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The Integration of Process Simulation within the Business Architecture

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Abstract. To deal with increased competition and technological change, organizations need to strive for a continuous improvement of their business processes. To realize this, simulation models offer a suitable approach to test different process alternatives. In particular, discrete-event simulation employs stochastic models to support operational decision-making inside the organization. However, this operational focus might cause suboptimization with respect to higher-level organizational goals. Therefore, an integrative view on the business architecture might align strategic, organizational and process perspectives. This has resulted in the expansion of the Process-Goal Alignment modeling technique with a simulation mechanism. This paper augments the previous research efforts by including simulation results expressed by confidence intervals, such that the results of process simulations can be accurately integrated with the overall business performance. The design of the business architecture simulation technique is guided by the Design Science Research methodology. This paper communicates about both the design and the demonstration of the simulation technique, while the evaluation of this artifact is subject to future research.

Keywords: Discrete-event simulation · Business Architecture · Design Science Research.

1 Introduction

Over the years, businesses have been facing intensified competition and an accelerated pace of technological change [1]. To keep a competitive advantage in this dynamic environment, they are continuously looking for ways to improve their business operations. During improvement processes, different alternative process designs need to be explored and the impact of strategic decisions needs to be evaluated with accuracy and speed [2]. However, it is often complicated to adjust business processes in practice as multiple adjustment rounds are needed to fine-tune the operational design and unforeseen circumstances can occur. This brings high risks and costs, which might endanger the business operations.

Simulation is used as a cost effective, accurate and rapid approach to analyze business processes and to evaluate different redesign alternatives by comparing their performance [2]. In particular, discrete-event simulation (DES) is an analytical approach that is useful to support decision-making activities [3] by making use of stochastic models that consider processes as queues of activities, where state changes occur at discrete points of time [4]. Although this DES application can result in process optimization on an operational level, the impact on the overall business performance is overlooked [5]. Consequently, it is not possible to realize the simultaneous optimization of operational performance and profitability [6]. This causes suboptimization when making business decisions.

To tackle this problem, the PGA (i.e. Process-Goal Alignment) modeling technique [7] offers an integrative representation of the business architecture by combining the strategic, infrastructural and process perspectives. In [8], a PGA simulation technique was developed to support the analysis of possible business process improvements. However, this technique assumes that process simulation results are expressed by a single value. As simulation results expressed by confidence intervals give more accurate information [2], the PGA simulation technique proposed in [8] needs further development such that accurate operational performance results obtained by process simulations can be integrated with the overall business performance (i.e. objective 1). The further development of the simulation technique must also enable to evaluate different process designs at an overall business performance level, such that decision-making within organizations can be improved [3, 5] (i.e. objective 2).

To address the solution objectives, the proposed business architecture simulation technique extends the work in [8] by a refinement of the following mechanisms: (i) obtaining process simulation results with a confidence interval that allows to make a univocal statement about the performance, (ii) propagating process simulation results throughout the business architecture hierarchy and (iii) analyzing the impact of operational changes on the realization of the organizational goals.

The proposed business architecture simulation technique is developed according to the Design Science Research (DSR) methodology. Besides the background literature in Sect. 2, this paper presents work-in-progress that includes the following DSR activities [9]: problem identification and motivation (Sect. 1), definition of the objectives for a solution (Sect. 1), design and development of the business architecture simulation model (Sect. 3) and the demonstration by means of an illustrative case example of a company operating in the industry of beauty products (Sect. 3). The evaluation of the artifact is not yet performed and is subject to future research. In this respect, Sect. 4 discusses what is needed to evaluate the functionality and effectiveness of the proposed artifact, such that further improvement opportunities can be detected [10].

