fields of application. Reaching out into new application domains is rewarding in two ways. Firstly, PSE offers a powerful set of methods and tools for systems problem solving in all those domains which share a lot in common with chemical engineering though they are not considered to be part of this field. Such domains are characterized by interacting transport phenomena in complex systems constituting of non-trivially interacting subsystems. Secondly, the transfer of methods and tools from one domain to another typically reveals new requirements which have not been faced yet. Hence, the migration of PSE methods and tools to another domain requires at least the tailoring of existing or even the development of completely new methods and tools to address the specific problems of the new domain in an effective way. Hence, reaching out to novel areas of application can be considered a necessity in order to avoid getting trapped in marginal improvements of existing PSE methods and tools. We will point out a few of those emerging application domains for the sake of illustration.

Processing of renewable feed stocks. There is a common understanding that the chemical and petroleum industries will have to switch from oil and gas carbon and hydrogen sources to alternative raw materials sooner or later. Most likely, the processing of coal to synthesis gas will see a revival in the near future at least in some parts of the world. However, in the longer run, the exploitation of renewable resources will face increasing interest. Solar powered thermo-chemical or electrical water decomposition is a potential green hydogen source. The processing of lignocelluloses from biomass feed stocks into platform chemicals or automotive fuels – preferably without competing with the food chain – is another challenge which will come up in the next decades. Novel large-scale processes will have to be developed. They will have to deal with new classes of materials, new chemical and bio-chemical pathways and with new intensified processing technologies. PSE is expected to significantly contribute to efficient development processes resulting in environmentally benign and sustainable manufacturing processes.

Small-scale production. PSE has been largely focusing on methods and tools for the design, control and operation of large-scale chemical processes operated in continuous mode. The scale of operation and consequently the potential economical benefit of optimized designs and operational strategies justify demanding modeling projects and costly implementations of model-based applications. PSE methods and tools have largely been focusing on this problem class in the past. However, there is a well-known trend towards small-scale productions in multi-purpose plants in particular in the highly developed countries. The variety of chemistries and the low volumes do not allow for expensive modeling studies. Model development and exploitation has to accompany process development and manufacturing following an incremental model refinement and process improvement strategy. Novel modeling strategies and tailored model-based methodologies and applications – possibly radically different from existing problem solving techniques – seem to be indispensable for this class of problems to facilitate economically attractive model-based methodologies.

Integrated micro-plants. Micro-reaction technologies have been steadily maturing in recent years. There is a tremendous effort spent on the development of industrial strength solutions not only aiming at the production of low-volume and high-price specialty chemicals but also of bulk intermediate chemicals. Some PSE methods and tools can be migrated to favorably address this class of problems. However, the distributed nature of the required process models, physico-chemical phenomena only emerging or becoming dominant in micro-plants as well as numbering-up rather than scaling-up of production facilities to larger capacity will call for novel PSE methods and tools or even for radically different paradigms.

Functional and nano-structured products. The chemical industries have been largely focusing on fluidic or particulate intermediate products. In recent years, a number of chemical companies have been reshaping the product portfolio to cover functional end-products often showing a high level of complexity in the systems engineering sense. Examples include lab-on-the-chip technologies for medical diagnosis or the electronic book. The design and development of such functional products resemble to some extent the design and development of manufacturing plants. Hence, PSE methods and tools can be favorably migrated and adapted to effectively address these kinds of design problems. Particulate or nano-structured products such as carbon nano-tubes, nano-particle additives, catalysts, nano-scale functionalized surfaces or nano-composite materials – although completely different in nature – also require the tailoring of PSE methods and tools (see e.g. [23] for an attempt in pharmaceutical product-process engineering). A first challenge is the modeling of the product which has to go well beyond chemical composition. Structure-property relations are of key importance to describe the function of the product. Next, the relation between the characteristic product properties and the processing conditions need to be understood. Multi-scale modeling – with particular emphasis on the molecular level – and novel PSE methods and tools employing such multi-scale models are still missing to a large extent.

