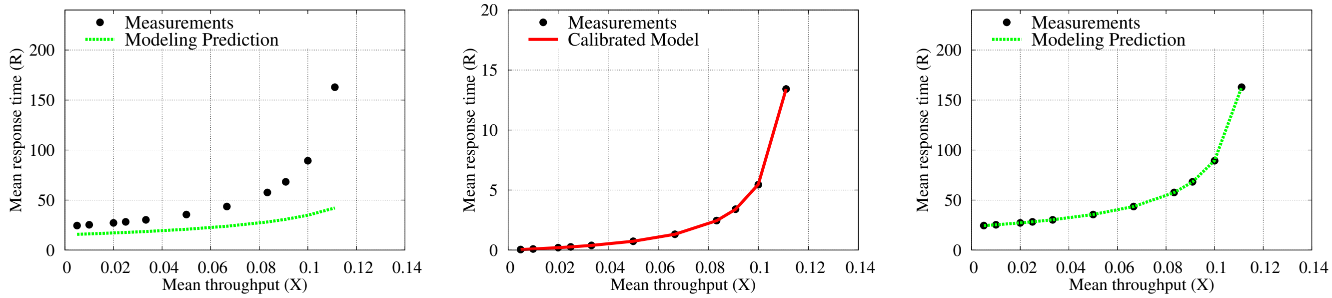

(a) Initial performance prediction (b) Modeling the residual performance (c) Refined performance prediction

Figure 11: Predictions of system performance against measurements for the centralized system with an unknown component.

is an additional component that was not measured (and perhaps even not instrumented) and therefore not modeled, we consider the difference in the performance metric between the system measurement points and the performance curve given by Formula (1). Given this residual pattern of performance, we apply a black-box modeling approach [6] to find a model that reproduces adequately this behavior. It turns out that a simple *M/M/1* queue can fit the data (see Figure 11b).

If the pattern was more chaotic and could not be matched by a reasonable model, it might imply that the residual performance difference is just measurement "noise", or that something else is amiss and that the system does not comply with the set of assumptions required for the proposed approach to work. A possible approach to try to determine whether the residual performance difference is due to "measurement noise" would be to apply simple statistical tests [1].

Now, having in hand a calibrated model for each of the four system components, we can re-apply the proposed approach to forecast the system performance. The corresponding results are shown in Figure 11c and clearly, including a new component was the right choice in our case.

6. CONCLUSIONS

In this paper we consider the problem of combining calibrated performance models of individual system components into an accurate system-level performance model. We concentrate on open workload systems and we show that under certain conditions the straightforward application of Little's law allows one to effect this integration. We give examples to illustrate the successful application of the proposed approach, as well as examples that show the extent of inaccuracies if the applicability conditions are not met.

Additionally, we show that by analyzing the discrepancies between the model predictions and the measurements it may be possible to determine if an important system component has not been correctly represented. This can be of help in the design of calibrated system performance models.

As future work, the authors plan to further investigate the important issue of distinguishing "measurement noise" from errors due to missing components. Another area of investigation pertains to the extensions of the proposed framework to closed systems.

7. REFERENCES

[1] Allen, A. O. (1990). *Probability, Statistics, and Queueing Theory: With Computer Science Applications*, Academic Press.

[2] Awad, M., & Menascé, D. A. (2014). On the Predictive Properties of Performance Models Derived through Input-Output Relationships. *Computer Performance Engineering*.

[3] Awad, M., & Menascé, D. A. (2014). Dynamic Derivation of Analytical Performance Models in Autonomic Computing Environments. In Proc. of *CMG*.

[4] Balsamo, S., & Iazeolla, G. (1982). An extension of Norton's theorem for queueing networks. *IEEE Transactions on Software Engineering*.

[5] Baskett, F., Chandy, K. M., Muntz, R. R., & Palacios, F. G. (1975). Open, closed, and mixed networks of queues with different classes of customers. *Journal of the ACM*.

[6] Begin, T., Brandwajn, A., Baynat, B., Wolfinger, B. E., & Fdida, S. (2010). High-level approach to modeling of observed system behavior. *Performance Evaluation*.

[7] Bolch, G., Greiner, S., Meer, H., & Trivedi, K. (2005). *Queueing Networks and Markov Chains*.

[8] Brandwajn, A. (1974). A model of a time sharing virtual memory system solved using equivalence and decomposition methods. *Acta Informatica*.

[9] Brandwajn, A. (1985). Equivalence and decomposition in queueing systems - A unified approach. *Performance Evaluation*.

[10] Chandy, K. M., Herzog, U., & Woo, L. (1975). Parametric analysis of queuing networks. *IBM Journal of Research and Development*.

[11] Courtois, P. J. (2014). *Decomposability: queueing and computer system applications*, Academic Press.

[12] Ganger, G. R., & Patt, Y. N. (1993). The process-flow model: examining I/O performance from the system's point of view. In Proc. of *ACM SIGMETRICS*.

[13] Harbaoui, A., Salmi, N., Dillenseger, B., & Vincent, J. M. (2010). Introducing queuing network-based performance awareness in autonomic systems. In Proc. of *IEEE ICAS*.

[14] Herzog, U. (1974). Some remarks concerning the extended analytic models for system evaluation. *IBM RR 4975*.

[15] Kühn, P. (1976). Analysis of Complex Queueing Networks by Decomposition. In Proc. of *IEEE ITC*.

[16] Kraft, S., Casale, G., Krishnamurthy, D., Greer, D., & Kilpatrick, P. (2011). IO performance prediction in consolidated virtualized environments. In Proc. of *ACM SIGSOFT*.

[17] Kraft, S., Casale, G., Krishnamurthy, D., Greer, D., & Kilpatrick, P. (2013). Performance models of storage contention in cloud environments. *Software and Systems Modeling*.

[18] Marie, R. (1979). An approximate analytical method for general queueing networks. *IEEE Transactions on Software Engineering*.

[19] Reiser, M. (1979). Mean Value Analysis fo Queueing Networks - A New Look at an Old Problem. In Proc. of *IFIP PERFORMANCE*.

[20] Reiser, M., & Lavenberg, S. S. (1980). Mean-value analysis of closed multichain queuing networks. *Journal of the ACM*.