2 Background

2.1 Related Work

Related research has attempted to link process simulation with goal modeling approaches. In [11], the i* modeling language is extended to represent the dynamic interactions between goals and dependencies, which establishes a link with the action language ConGolog and allows for process simulation. A similar idea is adopted in [12], which proposes a methodology to map an i* Strategic Rationale diagram to ConGolog by process specification annotations. Kushnareva et al. [13] introduce an approach to design a process from intentions to executable scenarios. This approach makes use of the MAP formalism to capture the intentions behind a crisis management process, while statecharts are employed at the operational level. This allows to analyze how process goals can be achieved by various scenarios. In [14], an approach is presented that employs the User Requirements Notation to model goals and processes and to build Key Performance Indicator models. This is combined with a Business Intelligence tool to monitor and measure business processes, with the aim of an iterative improvement of the business goals and processes.

The presented business architecture simulation technique adopts a different perspective as it considers the infrastructure perspective as the key intermediate layer to align the organizational goals and processes [15]. This is important, as it considers the business architecture as a multi-perspective blueprint of the enterprise that provides a common understanding of the formulation of the organizational objectives (i.e. the strategy perspective), the implementation of the strategy (i.e. the infrastructure perspective) and operational process decisions (i.e. the process perspective) [16].

The work in [17] executes attack simulations based on system architecture models. This is realized by the integration of the Meta Attack Language with an approach to visually model security domains in ArchiMate. Although this approach specifically focuses on cybersecurity, it shows the benefit of integrating simulation results with a multi-perspective view on the problem domain.

2.2 PGA Modeling Technique.

The PGA technique [7] is an enterprise modeling language that aims at realizing strategic fit by providing a coherent view on the business architecture. Strategic fit means the alignment of the company's strategy with the organizational activities or processes [18]. Within the business architecture, the infrastructure perspective covers the implementation of the enterprise strategy and therefore acts as an intermediate layer to align the strategy and process perspective of an organization [15]. Hence, the PGA modeling technique consists of the different elements that are part of the strategy, infrastructure or operational perspectives. The strategy perspective contains the organizational goals that describe the vision and strategy of the company. The infrastructure perspective represents strategy implementation, that describes which processes a company needs to perform and what is needed (i.e. capabilities and resources) to create and deliver value. The organizational processes and activities that create or deliver this value are embedded in the operational perspective. To ensure strategic fit between the different business architecture elements, the PGA modeling technique combines the following features: (i) alignment is realized by a modeling language including the different perspectives in the business architecture, (ii) a performance measurement mechanism that serves as a guideline for organizational operations to support the intended strategic business objectives and (iii) a heat mapping visualization that it is comprehensible for different types of business stakeholders. More specifically, a color code (i.e. red, orange or green) is used to express the performance and importance of different business architecture elements. For more background information, we refer the reader to [7].

2.3 PGA Simulation Technique.

The PGA simulation technique [8] combines the PGA modeling technique with a simulation mechanism to assess the impact of process simulation results on the overall business performance. This is realized in four steps: (i) building a business architecture hierarchy by means of the PGA modeling technique, (ii) simulating the operational performance measures, (iii) propagating the simulated performance throughout the business architecture hierarchy and (iv) performing a strategic fit improvement analysis to assess whether the simulated process change sustains a better realization of the organizational goals. The previously developed simulation technique only considered a single mean as simulation result. However, when considering simulation results, it is important to assess the reliability of that estimate. Compared to a single mean, confidence intervals give a better idea on the true performance measure value as they capture both the sample mean and variance of a simulation result.

3 Business Architecture Simulation Technique

The procedure of the simulation technique contains four steps: building a business architecture hierarchy (Sect. 3.1), performing a process simulation that generates simulation performance results in the form of a confidence interval (Sect. 3.2), the propagation of the confidence interval for the performance measure throughout the business architecture hierarchy (Sect. 3.3), analyzing if the simulation of a process alternative provides the expected improvements (Sect. 3.4). In the description, PGA meta-model elements are capitalized and model content of the running example is indicated by single quotation marks.

