Acquiring Performability Metrics of e-Commerce Systems

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Abstract – **In this paper, the performability of e-Commerce systems has been treated, by obtaining specific metrics, through stochastic modelling and discrete-event simulation approach. Two common configurations have been observed, including a system with a single module, and a system with a spare module in a cold standby. A comparison of the two configurations' availability levels has been made, as well.**

Keywords – **e-Commerce, Performability, Stochastic Petri Nets, Discrete-Event Simulation.**

I. INTRODUCTION

The gains, successfulness and effectiveness of a particular e-Commerce system, be it an existing one or a system in the phases of design and implementation, can be assessed by quantitative modelling and evaluation of its performance, reliability, and availability, unified under the notion of performability. It is a complex concept, which includes both the performances and the dependability of the observed system. On the other hand, e-Commerce systems are inherently complex by nature and exhibit a stochastic behaviour that can be mathematically described by the probability theory and stochastic processes, especially the Markov processes [1]. Still, both the specification and validation of Markov models are extremely difficult. Moreover, there is also the problem of a state-space explosion due to enormous number of states within their reachability sets, known as the problem of largeness, which makes these models be computationally intractable in practice, in most cases. In addition, one should be also aware of the existence of the problem of stiffness, since the events that correspond to system's performances are more frequent than those that correspond to its reliability. Therefore, we propose the appliance of the hierarchical composition approach instead of building a single, unified, and monolithic model, which can be decomposed into three sub-models, including the reliability, the performance, and the availability sub-models, which altogether comprise the performability model. Next, in order to avoid direct modelling with Markov processes, we propose the usage of some classes of stochastic Petri Nets. Nonetheless, despite the fact that methods for obtaining an analytical solution of these classes have been already developed, and several dedicated software tools for obtaining a numerical solution already exist, we propose the approach of solving these stochastic Petri models by discrete-event simulation (DES). In spite of the fact that there are many common-purpose software packages that support DES, we have turned to the SimPy/Python programming environment, due to its high level of flexibility, robustness, and semantic expressing power to build simulation models of an arbitrary complexity and to obtain plethora of metrics, as required.

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II. THE RELIABILITY SUB-MODEL

The fundamental part of all further stochastic sub-models is the GSPN reliability model (Fig. 1), derived from the DSPN Petri model of the e-Customer's online shopping behaviour, originally proposed by Mitrevski *et al.* (2002) [2]. Initially, the e-Customer resides in the place P_{SEARCH}, i.e. he/she invokes the function *Search*, for an exponentially distributed time $1/\lambda$, where λ is the firing rate of the transition T_{END_SEARCH}. If the desired item/product is found, he/she can put it into the shopping cart (function *Add-to-Cart*) and repeat the *Search* operation. If the shopping cart is not empty, he/she can proceed to the place $P_{CHECKOUT}$ and make an order.

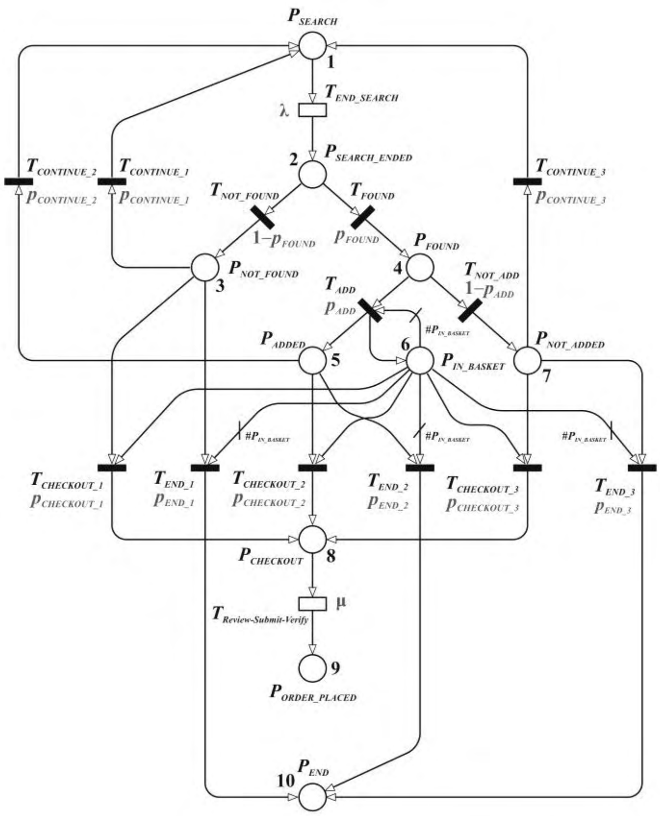

Fig. 1. A Generalized Stochastic Petri Net model of the e-Customer's online shopping behaviour

