SIMULATION-BASED PERFORMANCE MEASUREMENT: ASSESSING THE PURCHASING PROCESS IN A PUBLIC UNIVERSITY

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ABSTRACT

Performance measurement is becoming a must in the public sector in Italy, just as in other frontline economies. Public services have to be supplied to citizens under diminishing resources, but pursuing growing target levels as if they were operating in a competitive market. Discrete-event simulation is challenging as an effective methodology for a quantitative evaluation of different practices in non-profit organizations characterized by socio-technical environments guided by the central government's changing normative and often conflicting multiple stakeholders. This paper focuses on a scientific Department of an Italian University, after that a performance measurement and evaluation system has been adopted by the Board of Directors as required by recent laws aimed at increasing the level of accountability. A case study is described in which the "purchasing process" is analyzed by stochastic simulation in order to account for limited resources under various sources of uncertainty. Numerical results are presented to support possible managerial decisions towards improved efficiency, effectiveness and transparency in purchasing operations.

INTRODUCTION

Simulation is nowadays recognized as an effective methodology for computer-based (re)design of operations management systems under a dynamic stochastic environment (Shafer and Smunt 2004) and business processes (re)engineering in a socio-technical environment (Hlupic and de Vrede 2005; Gregoriades and Sutcliffe 2008). The development of specific business tailored paradigms (Melao and Pidd 2006) and friendly approaches (Robinson et al. 2014) to business process simulation (BPS) should encourage practitioners. The increasing dominant role of information systems and web services in the public sector call for revisiting BPS paradigms (Van der Aalst 2010) to also allow a useful integration of output analysis with spreadsheet-based tools for process analysis (Saldivar et al. 2016). Some interesting applications have already demonstrated the benefit of BPS in the public sector (Haysa and Bebbington 2000; de Boer et al. 2003; Greasley 2006; Dimitriosa et al. 2013). Moreover, the scientific debate on performance measurement systems (PMS) introduced in public and non-profit organizations is quite active (Micheli and Kennerly 2005; Trkman 2010; Bititci et al. 2012; Pekkanen and Niemi 2013; Bourne et al. 2014). So, the research community on simulation is stimulated to develop prediction tools to be used in conjunction with pre-existing process monitoring tools.

Non-profit and public organizations generate most of their income from public funds and have to account for several, sometimes conflicting, stakeholders. Their public mission is affected by budget cuts that are becoming more and more severe in several countries. Even educational organizations are becoming business-oriented in their core business despite the social-cultural inspiration at their basis. So, evaluating process-related performance measures in this sector (Jääskeläinen et al. 2015) is first viewed as a means for achieving increased targets of efficiency in the operational behavior of educational institutions as well as steering the allocation of scarce resources. Second, performance evaluation also allows pursuing purposes of accountability and transparency as required by recent laws. To align the business process of a public educational institution, located in Southern Italy, with enterprise like performances a PMS has been formally adopted. As well pointed out in (Han et al. 2009), whenever target organizational processes that need improvement are identified through a macro process analysis, then performance prediction by a micro process analysis using simulation may be worthy. Specifically, with reference to the above PMS we investigate by simulation one of the key (operational) processes in our University Department: the purchasing process. Our aim is to predict if specific objectives assigned to the Department by the Central Administration can be achieved and/or to what extent introducing different organizational set-ups may be necessary to accomplish the above targets.

The paper is organized as follows. In the problem statement, we first provide an overview of recent laws

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that have stimulated the introduction of PMSs in Italy and then describe the context of our case study. The Simulation section focuses on input and output modeling issues. The actual case study is presented in the subsequent section with numerical results on some what-if analysis. Conclusions are drawn at the end of the paper.

PROBLEM STATEMENT

With respect to the current public management trend known in literature as New Public Management (Brignall and Modell 2000; Pollitt and Bouckaert 2011), in Italy some recent laws have represented an important "formal" acceleration towards decision supporting in the public sector through the implementation of performance measurement systems.