3.1 Building a Business Architecture Hierarchy

Design. When representing the business architecture by making use of the PGA modeling technique, there is a clear and coherent view on how different processes and activities are related to other elements in the business architecture. Roelens and Poels [8] highlight that a particular constraint is needed in the context of simulation. As the simulation technique aims to evaluate the impact of operational changes upon the overall business performance, it is important that the operational elements are also explicitly included in the business architecture. Therefore, one needs to make sure that each chain of valueStream relations in the PGA business architecture ends at least at a Process or Activity element.

An improvement analysis can reveal where operational enhancements are possible within the business architecture. In case of unachieved business objectives, this allows to determine where the cause of the problem is situated. This is done by the identification of a critical path, which is a chain of valueStream relations that mostly have a high or medium importance and that connect business architecture elements on different hierarchical levels of which the performance can be improved [7]. For problematic operational elements, different alternative designs can be evaluated by applying the remaining steps of the business architecture simulation technique.

Demonstration. The company operates in the industry of beauty products and adopts a vertically integrated value chain as it manufactures products as well as sells them in the company's own stores. Currently, the company is looking for ways to increase both profit and customer satisfaction as competition is entering the market. Fig. 1 visualizes the business architecture of the company.

Starting from the two goals, 'increase customer satisfaction' represents a Customer Goal and 'increase profit' is a Financial Goal set by the company. To support the Financial Goal, a Financial Structure layer is added, structuring the costs and the revenues by making use of the components 'increase sales volume' and 'decrease costs' in the business architecture.

Next, the Value Proposition layer contains the different products and services that are offered by the company. Firstly, the company offers 'quality beauty products at a competitive price'. By offering these high-quality products, both an 'increase in sales volume' and 'customer satisfaction' can be realized. Additionally, the efficiency within the company's production to offer 'quality products at a competitive price' supports the 'decrease of costs'. The company also sells 'additional innovative products' that are not manufactured in-house, but are purchased from various start-up businesses. As the company's industry is sensitive to trends and innovation of products, 'offering additional innovative products' will 'increase the sales volume' and the 'customer satisfaction'. Besides its highly qualitative and innovative products, the company also 'offers services to the products', such as workshops and classes on how to use the products and on how to keep up with the latest beauty trends. By 'offering extra services', 'sales volume' and 'customer satisfaction' will be increased as hosting workshops on product usage and trends supports the company's image of high quality and innovation. Also, 'additional services offered' will guarantee more direct contact with the customers. This will result in a decrease of the number of complaints that needs to be handled by the customer service department and thus will have a positive impact on the 'decrease of costs'.

The Competences of the company represent the strengths of the company that are needed to offer its products and services. One of the three Competences of the company under study is the practice of 'high quality and effective operations'. This is an important Competence that addresses the in-house production department of the company and ensures that 'quality products can be offered at a competitive price'. This Competence is supported by three Processes, the 'purchasing process', the 'production process' and the 'distribution process', that consequently make up the lowest level in the business architecture. Another Competence of the business is the offering of 'exceptional customer service' to its customers, which focuses more on the end of the value chain and is supported by the 'sales process', 'complaint handling' and 'customer training programs'. 'Exceptional customer service' is important to all the components in the Value Proposition layer. It is clear that customer service is crucial when 'offering services to the products', but also to guarantee total product quality. A third Competence is the involvement of the company in 'innovative partnerships'. Without the partnering with innovative start-ups, it is not possible for