The order is being placed for an exponentially distributed time $1/\mu$, where μ is the firing intensity of the exponential transition $T_{Review\text{-}Submit\text{-}Verify}$. There are two possible outcomes (absorbing states) with this model, i.e. either a successful one, when the e-Customer places an order (a token in the place P_{ORDER_PLACED}) or an unsuccessful one, when the e-Customer leaves the virtual store without buying anything (a token in the place P_{END}).

Five different *classes of e-Customers* have been defined, both qualitatively and quantitatively, using the parameters, i.e. the weights of the immediate transitions and the firing rates of the exponential transitions within the GSPN model, depicted on Fig. 1. These include the classes of the Passionate, the Focused, the Reluctant, the Curious, and the Selective e-Shoppers, arranged in a descending order regarding the corresponding *conditional probability for a successful outcome of sessions* (Fig. 2), being estimated by simulations, too. The appliance of the Bowman-Shelton test of normality has shown that the conditional probability statistically follows the Normal distribution, for all classes of e-Customers. It has been also concluded that the highest *average successful rate* (0.85264 [s^{-1}]) is evident for the class of the Passionate, followed by the classes of the Focused (0.56816 [s^{-1}]) and the Reluctant (0.19756 [s^{-1}]) e-Shoppers. Contrary to all expectations, the class of the Curious e-Shoppers (0.09893 [s^{-1}]) exhibits an insignificant, yet a higher average successful rate than the Selective e-Shoppers' (0.02451 [s^{-1}]), a fact that confirms the previously listed arrangement of e-Customers' classes in a descending order.

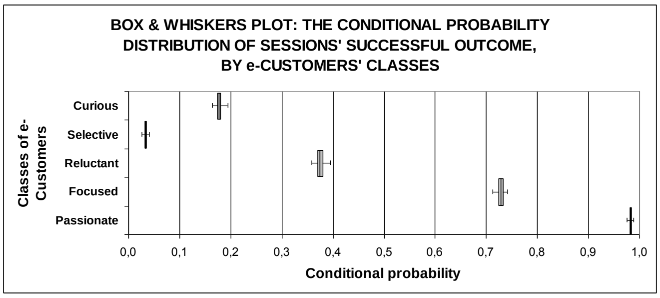

Fig. 2. Box & Whiskers plot of the conditional probability distribution of sessions' successful outcome

In addition, eight characteristic *operating profiles* have been defined on the basis of the *stochastic GSPN model of the operational environment*, including the following ones: OP#1(100%; 0%; 0%; 0%; 0%), OP#5(20%; 20%; 20%; 20%; 20%), whilst the rest six of them can be represented by the vector (80%; *a*%; *b*%; *c*%; *d*%), where *abcd* are combinations of class 4, of the values 0 and 10, given $a + b + c + d = 20$. The idea is to carry out evaluations for six other operating profiles in which the percentage of the most desirable class, i.e. that of the Passionate e-Customers, is 20% less than in the OP#1, and also to investigate the impact of the equal distribution of the classes within the workload mix. Based on these assumptions, an evaluation of the *total probability for a successful outcome of sessions* has been performed, by different operating profiles, as a measure of the reliability (Fig. 3).

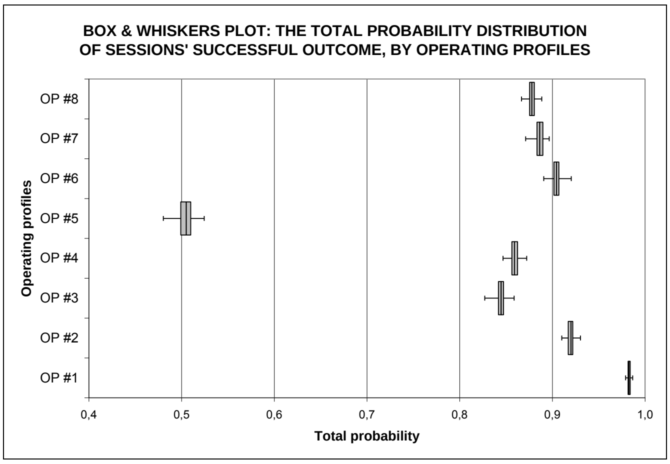

Fig. 3. Box & Whiskers plot of the total probability distribution of sessions' successful outcome, by various operating profiles

The appliance of the Bowman-Shelton test of normality has shown that the distribution of the total probability also follows the Normal distribution, for all defined operating profiles.