The common requirement of the Italian normative consists in implementing a strategic performance system to measure, evaluate and improve system performance in terms of efficiency, effectiveness, quality, outcome and customer satisfaction. Similar to the process management logic applied in profit-oriented private companies, the public management reform seeks to apply managerial criteria respecting the general non-profit finality of the public sector.

More specifically, the Italian legislative decree n°150/2009 imposes the implementation of a so-called "performance cycle" in all public organizations. Special government bodies such as the CiVIT (*Commissione per la valutazione, la trasparenza e l'integrità delle amministrazioni pubbliche* - an independent Commission for the evaluation, transparency and integrity of Italian public administrations and which today is known as ANAC, *Autorità Nazionale Anticorruzione* - the national anti-corruption Authority) and ANVUR (*Agenzia Nazionale di Valutazione del Sistema Universitario e della Ricerca* - an Agency for the evaluation of the activities of Italian public universities and other research bodies) work towards this specific goal and, among the other things, foster:

- transparency and integrity to prevent corruption, with a specific Section dedicated to transparency and integrity;
- improvement of performance management;
- quality of services.

In particular, in 2015 ANVUR issued the guidelines on the "integrated management of the performance cycle in Italian public universities" (ANVUR 2015). According to these guidelines, every university must adopt a system to:

- measure and evaluate the performance of their organization as a whole, as well as the individual performance pertaining to administrative and technical employees;
- establish the method, timelines, processes, instruments and involved subjects.

What was once an opportunity is now a formal requirement in all Italian public universities that may boost or reduce the amount of public funding.

Context of the Study

This study refers to the University of Calabria (www.unical.it) which is located in Southern Italy and counts more than 30,000 students. The document describing the Performance Measurement and Evaluation System of the University of Calabria was approved by its Board of Directors in July 2015. According to this system, whose implementation should be completed by the end of 2016, the so-called "performance cycle" consists in a set of activities aimed at guaranteeing the direction, coordination, control and reporting of university activities. It is composed by the following five phases:

1. medium-long term planning and strategy definition;
2. short-term objectives programming and indicator definition (i.e. specific, measurable, achievable, relevant, and trackable);
3. performance measurement and analysis;
4. organizational and individual performance evaluation and analysis;
5. reporting and transparency.

Within phases 3 and 4, which are currently under implementation, the Board of Directors has assigned a set of first-level objectives pertaining to the administrative management of its individual (and autonomous) Departments. The measurement indicators provided are the following:

- incidence of delay in invoice payment;
- reduction of the average travel refund;
- timely revenue regularization;
- cash balance;
- increase of foreign funding share;
- increase of auto-funding ratio on government financial funding;
- increase of auto-funding trend;
- improve of revenue trend;
- amount of revenue;
- percentage of transfer revenue over total revenue;
- percentage of internal transfer revenue over total revenue;
- full cost reduction of processes developed in different areas.

As a result of this step, every single Department is bound to define and assign second-level (operational) objectives to its employees and then measure their performance. To support the Chair of the Department in this task, a simulation model may be used as a twofold *in vitro* lab. On one hand, it can support the evaluation of employee performance under the current or future organization (and assign bonuses eventually) w.r.t. the assigned objectives. On the other, should the available resources fail to reach a pre-defined target level, it may be used to adjust the objectives and targets to the meet the potential of the Department's actual human resources. This is a crucial point in the production of public services, since in Italy the acquisition of human resources is currently restricted by the law.

Here we focus on the modeling and simulation of the purchasing process at the Department of Informatics, Modeling, Electronics and System Engineering

(DIMES) of the University of Calabria. Today's national and internal rules make purchasing activities reasonably standardizable. That is the reason of our choice, along with the fact that reducing the payment time of invoices related to the purchasing process is an objective assigned to the DIMES for the year 2016.

The Purchasing Process

In order to favor comprehension of the Department's purchasing process, the overall logic is illustrated by the flowchart in Figure 1. A step-by-step description follows for each block in the flowchart with respect to the activities to be performed, the (human) resources involved in doing so and decisions to be made.