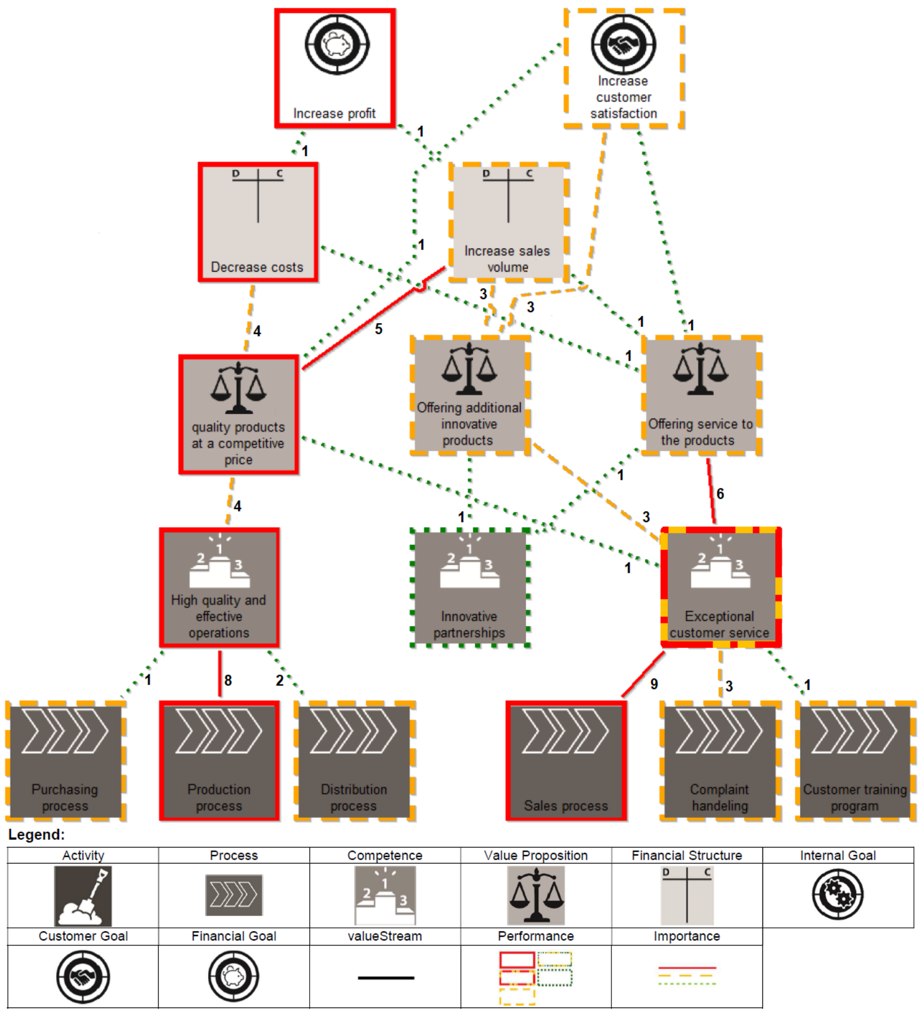

Fig. 1. Business architecture heat map of the current company situation.

the company to 'offer additional innovative products' that are not made in-house. Moreover, some of the workshops hosted are focusing on those innovative products and consequently also require the support of the partners.

As can be seen in Fig. 1, the performance of the company's Financial Goal, 'increase profit', is 'bad' and calls for improvement. The performance of the Customer Goal, 'increase customer satisfaction', on the other hand is 'as expected'. However, as the company is experiencing increased competition they would like to further improve this goal by increasing the satisfaction and perception of their customers. When following the critical path starting from the Financial Goal, it is clear that improvements are needed within the 'production process'. To improve the Customer Goal, the critical path indicates the need for improvements in the 'sales process'. In this case example, alternative 'production' and 'sales process' designs are simulated and their impact on the overall business performance is evaluated. Regarding the 'sales process', the company has employed two warehouse pickers and stores are able to reorder items every two weeks, only on Fridays. After analyzing the current situation, it seemed that often too many restock orders arrive at the same time and that the two pickers in the warehouse are not able to timely process these orders. Therefore, alternative designs with more warehouse pickers or different reorder policies, such that orders of the stores to the warehouse are divided more equally, could improve the company's situation. Within the current 'production process', it seems that the product lead time is too long. Therefore, it was proposed to add extra quality checks throughout the production line. In that way, bad quality products might be detected earlier, without going through the whole chain of production steps before being filtered and sent back for remake. Additionally, the company could also improve the performance (i.e. lower the percentage of quality violation) of the different production steps by, for example, investing in better machines.