III. The performance sub-model

The performance sub-model is a logical extension of the reliability model, by including the concept of faults, i.e. functional breakdowns. The GSPN reliability model (Fig. 1) has been upgraded to the class of Deterministic and Stochastic Petri Nets (DSPNs), since it had to include a timeout mechanism, i.e. a deterministic transition $T_{TIMEOUT}$, which models the maximum allowed time for staying in the states P_{SEARCH} and $P_{CHECKOUT}$ (Fig. 4). The deterministic time is always resampled with each consecutive change of the marking, according to the race with resampling policy [3]. The resulting DSPN performance model of is shown on Fig. 4.

In this particular case, the term 'fault' refers to a 'timing failure', an event that occurs each time the e-Commerce system terminates an e-Customer's session forcibly and prematurely, due to his/her inactivity. Such a non-regular behaviour of e-Customers can be viewed in a broader context. The e-Customer, with his/her non-responsible behaviour causes a fault. As a result, the session, as a basic process that occurs between the client- and the server-side, has been jeopardized in terms of its dependability. Many research activities are focused on investigating the origins of such an unexpected human behaviour, which can be characterized as a human error or human perturbation. All these activities are based on the observation that a system's dependability is a direct consequence of the synergy that comes out from the interaction between the human and the system. The human behaviour that causes faults is one of the most influential factors [4] and a main component responsible for systems' functional breakdowns [5].

A propos the performance measures, an evaluation of the *mean session length* has been carried out, for various operating profiles. Simulations have shown that the mean session length is shortest with operating profiles OP#4 (254.30 [s]) and OP#8 (254.87 [s]), whilst OP#5 exhibits the longest mean session length (324.00 [s]).

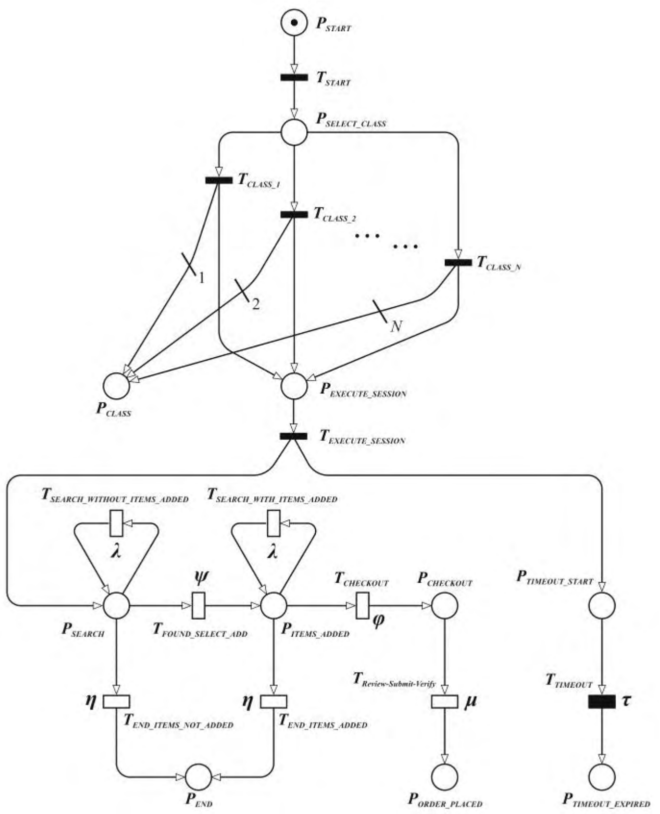

Fig. 4. A Deterministic and Stochastic Petri Net performance model

Further on, an evaluation of the *mean time to a timing failure* has been accomplished. It is highest with OP#5 (311.80 [min]), whilst OP#1 (122.07 [min]) and OP#2 (124.55 [min]) exhibit lowest mean time to timing failure. Finally, the *mean number of sessions to a timing failure* has been evaluated, too. It is highest with OP#5 (77.92), which is almost as twice as bigger value than with other operating profiles', ranging from 33.40 to 40.40.

