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Business Process Improvement using Multi-objective Optimisation

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Abstract

Business process redesign and improvement has become an increasingly attractive subject in the wider area of business process intelligence. Although there are many attempts to establish a business process redesign framework, there is little work on the actual optimisation of business processes with given objectives. Furthermore, most of the attempts to optimise a business process are manual without involving a formal automated methodology. This paper proposes a process improvement approach for automated multi-objective optimisation of business processes. The proposed framework uses a generic business process model that is formally defined. The formal definition of business process is necessary to ensure that the optimisation will take place in a clearly defined, repeatable and verifiable way. Multi-objectivity is expressed in terms of process cost and duration as two key objectives for any business process. The business process model is programmed and incorporated into a software optimisation platform where a selection of multi-objective optimisation algorithms can be applied to a business process design. This paper proposes a case study of business process design that is optimised by the state-of-the-art multi-objective optimisation algorithm NSGA2. The results indicate that, although business process optimisation is a highly constrained problem with fragmented search space, a number of alternative optimised business processes that meet the optimisation criteria can be produced. The paper also provides directions for future research in this area.

1. Introduction

In the modern competitive business world there is a frequent need for enterprises to modify the structure of their business processes to become more successful in the market place. The design and management of business processes is a key factor for companies to effectively compete in today's volatile business environment. By focusing on the optimisation and continuous improvement of business processes, organisations can establish a solid competitive advantage by reducing cost, improving quality and efficiency, and enabling adaptation to changing requirements. Multi-objective optimisation of business processes can result in novel approaches and more efficient ways of business process improvement. The advantages lie in two aspects: (i) more than one optimisation criteria can be selected and satisfied simultaneously and (ii) instead of a single optimised process, multi-objective optimisation can produce a population of alternative optimised business processes. The next section examines the relevant work in the specific subject area; the rest of the paper introduces a multi-objective optimisation framework for formally defined business process models.

2. Related work

Process modelling methodologies, such as the IDEF family, Computer Integrated Manufacturing – Open Systems Architecture (CIM-OSA), Object-oriented Modelling and Petri-nets, allow for a systematic and a well-defined representation of processes. Based on some of the above methodologies, a number of process modelling tools have been developed, such as ARIS, FirstStep, PrimeObjects and TEMAS [1]. These approaches provide powerful methods for visualising business processes, evaluating their particular characteristics (such as resource utilisation, cost and speed) and checking their structural and resource consistency [2], [3]. Zakarian [1] integrated the Fuzzy-rule-based Reasoning Approach with IDEF methodology for quantitative analysis of process models to model efficiently the uncertain and incomplete information in process variables. Grigori et al. [4] recently proposed a Business Process Intelligence tool suite that uses Business Intelligence Technologies (in particular data mining) for analysing business processes. Also in [5] an overview of business process analysis techniques and tools is presented and in [6] product data engineering principles are applied to the representation of business processes but there is no formal optimisation attempt in these papers. Hofacker and Vetschera [7] propose a business process modelling approach that can be optimised with three different techniques. They define a sequential business process using a single-objective mathematical model.

The qualitative nature of business process models explains the difficulty of developing 'parametric' models of business processes. There is therefore a lack of formal methods to support the design of business processes [7]. One of the main reasons for this is that design elements and constraints on process designs are hard to characterise in a formal way amenable to analytical methods. Therefore, although a considerable number of algorithms exist for dealing with process optimisation problems in areas such as Manufacturing, there is a lack of algorithmic approaches for the optimisation of business processes [8]. Much of the recent research in the area of business process optimisation has dealt with either selection of a process model from a set of alternatives [9] or simple single-objective optimisation [7] that does not address the strong synergistic/anti-synergistic effects among individual activities that constitute a process design. Therefore, the current research suffers from serious limitations in dealing with the scalability requirements and complexity of real-life processes. In summary, the optimisation attempts for business processes have a long way ahead due to three main issues:

1. Most business process models are diagrammatic approaches not capable of quantitative analysis and algorithmic optimisation.
2. The business process optimisation attempts have been mostly manual.
3. There is no attempt to optimise a business process under multiple criteria.