3.2 Simulate the Performance Level of Process Elements

Design. First, processes are simulated based on the current situation. When accurate simulations are used, the results of these simulations will be comparable to the actually measured performance measures of the current situation. These process simulations require different key components, such as the control-flow, simulation environment, activity durations, decision rules, resource requirements and probability distributions. Thereafter, alternative designs of these processes are evaluated. It is important that the simulated performance confidence interval is smaller than the defined acceptance interval to make a univocal statement about the performance of a process element. To achieve this, the following steps need to be performed:

Step 1. Define the desired half width h of the confidence interval as being smaller or equal to the half width of the 'as expected' performance interval, which can be calculated as follows:

$$h \leqslant PerformanceGoal \cdot AllowedDeviation\% \tag{1}$$

.

Step 2. Run the model for a small number of replications n_0 and determine the confidence interval. Depending on the size of the model and the time it takes to execute it, the number of replications might be 5, 10 or 15 [19].

Step 3. If the half width of the confidence interval based on the n_0 replications is smaller than h, one can stop the procedure. In this case, the generated confidence interval is smaller than the acceptance interval and a performance statement can be made. Proceed with the propagation of the performance measures (see Sect. 3.3).

If the half width based on the preliminary run is bigger than h, the confidence interval will be too big to make a univocal statement about the performance level. In this case, proceed to step 4.

Step 4. One needs to calculate the minimum number of replications needed to obtain a half width smaller than the 'as expected' performance half width as in (2). In this equation, $S(n_0)$ is the variance computed based on the simulation with n_0 replications and z is the statistical z-score associated with the confidence interval.

$$n = \lceil(\frac{zS(n_0)}{h})^2\rceil \tag{2}$$

.

Step 5. Rerun the process simulation with n subruns and determine the confidence interval for the performance measure.

Demonstration. In the case example, the 'sales' and the 'production process' of the company must be simulated. Given the page limit, the description is restricted to the simulation results of the 'production process', which was implemented in CPN tools [20][3]

The 'production process' is oriented towards how the company's high-quality products are manufactured. In this case example, the 'production process' is represented by one production line, which exists of multiple production steps and produces exactly 500 products with an approved quality. The performance of the 'production process' is expressed by the product lead time. The product lead time is calculated based on the time (in s) that it takes to collect production materials and the duration of the different production steps. Independent subruns are generated by performing five replications, which each contain 500 observations. As the subruns are independent and identically distributed, it allows to calculate a sample mean = 82.757s, variance = 2.757s$^{\mathbf{2}}$ and 95% confidence interval = [79.303s, 86.149s] for the simulation.

Step 1. Based on formula (1), a desired half width h of the confidence interval for the product lead time can be determined based on a performance goal of 65s and an allowed deviation of 2%.

$$h = 65s \cdot 2\% = 1.3s \tag{3}$$

.

[3] the basic CPN models can be found via https://doi.org/10.13140/RG.2.2.30599.68006.

Step 2. The 95% confidence interval based on the simulation with $n_0 = 5$ replications is [79.303s, 86.149s] with half width:

$$\frac{86.149s - 79.303s}{2} = 3.423s \tag{4}$$

.

Step 3. The half width of the 95% confidence interval based on five simulation runs 3.423s is larger than 1.3s, so additional simulation runs are needed to obtain meaningful results.

Step 4. The minimum number of simulation replications is calculated as

$$n = \lceil (\frac{2.776 \cdot 2.757}{1.3})^2 \rceil = 35 \tag{5}$$

Step 5. After rerunning 35 replications of the simulation, the 95% confidence interval for the product lead time is [81.361s, 82.931s]. Now, the half width of the 95% confidence interval (i.e. 0.785s) is smaller than h (i.e. 1.3s) and a univocal statement about the performance level is possible.

3.3 Propagation of Performance Measures

Design. In the third step, the simulated performance is propagated throughout the business architecture hierarchy to assess the impact on the performance of the overall business objectives. This step consists of three substeps [8]: (i) rescaling the performance, (ii) aggregating the rescaled performance to higher levels in the business architecture hierarchy and (iii) adapting the border color of the business architecture elements based on the resulting performance levels.