Systems biology for personalized medicine. The business of the pharmaceutical companies has been changing in recent times. Rather than discovering and manufacturing an active agent becoming part of a relatively simple tablet or capsule the market calls for complete diagnostic and therapeutic and personalized solutions. Diagnostic systems include sophisticated devices including array, biochip, biomarker and enzyme technologies to assess the status of the patient in an impressive level of detail. Modeling and simulation of the human body on multiple scale provides the information necessary to develop highly efficient therapy strategies which aim at providing the active agent in the desired level of concentration right at the biological target such as a tumor by appropriate dosing strategies. Successful therapeutical strategies require multiscale modeling of the metabolism on the level of cell, the organs and the complete human body on the one hand and the drug delivery and dosing systems on the other. The design of such therapeutic and diagnostic systems shares all the interesting features of process systems problem solving. It offers a plethora of interesting systems problems which should be amenable to PSE methods and tools after appropriate tailoring.

Infrastructure systems. Infrastructure systems comprise water and energy supply networks, waste processing including the recycling of valuable materials, transportation systems for people and goods and telecommunication systems. The complexity of such systems, in particular in urban centers has reached a critical level which calls for systematic analysis and synthesis method to establish proper functioning even in anomalous situations such as the recent collapses of a part of the electrical network in Europe and the US. The design and the management of active grids of interconnected infrastructure components of different kinds which adapt to supply and demand is a rewarding problem for process systems engineers [24]. Though infrastructure system improvement and design has a lot in common with the design of agile supply chains and their embedded process plants, there is the socio-economical dimension in addition to the technical dimension which calls for tailored methods and tools.

4.3. Towards a sustainable strategy for the future of PSE

The reflection on PSE subject areas has shown that the scope has widened since the early days and that it will continue to widen in the future. There is the obvious risk that a widening scope ultimately results in a diffuse profile of the discipline. Hence, it might get more and more difficult to define the boundaries and the essential core of expertise of PSE. Consequently, a reassessment of the essential core and the boundaries is mandatory if PSE does not want to risk loosing its appeal [25].

Where are we? The core competence of PSE has been undoubtedly related to MSO methods and tools and their application to the analysis and design of single pieces of equipment as well as of largely continuous complete processes. The further development and the application of these technologies are not anymore restricted to PSE experts. In particular, the application of modeling and simulation methodologies has not only become an integral part of problem solving in all segments of the process industries, but it is also considered to be one of the indispensable tools to routinely assist and accelerate the research process in all chemical engineering disciplines. Undoubtedly, there is a marked difference in the level of professional competence in MSO of both industrial practitioners and academic researchers on the one and PSE experts on the other hand. However, it is often not easy for the PSE experts to convince their colleagues on the value their expertise can bring to the problem solving process.

Furthermore, research on novel MSO methodologies and tools is not restricted to the PSE community anymore. For example, research on multi-scale modeling, molecular modeling, computational fluid dynamics or logistics and supply chain modeling is carried out by experts who would not consider themselves as process systems engineers. Even worse, most of these researchers would not even know about the core ideas of PSE and the relevance to their research.

Facing the risk. For these reasons, the PSE community is at risk to loose attention and influence in its core area of activity and hence its impact on research and industrial practice. A loss of reputation resulting in a loss of attractivity to students and young scientists, a loss of interest in industry and last but not least a loss of sources of funding could become consequences if no appropriate action is taken. Such a development seems to be inevitable to the authors, if the PSE community will only focus on the migration of its knowledge into non-traditional application domains which are not yet fully exploited. The following measures are suggested to diminish this risk.

Back to the roots. We need to refocus on the classic PSE topics, most notably modelling and numerical algorithms implemented in robust software tools, integrated product and process design, and last but not least manufacturing process management. The research should concentrate on the foundations of model-based methods. Systems thinking and the holistic treatment of design problems is a sustainable value in itself, well beyond the use of computers on simulation-assisted problem solving employing off-the-shelf commercial tools. The extension of the system boundaries – towards coarser scales to the supply chain and beyond and towards finer scales to the molecular level – is rewarding from the academics' as well as the practitioners' point of view. Such extensions naturally lead to an integration of problem formulations across the product and process lifecycles.

