Appendix E: Literature studies

Literature study for Section 2 - Process life cycle of continuous processes

For the search in the two databases, the following restrictions were applied in addition to the search terms:

- **Period** - Only results from the last 20 years were used. That is, from the beginning of 2002 until December 19, 2022.
- **Language** - Only publications in English have been selected
- **Title** - The search terms had to appaear in the title

The search terms and the corresponding results are listed in Table 1. The criteria for the stepwise selection of suitable publications are described by keywords in the "Criteria" column. Results for the search terms listed were taken from both the databases. In both cases, only publications published from 2002 onwards were selected to reflect the research activities of the last 20 years. The selected search terms had to appear in the title. Publications were sorted out if they were not written in English or if there were duplicate hits. In the case of duplicate results, the entry with fewer citations was deleted. For the next reduction, the titles of the publications were evaluated. Since the search terms essentially refer to continuous processes, the adjective "continuous" in the title of the respective paper was only allowed to refer to the process itself and not the extended search term (e.g., "continuous process evaluation" shall deliver results describing the evaluation of continuous process, but not the continuous evaluation of processes). The additional search terms such as “evaluation” have been selected in order to show which approaches for the description, analysis, modification and development of new continuous processes have been pursued in process industry. The results can be thematically separated by assigning a phase of the process life cycle and a thematic focus to each paper. For this classification we chose to combines the process life cycle description of [440] and [207]. In this work, the process life cycle consists of the phases Design, Configuration, Enactment, Evaluation and Change. Following the definitions in [440] and [207], we interpret the phases for processes in process industry as follows: Continuous processes in process industry are in the Design phase if the paper focuses on the development, modeling, simulation and validation of models of continuous processes. The Configuration phase is entered as soon as the concrete implementation of the process or the commissioning is described. The Enactment phase comprises the

execution of a continuous process. This also includes the execution on laboratory scale process plants that can server as a blue print for industrial applications. The continuous process is monitored at run-time and process data is collected. In the Evaluation phase, the collected process data is evaluated and analyzed. Publications fall into this category if additional insights are derived from the collected data using specific methods. The last phase, “Change”, classifies publications which describe an approach to improve a continuous process based on the preceding collection and analysis of process data. The second classifier is the thematic focus of the research, which is derived from the process mining perspectives as described in [405] and [457]. Here, the “Control” perspective is chosen for papers which evaluate different process flows to reach the same or a similar final product. An example is the comparison of a discrete or batch and an equivalent continuous process. Papers have been assigned to “Data” if the collected process data has been the research focus. The class “Time” marked papers that concentrate on events or time as a process parameter. “Resources” can be used as a class for publications, that focus on the involvement of technical equipment and operators.

Of a total of 700 initial search results, 565 were selected based on matching titles. If the title did not indicate that the work dealt with continuous processes, the corresponding results were deleted. After reading abstracts and keywords and extracting further details from the main text, a total number of 401 papers has been selected and classified. In Tab. 1 the numbers of initial hits and selected publications per key words and database are listed. Table 2 on the other hand shows the respective references that have been assigned to the respective process life phases and perspectives.

Table 1: Literature study on the life cycle of continuous processes in process engineering

Database	**Search terms**	**Hits**	**Selected results**	**Criteria**
Scopus	continuous process optimi* [sation | zation]	378	288	Continuous refers to process
Scopus	continuous process mining	22	3	Continuous refers to process
Scopus	continuous process evaluat* [e | ion]	113	73	Continuous refers to process
Scopus	continuous process valid* [ation | ate]	47	25	Continuous refers to process
Scopus	continuous workflow optimi* [sation | zation]	3	3	Continuous refers to workflow
Scopus	continuous workflow mining	3	0	Continuous refers to workflow
Scopus	continuous workflow evaluat* [e | ion]	2	0	Continuous refers to workflow
Scopus	continuous workflow valid* [ation | ate]	0	0	Continuous refers to workflow
dblp	continuous process optimi* [sation | zation]	84	4	Continuous refers to process
dblp	continuous process mining	9	0	Continuous refers to process
dblp	continuous process evaluat* [e | ion]	27	2	Continuous refers to process
dblp	continuous process valid* [ation | ate]	8	2	Continuous refers to process
dblp	continuous workflow optimi* [sation | zation]	1	1	Continuous refers to workflow
dblp	continuous workflow mining	1	0	Continuous refers to workflow
dblp	continuous workflow evaluat* [e | ion]	2	0	Continuous refers to workflow
dblp	continuous workflow valid* [ation | ate]	0	0	Continuous refers to workflow
	SUM	**700**	**401**	

Table 2: References for the literature study on the life cycle of continuous processes in process engineering