A purchase request is generated by a faculty member to notify the Department's Purchasing Office of items he/she needs to order, along with the quantity and the research funds to be used for such purpose. The request is actually prepared with the support of personnel from the Purchasing Office and not only dispatched to this office after it has been filled in by the faculty member. Consequently, this stage also accounts for the time during which interaction between the two parties takes place if the request contains missing and/or unclear details. Once the request is complete, staff from the Purchasing Office first verifies if the goods/services are available on the Italian Public Administration Marketplace, also known as MEPA. On this digital marketplace (e-procurement) public administrations purchase goods/services, as long as their cost is below a prefixed European threshold. Goods/services are chosen among those offered by suppliers that have been vetted and authorized to post their catalogues on the system. If the goods/services are available on MEPA, then one of the two situations may occur:

- the cost is greater than €4,000 (VAT excluded);
- the cost is less than or equal to €4,000 (VAT excluded).

In the former case, a request for proposal (RFP) is generated on the MEPA portal. This document triggers a sealed-bid procurement procedure through which the Purchasing Office informs the potential MEPA suppliers of the description, technical details, terms and conditions of the goods/services to be procured. Suppliers must submit their offer before the proper time interval (usually, 10 days) has expired. Bid opening, examining and evaluation are carried out by a commission appointed by the Chair of the Department. In particular, the commission usually provides a score for the technical aspects, while MEPA assigns a score for the economic aspects of the bids. If the contact is awarded, than the related legal document is drawn up; otherwise, the procedure overrides any other step and the process is terminated without a winner. In the latter case, the goods/service are chosen from the catalogue of one of the MEPA suppliers and a purchase order (PO) is issued by the Purchasing Office immediately after.

When the goods/services are not available on MEPA, one of the following situations may occur with respect to the extra-MEPA options:

- there is a single supplier;
- there are multiple suppliers.

If there is a single supplier, then only one quotation is requested and a PO is issued by the Purchasing Office. If there are multiple suppliers, but the cost of the goods/services is less than or equal to €4,000 (VAT excluded), then, again, only one quotation is necessary and a purchase order is issued by the Purchasing Office. If the cost is greater than €4,000 (VAT excluded), at least three quotations are acquired and the "best" among these offers is selected. Whatever be the cost of the goods/services of interest, the Purchasing Office completes all extra-MEPA purchases by issuing a PO.

At this point, the order is placed and the lead time between goods/services delivery may vary from time to time. According to the current practice, the Purchasing Office contacts on a, more or less, regular basis the supplier to receive updates on the scheduled due date. If the goods/services have not been delivered, the office urges the supplier to act quickly in order to meet the delivery date or minimize the delay time when already overdue. Once delivered, the Purchasing Office checks to see if the supply is compliant with the order, otherwise the supply is returned to the supplier for replacement/repair. In this stage, the correctness of the related invoice is verified as well and followed by a correction request eventually. After the final approval by the faculty member-funds holder, other formal details are verified in the last stage by the Purchasing Office. The payment order is then prepared, printed, controlled and then signed by those delegated with procurement authority and transmitted to the bank. The purchasing process is terminated, unless the purchased items require being added to the inventory.

SIMULATION

It is easy to recognize from the flowchart in Figure 1 that the state dynamics of the process under examination are determined by the occurrence of some well identified fundamental events, such as request, order, delivery and payment. As a response to the triggering effect of these events, specific activities are performed. Therefore, events and activities determine the evolution over time of the performed payments, by which one should measure the throughput of the entire process. Due to the unavoidable presence of randomness in event occurrence and activity duration, discrete-event (stochastic) simulation (Law and Kelton 2000) appears to be the most appropriate methodology for a quantitative analysis aimed at predicting the performance of the organization policies for the process of interest. If the model had to account for cooperation among staff units or other forms of interaction-based working methods, an agent-based stochastic simulation (Wilensky and Rand 2015) would have been the most natural choice.

Several commercial tools (e.g. Arena 2006; Process 2015) support the implementation of the above flowchart model, as well as its time behavior reproduction.