This paper addresses the above three issues.

3. A formal business process model

The first step towards business process optimisation is the business process model specification. The model has a mathematical basis to ensure formality, consistency and rigour. The business process model has a series of mathematical constraints that define the feasibility of the business process and a set of objective functions that consist of the various business process objectives. Representing a business process using a formal mathematical model guarantees the construction of consistent and rigorous business processes following a formally correct, repeatable and verifiable approach [10].

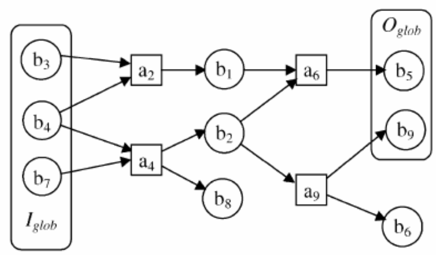


Figure 1. A feasible business process design with activities and resources

Figure 1 sketches a feasible business process design using two key concepts: activities (in squares) and resources (in circles). Apart from the resources that are generated within the process, the business process design of figure 1 has two other sets of resources, the initial (I_{glob}) and the final (O_{glob}) resources. The initial resources are available at the beginning of the business process and the final resources form the final output. The resources flow through the process and belong to two categories: physical and information resources. The activities are perceived as the transformation steps within the process that use some resources as inputs and produce others as outputs.

The business process model receives as input parameters the participating activities and their starting times. The aim is to produce an optimised process in terms of minimising two objectives, the process duration and cost. For each process design there is a library of candidate activities with attributes such as activity duration and activity cost. The mathematical model of business process defines the two objective functions and ensures the business process consistency and feasibility with thirteen constraints. Further objectives can be added with extra functions. The complete mathematical model is the following:

$$f_1(P) = \max(q_j) \rightarrow \min, \forall j : b_j \in go_j$$

$$f_2(P) = \sum u_{i1} x_i \rightarrow \min$$

$$s.t.$$

$$1. x_i \leq r_{ij}, \forall i, j : b_j \in I_i, b_j \in B_P,$$

$$2. x_i \leq y_j, \forall i, j : b_j \in I_i, b_j \in B_I,$$

$$3. go_i + \sum_i r_{ij} \leq M \cdot gi_j + \sum_i t_{ij} x_i, \forall j : b_j \in B_P,$$

$$4. y_j \leq gi_j + \sum_i t_{ij} x_i, \forall j : b_j \in B_I,$$

$$5. y_j \geq go_j,$$

$$6. p_i \geq q_j - M(1 - x_i), \forall i, j : b_j \in I_i,$$

$$7. q_j \leq p_i + \delta_i + M(1 - x_i), \forall i : b_j \in O_i$$

$$8. q_j \geq p_i + \delta_i - M(1 - x_i) - M(1 - \lambda_{ij}), \forall i : b_j \in O_i,$$

$$9. \lambda_{ij} \leq x_i, \forall i, j : b_j \in O_i,$$

$$10. \sum_{i: b_j \in O_i} \lambda_{ij} \geq \sum_i r_{ij} + og_i - M(1 - y_j), \forall j : B_P, gi_j = 0,$$

$$11. \sum_{i: b_j \in O_i} \lambda_{ij} \geq 1 - M(1 - y_j), \forall j : b_j \in B_P, gi_j = 0,$$

$$12. x_i \in \{0,1\}, \forall i,$$

$$13. \lambda_{ij} \in \{0,1\}, \forall i, j : b_j \in O_i.$$

Parameter	Explanation
u_{i1}	Cost of execution for activity a_i.
x_i	Binary variable that indicates whether a candidate activity a_i participates in the business process design.
y_j	Binary variable that indicates whether resource b_j is or becomes available during the business process.
$t_{i,j}$	Matrix of binary variables that links the activities with their output resources.
r_{ij}	Matrix of binary variables that indicate if a unit of physical resource b_j is available for use by activity a_i.
gi_j & go_j	One-dimensional binary constants that indicate which resources belong to global inputs and/or global outputs.
M	Large constant indicating that physical resources contained in the set of global inputs are available in unlimited amounts.
p_i	Starting time of activity a_i.
q_j	The time resource b_j becomes available.
δ_i	Duration of activity a_i.
λ_{ij}	Binary variable indicating that activity a_i is used to create resource b_j.
I_i / O_i	Sets of input/output resources of activity a_i.
B_P / B_I	Set of physical / information resources b_j.