Persp. / Phases	**Control (61)**	**Data (265)**	**Time (59)**	**Resources (45)**
Design (186)	[31],[26],[95], [98],[214],[240], [410],[477],[267], [303],[298], [124],[147],[156], [180],[211],[375], [376],[445],[456], [458]	[329], [17], [286], [199], [79], [143],[160], [323], [26],[37], [261],[345],[374], [382],[178], [285],[417],[371], [126],[263],[319], [305],[324],[353], [179],[3],[6], [18],[21],[29], [39],[44],[68], [87],[88],[241], [93],[94],[96], [101],[129],[131], [132],[134],[137], [141],[142],[146], [150],[152],[157], [162],[165],[166] [177],[176],[192], [194],[204],[219], [245],[248],[250], [252],[255],[262], [265],[280],[300], [301],[311],[315], [328],[332],[334], [340],[341],[347], [348],[349],[363], [365],[369],[377], [388],[389],[391], [393],[394],[397], [404],[412],[420], [422],[429],[430], [432],[435],[437], [447],[446],[91], [460],[465],[468], [469],[470],[471]	[89], [268],[102], [416],[80],[122], [309],[174],[210], [218],[251],[284], [288],[325],[342], [352],[351],[354], [144],[398],[399], [414],[434],[443], [455],[459],[464], [472],[473],[474]	[268],[38],[78], [15],[22],[63], [64],[309], [270],[312],[335], [342],[352],[351], [354],[144],[375], [376],[399],[414], [434],[455],[459], [464],[472],[473], [474]
Configuration (15)	[30]	[418],[5], [247],[249],[281], [427],[346]	[34],[35],[296]	[346],[273],[260], [53]

Persp. / Phases	Control (63)	Data (270)	Time (59)	Resources (45)
Enactment (75)	[283],[96],[362], [415],[4],[269], [84],[441], [360],[336],[386], [127],[130],[135], [170],[183],[229], [302],[356],[436], [442],[450],[462], [461],[467]	[267],[276],[274], [8],[184],[409], [433],[140],[103], [212],[360],[1], [12],[19],[23], [51],[57],[83],[85], [107],[115],[116], [117],[118],[150], [153],[164],[197], [209],[308],[339], [413],[423],[451], [452],[453],[346]	[331],[224],[463], [55],[441],[294], [149]	[295],[224],[346], [14],[46],[277],
Evaluation (69)	[454],[110],[84], [72],[97],[113]	[448], [89], [167] [16], [238], [282], [112],[67],[407], [47],[20],[185], [278],[279],[358], [259],[8],[108], [56],[100],[99], [140],[318],[306], [2],[9],[11], [24],[25], [27],[28],[54], [62],[86],[90], [106],[121],[138], [161],[169],[180], [184],[191],[244], [254],[257],[293], [313],[326],[337], [364],[370],[400], [411],[419]	[226],[357],[186], [7],[151]	[208],[350],[226]
Change (85)	[98],[298],[75], [139],[148],[232], [242],[367]	[45], [13], [163], [401],[2],[10], [40],[48],[58], [66],[69],[92], [136],[145],[327], [171],[175],[182], [190],[193],[205], [206],[211],[215], [216],[217],[222] [223],[227],[235], [236],[239],[316], [266],[275],[287], [289],[320],[321], [330],[359],[366], [368],[373],[378], [384],[387],[396], [408],[424],[425], [426],[428],[438], [439],[444],[466], [475]	[36],[70],[76], [200],[221],[220], [225],[233],[307], [310],[379],[213], [380],[381]	[104],[401],[74], [310],[381]

Below, we provide thematic summaries for all the papers of the literature reviews grouped by different perspectives:

Control perspective:

Papers assigned to this class discuss the development of new process variations, with focus on the difference between batch and continuous operation. These papers cover the design phase, which is characterized by modeling and simulation activities. The comparison of batch and continuous processes deals with the different procedures in these process types (e.g., [95],[124]). For the next process life cycle phase, configuration, one reference could be identified that discusses preliminary tests to find optimal process parameters [30]. As this reference also includes simulation methods, it is contained in both, design and configuration phases. In the enactment phase, processes are executed and parameters are monitored. In this phase, from the control perspective, batch and continuous processes are often compared by implementing both operation modes. In process industry, a common practice is to use laboratory scale plants and reactors to execute processes before deployment to the industrial scale plant. Publications discussing process execution and process monitoring with the focus on process flow variations, batch and continuous, either on laboratory or industrial scale, can be assigned to this class (e.g., [84],[127]). Publications in this class may also discuss processes with a completely new setup (i.e., alternative technical realizations) as alternative to common process flows (e.g., [229]). Papers in the evaluation phase focus on the control perspective regarding the evaluation of different process flows (e.g., [110],[72]). The last process life cycle phase, change, with focus on the control perspective, comprises papers discussing the revision of processes. The revision measures are derived from analysis of different process flows (e.g., [98],[148]).