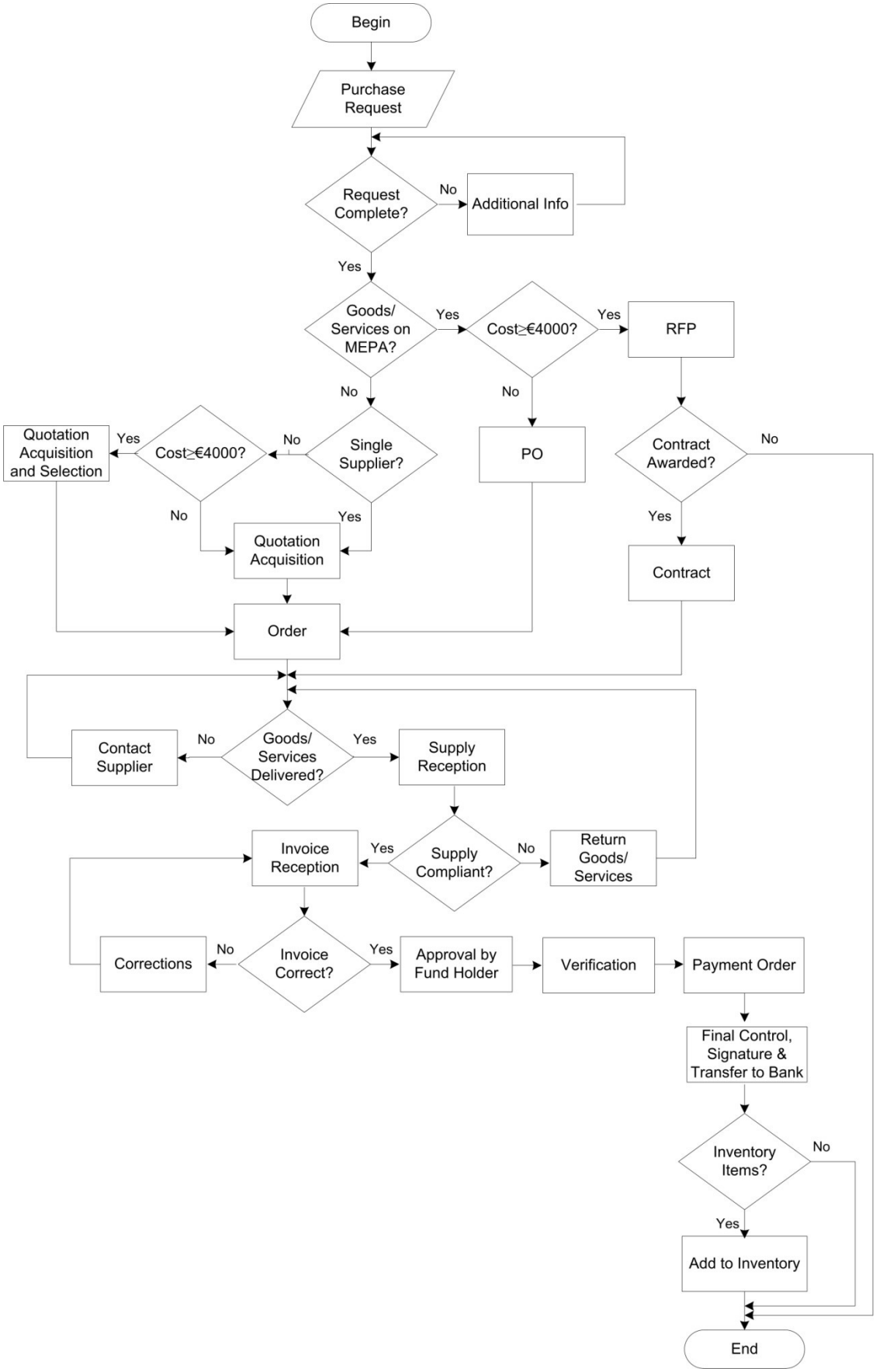

Figure 1: The Purchasing Process

Despite this, simulation input and output analysis is still challenging when facing processes where limited resources play a significant role in determining the process throughput. Hence, among all the steps carried out within our sound and thorough simulation study, here we focus on the statistical analysis of both the simulation input and output data.