Table 1. Main Parameters in Mathematical Model

The mathematical model consists of a number of binary variables and binary matrices that have an impact on the production of feasible process designs since they result in a fragmented search space. Table 1 explains the main parameters used in the mathematical model. The first objective function (*f1*) of the model calculates the duration of the business process. The total duration for a feasible process equals the time that the last resource belonging to global outputs is produced. The second objective function (*f2*) calculates the business process cost as the sum of costs of all participating activities. The mathematical model constraints ensure that the model produces feasible business processes by examining different aspects of the business process model. The proposed mathematical model is an extension of the single-objective model in [7].

It is important to highlight two features of the business process model. The mathematical model consists of many discrete binary variables that increase the complexity of the search space by making it fragmented. Another feature of the business process model is, that although it is simple to conceive, understand and visualise, it proves to be highly constrained when it comes to formal mathematical definition. This can create difficulties in locating the optimum solutions since even feasible solutions are hard to produce. Table 2 provides a short description of each constraint of the mathematical model in order to enhance its understanding. The next section optimises the business process model using a multi-objective evolutionary algorithm.

4. Case study

This section describes the construction of a test business process design problem. In total, five different test process designs were constructed for optimisation, but only the construction of one of these problems is described here in detail. The test problems constructed have an increasing number of activities participating in the process design. Each of the problems has a fixed predefined number of participating activities in the process. The initial and final resources of the business process are given. The optimisation algorithm that is selected is NSGA2. Non-dominated Sorting Genetic Algorithm II (NSGA2) is non-dominated, sorting-based, multi-objective evolutionary algorithm [12]. NSGA2 has been quite popular due to its robustness and performance.

NSGA2 attempts to optimise the process designs by selecting different sets of activities and defining their starting times. Note that for each process design there is a library of candidate activities that can potentially participate in the process. The case study discussed here is a business process design under the name ActivitiesST4 and it is based on the mathematical business process model described in the previous section. It involves four participating activities. The library of candidate activities contains ten activities that can be alternatively used in various combinations of four. Process optimisation depends on two criteria:

1. The appropriate activities need to be selected and combined from the library based on their duration and cost attributes and
2. The starting times of activities need to be determined in order for the process outputs to be produced as early as possible, thus minimising the total process duration.