IV. The availability sub-model

The analysis of performability measures has been done in two specific cases: i) When the e-Commerce system is comprised of a single module (a standard configuration) (Fig. 5); ii) When, besides the main module, there is an additional, redundant, spare, and non-active module, waiting to be activated in the case of failure of the main module (cold standby configuration) (Fig. 6). The evaluation of performability measures has been carried out taking into account the following parameters: the *mean time to failure* (*MTTF*) and the *mean time to repair* (*MTTR*). In the case of the cold standby configuration, in addition to the previously mentioned ones, the *mean activation time* (*MAT*) of the spare module has been taken into account. The values of all of these parameters correspond to the specification of a 'well managed system' [6].

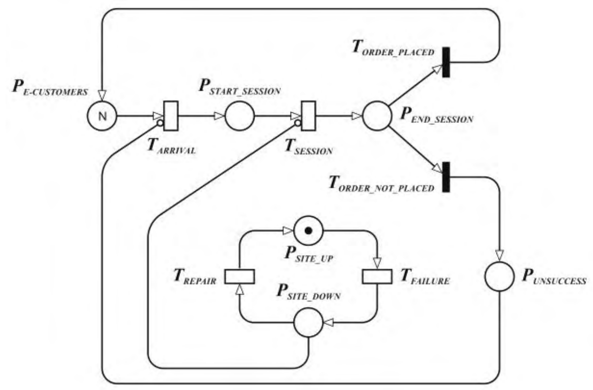

Fig. 5. A Generalized Stochastic Petri Net availability model (a standard configuration)

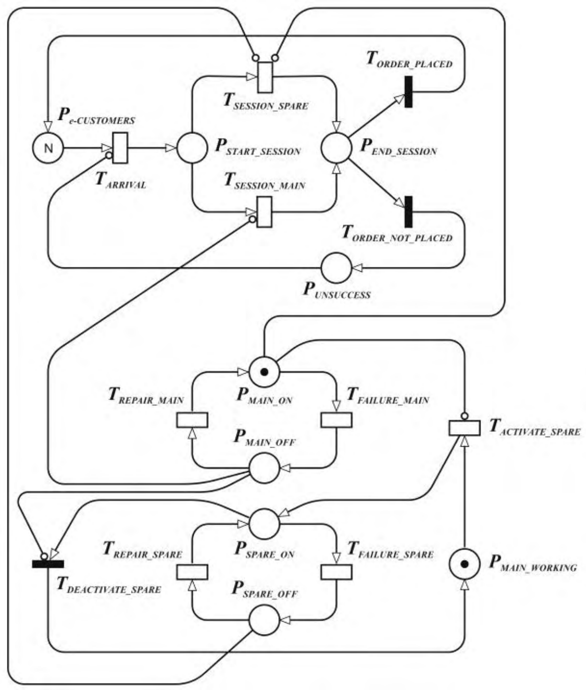

Fig. 6. A Generalized Stochastic Petri Net availability model (a cold standby configuration)

The hierarchical composition approach requires the input parameters for both GSPN models (Fig. 5 and Fig. 6) should be the *total probability for a successful outcome of sessions*, obtained by solving the reliability sub-model, as well as the *mean session length*, obtained by solving the performance sub-model. The following performability measures have been evaluated for the two considered configurations, including: i) the *mean time to an unsuccessful session* (Fig. 7); ii) the *mean number of successful sessions to an unsuccessful one* (Fig. 8); iii) *availability* of the e-Commerce system's configuration.

Fig. 7 shows that the *mean time to an unsuccessful session* is inversely proportional to e-Customers' arrival rate, for all operating profiles. Its function decreases monotonously from

∞ (for $\lambda = 0$ [e-Customers/s]), and asymptotically approaches a limit value, which is different and characteristic for each operating profile (for $\lambda \to \infty$ [e-Customers/s]). The operating profile OP#1, comprised of 100% Passionate e-Customers, exhibits the smallest, whilst the operating profile OP#5, where all classes of e-Customers are being included equally, exhibits the largest mean time to an unsuccessful session. The value of the Pearson's correlation coefficient (–0,987) shows that there is a statistically significant, yet a negative correlation between the mean time to an unsuccessful session and the total probability for a successful outcome of sessions.