In particular, let $\lambda(t)$ be the average number of "purchase requests" arriving in the time unit t (i.e. one week in our case). We partition the real-event data into a suitable sequence of weekly subintervals over a one-year horizon to model the peaks (i.e. before/after breaks and holiday seasons) and troughs (i.e. during breaks and holiday seasons) that can significantly impact on system performance. We then adopt point and interval estimators for the cumulative intensity (or mean value) function (1) of the purchase request events that occur over time in a non-stationary process evaluated at the weekly endpoint t_2, as suggested by (Leemis 1991).

$$\Lambda(t_1, t_2) = \int_{t_1}^{t_2} \lambda(t)dt \qquad (1)$$

Basically, we assume that a non-homogeneous Poisson process (NHPP) with a piecewise constant intensity (rate) function is appropriate enough to model the series of events that occur over the weeks in a non-stationary fashion (see Table 1). Algorithms presented by (Leemis 2004) are then used in the simulation experiments to generate purchase order arrival times from the estimated NHPP.

Table 1: The Piecewise Constant Intensity Function for Modeling the Arrival of Purchase Requests

	Rate [arrivals/week]	**Duration [week interval]**
λ_1	4	1-8
λ_2	13	9-30
λ_3	8	31-52

To complete the input modeling analysis, other types of distribution probability functions have been identified (with Arena's Input Analyzer) for the second major sources of uncertainty, i.e. the activity durations:

- PO processing times are well captured by a 2-order Erlang distribution with mean value equal to 19.1 and shifted to the right by 0.999 (0.999 + *Erlang*(19.1,2));
- RFP preprocessing and processing times profiles are well fitted by a 2-order Erlang distribution with mean value equal to 8.22 and shifted to the right by 8.5 and a Beta-based distribution with shape 1 equal to 0.857, shape 2 equal to 1.65 and shifted to the right by 10, respectively (8.5 + *Erlang*(8.22,2) and 10 + 142 * *Beta*(0.857,1.65));
- Extra MEPA processing time profiles agree with a 2-order Erlang distribution with mean value equal to 25.6 and shifted to the right by 5 (5 + *Erlang*(25.6,2));
- Final control and transfer of payment documents to the bank are modeled by means of a Normal density function with mean value equal to 4.54 and standard deviation equal to 2.28 (*Normal*(4.54, 2.28)).

As for simulation output analysis, we used a first set of results to perform validation, i.e. assess if the real purchasing process is accurately represented by the simulation model. Besides discussing the structural assumptions and data assumptions with the key figures of the Department's Purchasing and Administration Offices, model input-output transformations have been compared to the corresponding input-output transformations for the real system.

As a result of both of these validation activities, one can appreciate the capability of the simulator to mirror the real system performance by observing the 95% interval estimates vs the real figures in Table 2 and the simulated vs the real trend in Figure 2. In the former case, although the X-MEPAs real measure (i.e. 147) is right-adjacent to the interval returned via simulation, it is still a good result if one considers the overall degree of uncertainty intrinsic in the specific X-MEPA process due to the difficulty in measuring the time effort required by the Commission. As for the latter case, the real (blue) trend in Figure 2 refers to the unique real throughput trajectory available, whereas the simulated (red) trend is an estimate of the average throughput behavior. The degree of matching between the two above trends is satisfactory enough, especially after the first weeks (once transient behavior has died out).

Table 2: Real vs Simulated N° of Purchase Requests

Source	**Purchase Requests**		
	RFPs	**POs**	**X-MEPAs**
2014 Records	35	277	147
Simulator	[31-38]	[265-280]	[134-146]

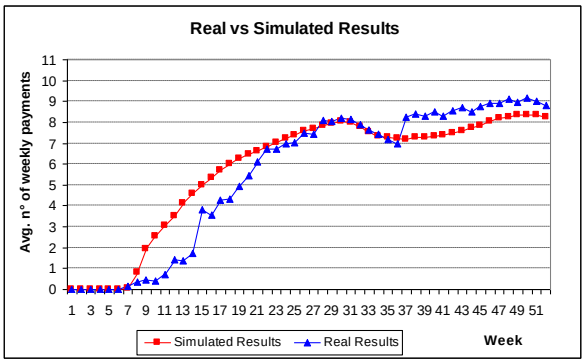

Figure 2: Real vs Simulated Trend of the Average N° of Purchases Completed (Throughput) per Week