Brief description of constraints
1. $x_i \le r_{ij}, \forall i, j : b_j \in I_i, b_j \in B_P$ All input physical resources of an activity must be available ($r_{ij}=1$) at some stage of the process if the activity is participating ($x_i=1$).
2. $x_i \le y_j, \forall i, j : b_j \in I_i, b_j \in B_I$ All input information resources (y_j) of an activity must be available at some stage of the process if the activity is participating ($x_i=1$).
3. $go_i + \sum_i r_{ij} \le M \cdot gi_j + \sum_i t_{ij} x_i, \forall j : b_j \in B_P$ The output physical resources -final or not- must not exceed the sum of initial and produced -during the process.
4. $y_j \le gi_j + \sum_i t_{ij} x_i, \forall j : b_j \in B_I$ An information resource (y_j) can be available either at the beginning of the process -as initial resource (gi_j)- or as an output resource of a participating activity.
5. $y_j \ge go_j$ A resource (y_j) cannot be part of the output without first being available at some stage of the process (go_j).
6. $p_i \ge q_j - M(1 - x_i), \forall i, j : b_j \in I_i$ In terms of time, a participating activity must start (p_i) only after the time that all its input resources have become available.
7. $q_j \le p_i + \delta_i + M(1 - x_i), \forall i : b_j \in O_i$ 8. $q_j \ge p_i + \delta_i - M(1 - x_i) - M(1 - \lambda_{ij}), \forall i : b_j \in O_i$ In terms of time, an output resource must become available exactly when the generating activity has been completed ($q_j=p_i$).
9. $\lambda_{ij} \le x_i, \forall i, j : b_j \in O_i$ A non-participating activity ($x_i=0$) cannot have output resources ($\lambda_{ij}=1$).
10. $\sum_{i:b_j \in O_i} \lambda_{ij} \ge \sum_i r_{ij} + og_i - M(1 - y_j), \forall j : B_P, gi_j = 0,$ When a physical resource does not belong to initial resources, it must be produced during the process in greater or equal amounts to the required resource inputs of the participating activities.
11. $\sum_{i:b_j \in O_i} \lambda_{ij} \ge 1 - M(1 - y_j), \forall j : b_j \in B_P, gi_j = 0$ Each physical resource that does not belong to initial resources but appears in the output of a participating activity must be produced at least once.
12. $x_i \in \{0,1\}, \forall i$ The variable x (indicating participating activities) must be binary.
13. $\lambda_{ij} \in \{0,1\}, \forall i, j : b_j \in O_i$ The variable λ (indicating output resource j of activity i) must be binary.

Table 2. Summary of constraint explanations

The process design sketch of ActivitiesST4 problem is demonstrated in figure 2 and can be described as follows: There are two global input resources to start the process. These two resources together with the two global outputs are considered as constants. The system variables of the problem are the four participating activities and their starting time attribute. This means that the optimisation algorithms will attempt to satisfy the optimisation objectives by selecting a set of four activities (from a library of 10 alternatives) and defining the starting time for each of them. All the potential activities are stored in a built-in library and the algorithms can select any four. For a process to considered feasible, the four potential activities of the process design must be combined in a way that the given output resources are produced**.**

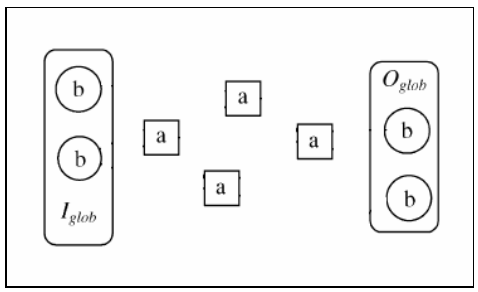
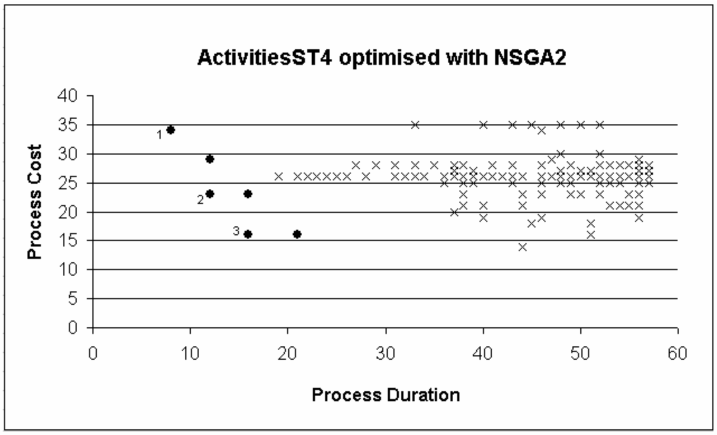


Fig. 2. ActivitiesST4 initial process sketch

5. Results

This section describes the experimental results for the test problem sketched in the previous section (fig. 2) as those were generated by NSGA2 evolutionary algorithm. In this paper, the focus is on the effect of optimisation algorithm to business process in terms of improving the performance of the business objectives. The optimised solutions were produced by executing NSGA2 30 times with different random seed values. 28 of these 30 runs produced similar results. The results presented here belong to one of the typical runs. The generated solutions represent feasible business processes with minimised process duration and cost.