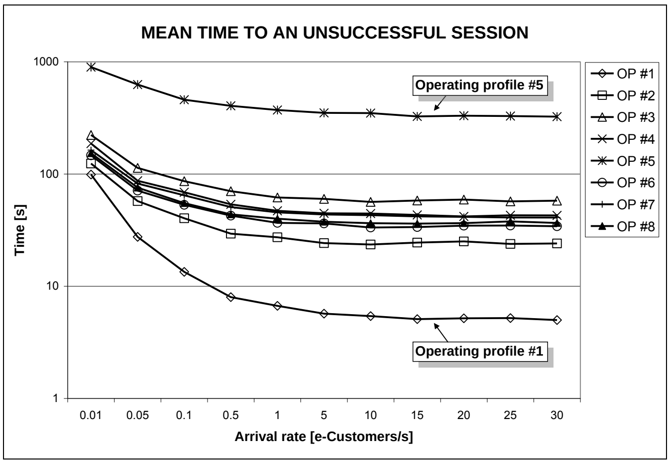

Fig. 7. Mean time to an unsuccessful session, for various operating profiles and e-Customers' arrival rates ($0.01 \le \lambda \le 30.0$ [s^{-1}])

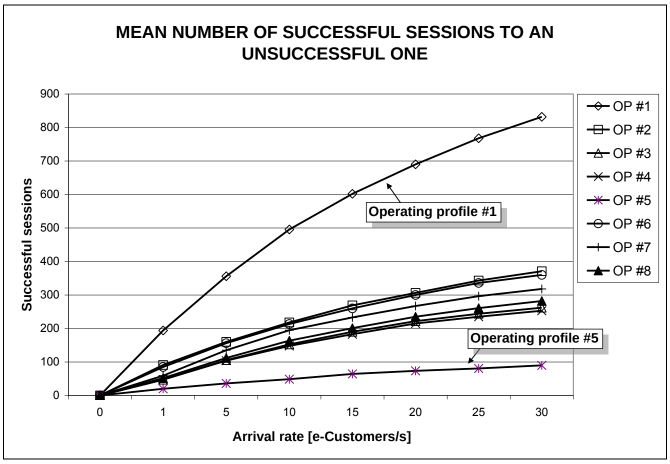

Fig. 8. Mean number of successful sessions to an unsuccessful session, for various operating profiles and e-Customers' arrival rates ($0.00 \le \lambda \le 30.0$ [s^{-1}])

The shape of the *mean number of successful sessions to an unsuccessful session*'s function is logarithmic (Fig. 8). For a given arrival rate λ, the operating profile OP#1 demonstrates the highest, whilst the operating profile OP#5 yields the lowest value of this measure. The simulations have also shown that there is no statistically significant variation in the values of this measure and the previous one in the case of the cold standby configuration.

Regarding the *availability* of both configurations, the simulations have shown that, in average, the cold standby configuration results in slightly more than 1% better availability compared to the standard configuration's one, which is equivalent to 89.17 hours additional working time of the e-Commerce system, per year. Now it is trivial to estimate the number of additional sessions per annum due to increased availability, at various arrival rates of e-Customers. Knowing the total probability for a successful outcome of sessions, and assuming the percentage of participation of various operating profiles per annum, it is easy to estimate the annual gain in number of successful sessions for each operating profile, given a specific arrival rate λ. Finally, if one supposes the average profit being made by each successful session, the total extra annual profit can be easily estimated, at various arrival rates λ.

V. CONCLUSION

The hybrid approach to evaluation of performability measures of e-Commerce systems, relying on the usage of various classes of stochastic Petri Nets (e.g. DSPNs, GSPNs) for modeling purposes, as well as the choice to solve such models numerically, using a programming language for discrete-event simulation based on active processes (e.g. SimPy/Python environment), has proven to be extremely flexible, efficient, robust, and general by nature. The semantic expressing power of stochastic Petri Nets allows a rapid prototyping and building predictive stochastic models of arbitrary complexity, whilst Simpy/Python offers unlimited possibilities to successfully translate the Petri models into an executable programming code, useful for assessing arbitrary number of output parameters, as a function of a plethora of input parameters.

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