CASE STUDY

The purpose of this case study is to compare the "as is" organization of the Department's purchasing process with its "to be" organization based on policies compliant with national compulsory anticorruption and transparency service regulations. In particular, within the wider objective of rationalizing the public expenditure and reorganizing the administrative structure, here we intend to perform two what-if experiments. In the first, the idea is to lower the €4,000 disclosure threshold referred to in the description of the purchasing process. As a result, more RFPs, rather than POs should be generated on the MEPA portal, thus, preventing the use of working policies in the public sector that lack transparency and encourage, in some sense, favoritism. In the second, in shifting from one set-up to another, we wish to account for non-secondary organizational issues in the purchasing process such as introducing a new policy when carrying out final controls and transferring payment orders to the bank.

The simulation experiments for both cases have been carried out under Rockwell's Arena simulation package (version 11) and run on a personal computer equipped with an Intel® Core™2 Duo 1.58 Ghz processor and 2.93 gigabytes of RAM. The models in Arena include VBA (Visual Basic® for Applications) blocks that allow inserting user-defined code. In our study, these blocks are used to interact with worksheets under Microsoft® Excel in order to record the output data produced by the simulator and generate 95% interval estimates. All the experiments share the same computational effort (i.e. 30 runs for each 1-year scenario), the same number of resources (i.e. 1 unit in the Administration Office, 1 unit in the Purchasing Office and 1 unit in the Payment Office) and the same *modus operandi*.

The "Transparency" What-if

In this first what-if analysis, we consider the importance of the so-called disclosure threshold of the goods/services available on MEPA. As previously stated, the value of this threshold determines whether the goods/services of interest should be purchased via a sealed-bid RFP or chosen directly with a PO from the catalogue of one of the MEPA suppliers. This value is currently set at €4,000. However, in order to increase transparency, we believe worthy investigating the effect of lowering the above disclosure threshold. Since in our Department only 7.6% of the purchases are carried out according to the RFP option (see column 2 in Table 3), the point becomes whether or not the organization and personnel can cope with the greater operational effort required by a decrease in the above threshold.

Let us assume that one of the Department's operational objectives consists in decreasing the threshold from €4,000 to another value between €3,000 and €1,000. As a result, the RFP-based purchases will go from 7.6% to some value between 10.7% and 22%, respectively (see columns 3 to 5 in Table 3).

Table 3: Composition of Purchase Types according to Disclosure Threshold

Type	Disclosure Threshold			
	€4,000	**€3,000**	**€2,000**	**€1,000**
X-MEPAs	32.0%	32.0%	32.0%	32.0%
POs	60.4%	57.3%	55.3%	46.0%
RFPs	7.6%	10.7%	12.7%	22.0%

As one may see from the simulation results reported in Table 4, fixing the disclosure threshold to either €3,000 or €2,000 is well-supported by the overall purchasing process: only small changes occur in the average number of purchases completed per week. On the other hand, if the threshold value drops to €1,000 (or below), then the overall performance of the process will drop considerably as well: the average value of the number of purchases completed per week will go from 8.37 to 6.54. This is probably due to the fact that the moderate-high level of utilization of one of the key resources in the purchasing process (i.e. an average 75% for the unit in the Purchasing Office) inevitably drives this resource to become the system bottleneck. Thus, the level of human resource utilization cannot be disregarded when tuning the value of the disclosure threshold.

Table 4: Average N° of Purchases Completed per Week for a Range of Disclosure Thresholds

Disclosure Threshold			
€4,000	**€3,000**	**€2,000**	**€1,000**
[8.28-8.45]	[7.96-8.20]	[7.56-8.10]	[6.32-6.75]

The "Final Control and Delivery Policy" What-if

In this second what-if analysis, we consider the effect of introducing a new policy when carrying out the final controls and transferring the Department payment orders to the bank. As of today, control and transfer occurrences depend on a variety of contingencies (e.g. deadlines, priorities and personnel availability), rather than a fixed scheduling policy.