Data perspective:

In the design phase, publications focusing on the data perspective are dealing with the modeling and simulation of processes, taking process parameters (i.e., measured and monitored values) into account. A typical use case is the simulation of a process based on a model in order to optimize process parameters (e.g.,[142],[205],[248]). In the configuration phase the goal is to test optimal process parameters on laboratory equipment prior to deployment to industrial equipment(e.g.,[247],[427]). In the enactment phase, process parameters are monitored and collected for further validation steps or comparison to process models (e.g.,[423],[150]). Papers discussing processes in the evaluation phase focus on the evaluation of preliminary collected process parameters (e.g.,[140],[138]). In the change phase, the de-

velopment and application of optimization measures based on the evaluation of process parameters is discussed (e.g.,[190],[217]).

Time perspective:

In the design phase, the time perspective is represented by taking time into account as a process parameter. For example, time is important for key performance indicators or life cycle estimation for process equipment (e.g., [218],[251]). Publications with focus on time, discussing preparations for process execution (configuration phase) treat time as a process parameter that needs to be taken into account (e.g.,[34]). Time as a process parameter is also important in the enactment phase (e.g., [55],[224]). For the evaluation of a process, processing or cycle time is in the focus (e.g., [7],[151]). Again, in the change phase, optimization efforts are described, especially timing (e.g., timing of start up or shut down sequences) and other physical parameters. (e.g., [200],[221]).

Resource perspective:

From the resources perspective, the process equipment and operators are of interest. Therefore, in the design phase, process reactors, plants, or smaller parts, are modeled and simulated (e.g., [270],[312]). In the configuration phase, the dimensioning or setup of process equipment as well as the training of operators take place (e.g., [346],[260]). In the enactment phase, data for further analysis of the process equipment and tasks performed by operators is collected (e.g., [295],[46]). In the evaluation phase, the collected process parameters are again the basis. Here, the performance of process equipment and operator actions are evaluated (e.g., [208],[226]). In the change phase, insights gained from the preliminary evaluation of process parameters related to process resources, help to define measures for optimization (e.g., [301],[381]).

Literature study for Section 3 - Automation of continuous processes in industry

A literature search with results from the last 20 years on the keywords “automation industry continuous process” using the Scopus database generates 336 of initial results. Search criteria are a publication date from 2002, written in English as well as the search terms had to appear in the title, in the abstract or in the keywords. A first reduction of the results was achieved by checking the titles. In a next step, the abstract, keywords and main text of the publications were checked. Publications indicating that the search term “continuous” did not relate to “process” and works that were not available for evaluation were excluded

from the results. The remaining results were used to determine which of the requirements play a role in the respective work.

Table 3: Characteristics of continuous processes represented in literature of the last 20 years

Characteristic	**References**	**Count**
Continuity	[41],[43],[60],[77],[111],[119],[155],[158],[172],[188],[189],[196], [264],[290],[299],[304],[344],[128], [383]	19
Break conditions	[41],[71],[73],[77],[111],[119],[158],[187],[203],[228],[230], [234],[333],[343],[348],[390],[392],[395],[402]	19
Real-time process	[32],[33],[42],[43],[49],[50],[59],[61],[65],[71],[73],[81],[82],[105], [111],[114],[120],[123],[125],[133],[154],[155],[158],[159],[168],[181], [172],[173],[188],[189],[196],[198],[201],[203],[230],[231],[234],[237], [243],[246],[253],[256],[258],[264],[271],[272],[291],[292],[299],[304], [314],[317],[322],[333],[338],[343],[344],[128],[348],[355],[361],[372], [383],[385],[390],[392],[402],[403],[406], [421],[431],[449],[476],[297],[52]	75
Parallelism	[32],[81],[111],[125],[154],[189],[203],[253],[299],[304], [338],[344],[348],[297],[52]	15
Exception handling	[32],[41],[43],[49],[61],[73],[77],[82],[111],[114],[120],[133], [154],[155],[158],[159],[168],[172],[187],[195],[198],[201],[203],[228], [231],[234],[237],[246],[291],[299],[304],[314],[333],[343],[344],[128], [348],[355],[372],[390],[392],[395],[402],[406],[421],[476]	46
Limited complexity	[33],[41],[49],[61],[82],[109],[119],[133],[155],[187],[188],[189], [202],[203],[228],[253],[258],[304],[343],[372],[383]	21

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