Legend:

x	random solutions
●	NSGA2 generated solutions
1●	optimised solutions

Fig. 3. ActivitiesST4 optimisation results with NSGA2 multi-objective evolutionary algorithm

Figure 3 demonstrates the NSGA2 generated business processes and also a set of randomly generated solutions in order to provide a comparison measure for the optimised results. The dotted points represent the NSGA2-generated solutions whereas the ‘x points’ random solutions that demonstrate feasible business process designs. The numbered-dotted points correspond to the sub-set of optimised solutions among the NSGA2-generated results. As illustrated in figure 3, the numbered-dotted solutions are better than both random and the rest of NSGA2-generated solutions as the have both shorter process duration and lower cost. However, none of the three numbered-dotted solutions is considered better among them as they are optimised alternatives with different trade-offs between the two objectives. These three solutions are further discussed below. Figure 4 provides a pictorial view of the three numbered-dotted solutions of figure 3 and gives the opportunity to see what each solution represents.

Figure 4 demonstrates graphically that each optimised process holds a different trade-off between process duration and cost. At time 0 the two input resources are available and the process starts. The grey boxes represent the activities and their length depicts their duration. Each box states the name of the activity used (e.g. a4) and in brackets the cost of its execution. The process cost is calculated by adding all the activity costs, while the process duration is defined by the time that the last resource is being produced.