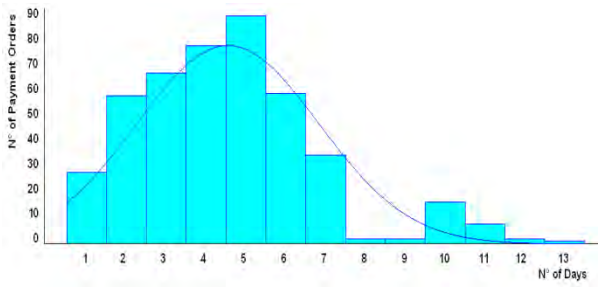

Figure 3: Duration of the Time to Control and Transfer Payment Orders to the Bank

In our actual case, once payment orders are authorized, then signing, control and transfer operations are carried out according to the profile illustrated in Figure 3, which bears an average value of 4.54 days, a 2.29 standard deviation and a 0.89 skewness. The profile has been obtained with Arena's Input Analyzer and fitted to a Normal shape (with skewness set to zero).

Time-based or batch-based policies are two of the new possible scheduling options. In the former case, a payment order is controlled and transferred only if it arrives within a given time interval. In the latter, payment orders are collected, controlled and transferred to the bank only when the number of orders in a batch reaches a target maximum.

Table 5: Duration of the Overall Completion Time of the Purchasing Process

Lead Time (days)			
Policy	**X-MEPAs**	**Pos**	**RFPs**
current	[27.6-34.1]	[25.1-30.9]	[53.3-59.0]
time-based	[26.1-34.4]	[23.4-31.5]	[51.5-59.7]

Here we focus on a 24-hour time-based policy according to which payment orders are controlled and transferred (by the unit working in the Administration Office) if they arrive duly approved before 1:00 p.m. of every day; otherwise, they are controlled and transferred the day after.

As one may expect, the Department's purchasing process benefits from introducing a time-based scheduling policy: the average control and transfer time decreases from 4.54 days (1 day = 7 working hours) to 3.22 hours and the resulting shape in Figure 4 is only slightly skewed to the left (-0.13).

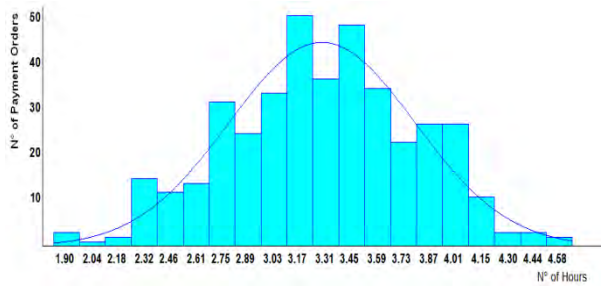

Figure 4: Duration of the Time to Control and Transfer Payment Orders to the Bank with New Policy

The great reduction from approximately 30 to 3 working hours is certainly due to the daily-based control and transfer mechanism of the new policy against the contingency-based decision pertaining to the previous practice. As a matter of fact, the central (average) value of the interval estimates for the lead time of the overall purchasing process reported in Table 5 is shifted towards the left (i.e. reduced), although the whole interval has become slightly larger.

CONCLUSIONS

It has been shown that computer simulation of the "purchasing process" in a University Department is both appropriate and effective for predicting process performance and the benefit of innovation. Validation has been successfully carried out to assess the reliability of the chosen data modeling method for input events (purchase requests). Then a what-if analysis has been presented to illustrate the practical use of the simulator when pursuing increased levels of efficiency in terms of both order cycle times and process transparency. In particular, the latter could be achieved through a sustainable reduction of the threshold level enabling a specific procedural variant within the purchasing procedure. The impact of human resources availability and utilization on the performance of the whole process could also be predicted to drive a rational resource allocation over the set of operational activities. More generally, this study should encourage the adoption of discrete-event simulation as the most appropriate prediction tool aimed at supporting the integration of strategic plans and performance targets with operational processes in the public sector.

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