Reaching out. PSE has a strong culture in cross- and trans-disciplinary collaboration. Method development requires PSE to team up with experts in the fundamental scientific disciplines, in particular with experts in mathematics and computer science, on the one hand. On the other hand, PSE experts have to absorb and integrate MSO technologies developed in neighbouring fields (such as computational fluid dynamics, molecular simulation and the like) in the systems tradition to provide the domain experts the tools to address systems problems. PSE should also bridge the gap to established disciplines in engineering and science dealing with systems problems and offer the sensible application of the powerful PSE toolbox to solve the problems of those disciplines. Obviously, PSE first has to take the initiative, and next has to raise confidence of the collaborators in its skill set. Often a natural reluctance has to be overcome, until a win-win situation can be proven in a concrete collaborative project. This interaction should also lead to an improved split of work between systems engineers and domain experts to exploit the available expertise in a synergistic manner towards high quality solutions to complex problems of a systems nature. Some of the scientific target areas have been discussed in the last subsection. In all these cases, PSE should not content to the role of a scientific service provider but should consider itself a partner to the domain experts who has to offer a self-contained contribution which is a crucical stepping stone to solve the scientific problem of the domain.

Towards a new paradigm. The future challenges in chemical engineering [26] are essentially systems problems. PSE can contribute to their solution if it reshapes its profile and readjusts its target of research. *Process Systems Engineering* has to further develop from a systems engineering discipline with a focus on process systems problems on the granularity of a unit, a plant, a site and beyond, grossly simplifying the meso- and micro-scale phenomena, to *Multi-scale Product and Process Systems Engineering (MP^{2}SE),* a chemical engineering discipline which bridges the scales and addresses product and process design in an integrated manner. Such a shift requires a recalibration of the interfaces of PSE to the other sciences; in particular, the interfaces to the natural sciences and to core chemical engineering – probably neglected in the past in favor to the interfaces to mathematics and computer science – have to be re-emphasized.

Functionally integrated process units combining at least two functional objectives in one piece of equipment (e.g. reactive distillation) and intensified process units systematically exploiting meso-scale phenomena (e.g. intensified energy supply by microwaves or ultrasound) are naturally incorporated as subsystems in the complete plant in the spirit of systems engineering. Hence, PSE and process intensification under the roof of MP^{2}SE are faced with a very natural way to establish not only a friendly symbiosis [13] but a strong partnership with an increasing impact on the chemical engineering profession.

Furthermore, product design has to rely on the molecular sciences, in particular chemistry, physics and biology, to tailor product properties via a profound understanding on the molecular level. The integration of this objective with the process plant scale comes again naturally because the processing conditions will ultimately determine the product properties.

If the PSE community will succeed in this transformation process, a bright future with sustainable impact on the chemical engineering sciences and related fields can be expected.

5. Summary and concluding remarks

We have sketched the past and present of PSE and have reflected on the future of our field. PSE has significantly contributed to the chemical engineering profession in the last decades by providing MSO technology to routinely address demanding and large-scale process problems in academia and industrial practice. Systems thinking and systems problem solving are considered to be an indispensable ingredient in the academic education of chemical engineers and in

industrial practice. Consequently, the objective of PSE is the penetration of other chemical engineering disciplines with systems thinking.
The risk of loosing its identity can only be diminished by long-term research on the core expertise with a focus on model-based systems engineering methods and tools to assist problem solving in order to establish high quality solutions. A plethora of interesting and challenging problems will show up if this research on the core MSO technologies is positioned in the broader perspective of MP^2SE.
Nevertheless, PSE has to also reach out and contribute to the solution of systems problems in related disciplines, not in competition but in close collaboration with the domain experts. PSE has to strengthen its position in chemical engineering by cooperation within and outside its community. The PSE community has to further emphasize its efforts to further develop and integrate methodological advances into industrial work processes by means of a combination of technology push and market pull. Specific technology transfer agencies such as AixCAPE e.V. [27] may act as an enabler of the interaction between academia and industry.
Since PSE is a relatively small community in between the disciplines with many interfaces and with a lot of commons grounds with systems engineering communities in other fields of science and engineering, one may think of joining forces to form a larger community spanning different engineering and scientific fields. There is scope for such a concentration of forces, since model-based and computational approaches to systems problem solving will rely on the same principles, conceptual and algorithmic methods and tools regardless of the type of engineering discipline.

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