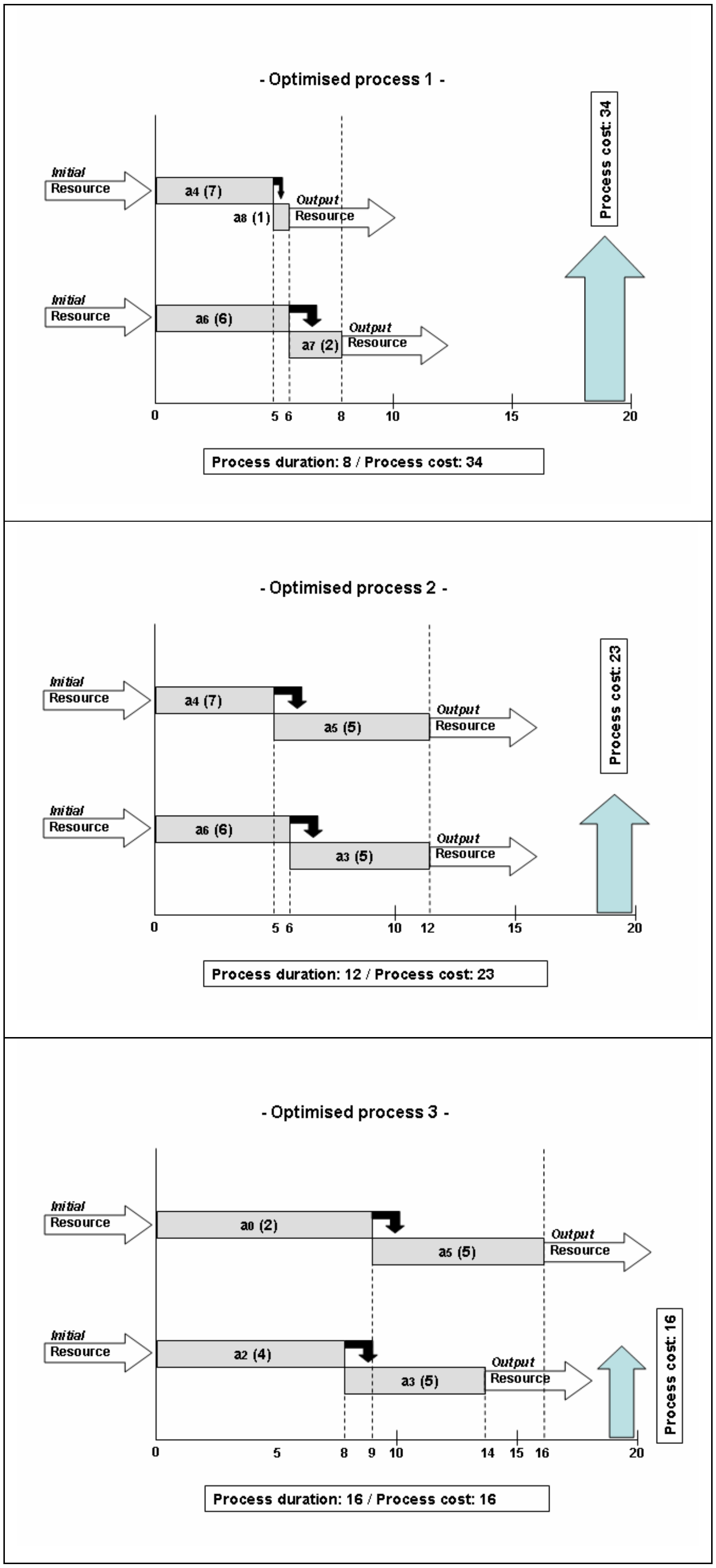


Figure 4. Optimised business process values for 3 different solutions

Business processes - using the same resources to produce standard outputs- can have different performance. Optimised process 1, for example, has the shortest duration (8 units) but it is also the most expensive. Optimised process 2 on the other hand, has reduced cost but has a 50% increase on process duration. Optimised process 3 costs less than half of the first instance but it lasts twice as long. Therefore, the optimised solutions provide a range of selection to the business analyst to make a decision. The decision making criteria could be the company's priorities or policy at a given time or external factors such as competitor's performance. Having the opportunity to shape a business process according to two or more objectives and being able to review the trade-offs between the objectives empowers the process analyst when it comes to business process selection and realisation.

6. Discussion

This section discusses the practical implications of the framework, along with its limitations and directions for future research. The test problem demonstrates that the proposed framework is capable of applying multi-objective optimisation to business process designs and generating optimised alternative business processes with trade-offs between the process objectives (duration and cost). This gives the capability to the process analyst to select, according to decision making priorities, a business process from a range of optimised ones. The results are promising and future research can lead to better quality results.

During the development of the proposed multi-objective optimisation methodology a number of limitations were unveiled. The first limitation originates from the mathematical model of the business process. The mathematical model focuses on activities and resources as its two main concepts and it ignores the participating (physical or mechanical) actors. This results in what is criticised as 'a mechanistic viewpoint of business processes' [11]. However, it is more difficult for a formal business process modelling technique to capture the roles of the participants than a diagrammatic approach which visualises the flow of the process. Another limitation lies in the selection of a process design as test problem. The business process optimisation capabilities can be better demonstrated using a series of test business process designs involving a wide range of activities and patterns like decision boxes or feedback loops.

Future research in the relevant area should focus on areas such as building more complete process models and testing more complicated process designs. The construction of a business process model that can cover more aspects of a ‘closer to real world’ business process can prove a challenging research area. Modelling and optimisation of ‘closer to real world’ process patterns can significantly increase the problem complexity. Future research should also focus on selecting the most appropriate techniques for business process multi-objective optimisation from a wider set of techniques and algorithms and thus locating more accurately the most suitable optimisation method.

7. Conclusions

This paper presented a framework for applying multi-objective optimisation to business processes. By developing a formal business process model and orienting it to multi-objectivity, the generation of optimised business processes is facilitated and demonstrated by a case study. What makes the business process optimisation problem distinctive is its highly constrained nature and the fragmented search space that has a significant impact on locating the optimum solutions. It is shown that state-of-the-art multi-objective optimisation algorithms, such as NSGA2, can produce satisfactory results by managing to generate and preserve optimal solutions on a process design. This provides an adequate number of alternative optimised process designs for the business analyst to decide the trade-offs between the different objectives. The results presented here are encouraging for further research in the area of business process multi-objective optimisation.

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