Rescaling the performance. It is first needed to rescale the simulated performance levels such that they can be interpreted independently of specific measurement details (i.e. measure type, performance goal and allowed deviation %). The formulas proposed in [8] need to be adjusted as the technique considers confidence intervals for the simulated performance. Four rescaled indicators are needed: upper performance upper acceptance level (UPUAL), lower performance upper acceptance level (LPUAL), upper performance lower acceptance level (UPLAL), lower performance lower acceptance level (LPLAL).

When considering a positive performance measure, formulas (6)-(9) are relevant:

$$UPUAL_p = \frac{UpperBoundConfidenceInterval}{PerformanceGoal \cdot (1 + AllowedDeviation\%)} \tag{6}$$

$$LPUAL_p = \frac{LowerBoundConfidenceInterval}{PerformanceGoal \cdot (1 + AllowedDeviation\%)} \tag{7}$$

$$UPLAL_p = \frac{UpperBoundConfidenceInterval}{PerformanceGoal \cdot (1 - AllowedDeviation\%)} \tag{8}$$

$$LPLAL_p = \frac{LowerBoundConfidenceInterval}{PerformanceGoal \cdot (1 - AllowedDeviation\%)} \tag{9}$$

To cope with negative performance measures, formulas (10)-(13) are needed:

$$UPUAL_n = \frac{PerformanceGoal \cdot (1 - AllowedDeviation\%)}{LowerBoundConfidenceInterval} \tag{10}$$

$$LPUAL_n = \frac{PerformanceGoal \cdot (1 - AllowedDeviation\%)}{UpperBoundConfidenceInterval} \tag{11}$$

$$UPLAL_n = \frac{PerformanceGoal \cdot (1 + AllowedDeviation\%)}{LowerBoundConfidenceInterval} \tag{12}$$

$$LPLAL_n = \frac{PerformanceGoal \cdot (1 + AllowedDeviation\%)}{UpperBoundConfidenceInterval} \tag{13}$$

Based on the values of the rescaled indicators, the performance level of an element can be determined. Based on the above formulas, the upper performance score is mathematically higher than the lower performance (i.e. $UPUAL \geqslant LPUAL$ and $UPLAL \geqslant LPLAL$) and the lower acceptance score is higher than the upper acceptance (i.e. $UPLAL \geqslant UPUAL$ and $LPLAL \geqslant LPUAL$). Consequently, five performance levels can be distinguished (i.e. 'excellent', 'positive ambiguous', 'as expected', 'negative ambiguous' or 'bad'). Table 1 indicates how to interpret the rescaled performance values.

Table 1. Performance level based on the rescaled indicators.

UPUAL	LPUAL	UPLAL	LPLAL	Performance level	Visualization
$\geqslant 1$	$\geqslant 1$	$\geqslant 1$	$\geqslant 1$	Excellent	
$\geqslant 1$	<1	$\geqslant 1$	$\geqslant 1$	Positive ambiguous	
<1	<1	$\geqslant 1$	$\geqslant 1$	As expected	
<1	<1	$\geqslant 1$	<1	Negative ambiguous	
<1	<1	<1	<1	Bad	

Aggregation to higher-level business architecture elements. The rescaled indicators are used to aggregate the performance of lower-level elements to the appropriate higher-level element. For each of the rescaled indicators, the aggregation value must be calculated. Afterwards, the analysis of Table 1 can be used to determine the performance level of the higher-level element.

When a clear mathematical relation exist between the performance measures of the lower- and higher-level elements in the business architecture, business formulas (e.g. financial ratios) can be used to calculate the aggregated performance.

If there is no mathematical relation between the performance measures of two related elements in the business architecture, the Analytic Hierarchy Process (AHP) [21] can be used. As can be seen in Fig. 1, each valueStream relation between two hierarchical elements in the business architecture is characterized by an importance value (i.e. indicated by a number and corresponding color). These values express how important each lower-level element is to support the value of the higher-level element in the hierarchy. To calculate the rescaled performance of higher-level elements, the weighted average of the rescaled lower-level performances can be calculated by incorporating the appropriate importance values as weights.

As the goal is to obtain the impact on the overall business goals, this aggregation will be repeated in the business architecture until the simulated performance is propagated to all higher levels in the hierarchy.

Adapt border color in business architecture. After propagating the operational simulation results throughout the business architecture, each element will be characterized by a simulated performance level. Based on the results, the visualization of the element border can be adapted (see Table 1). As we define two new performance levels, the original PGA color-coding is extended.

Demonstration: production process.

Rescaling the performance. The product lead time is a negative performance measure, such that the simulated performance of the product lead time [81.361s, 82.931s] can be rescaled as follows:

$$UPUAL_{production} = \frac{65s \cdot (1 - 2\%)}{81.361s} = 0.783 \tag{14}$$

$$LPUAL_{production} = \frac{65s \cdot (1 - 2\%)}{82.931s} = 0.768 \tag{15}$$

$$UPLAL_{production} = \frac{65s \cdot (1 + 2\%)}{81.361s} = 0.815 \tag{16}$$

$$LPLAL_{production} = \frac{65s \cdot (1 + 2\%)}{82.931s} = 0.799 \tag{17}$$

Based on the values in (14)-(17), the performance level of the 'production process' can be determined. As all the values are smaller than one, it can be concluded that the performance level is 'bad'.

Aggregation to higher-level business architecture elements. In the case example, the AHP mechanism is applied to aggregate the performance to the higher-level elements in the company's business architecture. As an example, the UPUAL of the Competence 'high quality and effective operations' is calculated as the following weighted average, see (18):

$$\frac{1 \cdot UPUAL_{purchasing} + 8 \cdot UPUAL_{production} + 2 \cdot UPUAL_{distribution}}{1 + 8 + 2} = 0.816 \tag{18}$$

The remaining rescaled performance values for ‘high quality and effective operations’ are: LPUAL = 0.805, UPLAL = 0.879 and LPLAL = 0.868. Based on these values, it can be concluded that the performance level is ‘bad’.

Adapt border color in business architecture. Based on the performance levels, the visualization of the border of ‘production process’ and ‘high quality and effective operations’ can be adapted accordingly. Fig. 1 shows the current heat map of the company after the simulated performance is aggregated through the complete business architecture.

3.4 Improvement Analysis

Design. This step is oriented towards the analysis of the impact of the operational changes on the different business architecture elements. Based on the visualized performance levels, it can be determined whether an operational change leads to a better realization of the organizational objectives and which of the improving designs are most preferable for the company to implement. For this purpose, the simulated performance of each design combination is studied, while taking into account the investment in time and costs, as indicated by the number of required changes.

Demonstration. To improve the current situation, the company identified two possible alternative designs for each process. Table 2 shows the different combinations of the alternative production and ‘sales process’ designs with their simulated impact on the goals of the business. The last column indicates how many operational changes are made compared to the processes in the current business situation (i.e. scenario #0).

Scenario #0 represents the current situation, in which the ‘production process’ contains only one quality check (i.e. 1QC) and the replenishment of stores in the ‘sales process’ occurs biweekly on Fridays by two warehouse pickers (i.e. 2P, 2W, Fri). A first alternative design for the ‘sales process’ is to adjust the current reorder policy of the company’s stores (i.e. biweekly on Fridays) to weekly and to keep the current number of warehouse pickers (i.e. two pickers) intact (i.e. 2P, 1W). A second, more drastic and therefore costly adjustment to the ‘sales process’ is to both change the number of pickers to three and the reorder policy to a weekly reorder (i.e. 3P, 1W). For the ‘production process’, a first possible alternative design for the company is to introduce three quality checks into the production line instead of only one (i.e. 3 QC). When this alternative design does not suffice, additionally quality improvement can be made to the first, fifth and sixth production step (i.e. 3 QC + QI). The underlying reason is that the time between these production steps and the subsequent quality check is longer compared to other production steps, which implies that it takes longer to detect products with a bad quality.

The results in Table 2 show that design combinations #3 and #6 do not have a positive impact on the performance of the business goals and are therefore not worth pursuing. As design combinations #1, #2, #4, #5 and #7 all have the same impact on the business performance (i.e. both goals are ‘as expected’), design combination #1 is preferred because it requires the least operational

Table 2. Impact of different operational changes upon the business goals.

#	Process design: Sales	Process design: Production	Goal Performance: Increase profit	Goal Performance: Increase customer satisfaction	# changes required
0	2P, 2W, Fri	1QC	Bad	As expected	0
1	2P, 2W, Fri	3QC	As expected	As expected	1
2	2P, 2W, Fri	3QC+Q1	As expected	As expected	2
3	2P, 1W	1QC	Bad	As expected	1
4	2P, 1W	3QC	As expected	As expected	2
5	2P, 1W	3QC+Q1	As expected	As expected	3
6	3P, 1W	1QC	Bad	As expected	2
7	3P, 1W	3QC	As expected	As expected	3
8	3P, 1W	3QC+Q1	As expected	Excellent	4

changes. Finally, design combination #8 improves both business goals compared to the current situation, but has a high implementation cost with four operational changes. It is advisable for the company to gradually make improvements in its business. In the short term, the company should implement three quality checks in the 'production process' to improve short-term profit (i.e. design #1). In the long term, when more resources and time are available, additional quality improvements need to be made to the 'production process' and also the 'sales process' needs to be revised (i.e. design #8), such that customer satisfaction further increases.

4 Conclusion

This paper presents and demonstrates the design of a business architecture simulation technique that allows to evaluate the impact of alternative process designs on the overall business performance. The simulation technique is based on an integrative business view and therefore provides a solution to the problem of suboptimization of existing process simulation techniques. More specifically, the business architecture can be defined by using the PGA technique, which visualizes the different business architecture elements and their valueStream relations. The proposed technique defines how to integrate the output of process simulations with other elements in the business architecture. The design extends the work in [8] to express simulated operational performance by means of a confidence interval. This enables a more accurate analysis of the impact of process performance on the overall business performance.

Several mechanisms are extended to realize this. First, the performance of different strategic decisions needs to be determined by performing process simulations. To obtain accurate and meaningful information on the performance of processes, the results are expressed by performance confidence intervals, which are based on multiple observations of multiple simulation runs. Next, the simulated processes need to be embedded into the overall business architecture. Based on the rescaled performance indicators (i.e. UPUAL, LPUAL, UPLAL and LPLAL), that can be propagated them to higher-level elements in the business architecture (i.e. by business formulas or the AHP mechanism), the elements can be labeled with a performance level (i.e. 'bad', 'negative ambiguous', 'as expected', 'positive ambiguous' or 'excellent') and an according visualization. Finally, the overall impact of alternative process designs can be analyzed, which offers a tool for organizational decision-making.

Important for future research is to evaluate the functionality and relevance of the proposed simulation technique by applying it in a real-life case study. This offers the possibility to evaluate the effectiveness and accuracy of the model as results can be compared to reality. More specifically, it is interesting to check for the accuracy of the performance measure aggregation mechanism, by comparing the performance results obtained by aggregation with the real performances measured in the business architecture. Also, a real-life case study allows to set up more complex simulation models. This is particularly useful to analyze the scalability of the new mechanisms, such as the feasibility of specifying the confidence interval width upfront. Additionally, an opportunity for future research is to automate the calculations for the rescaled performance indicators and the propagation through the business architecture. Therefore, it would be interesting to extend the existing PGA tool support[4] with the concept of confidence intervals and to include the propagation mechanism. Finally, it is worth examining how an automated link could be provided between the results of process simulation tools and the PGA tool, such that simulated process performances can be automatically introduced into the PGA business architecture.

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