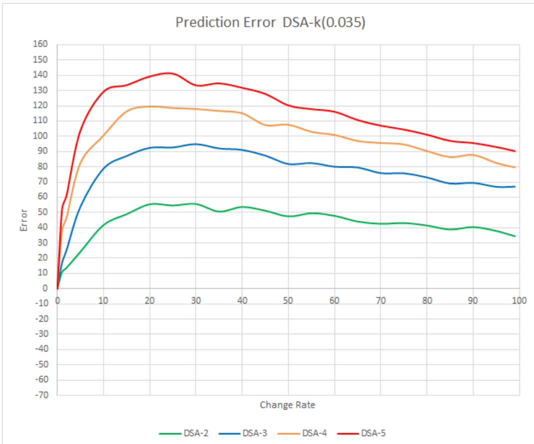

Figure 1: Prediction error for DSA-k for various values of k

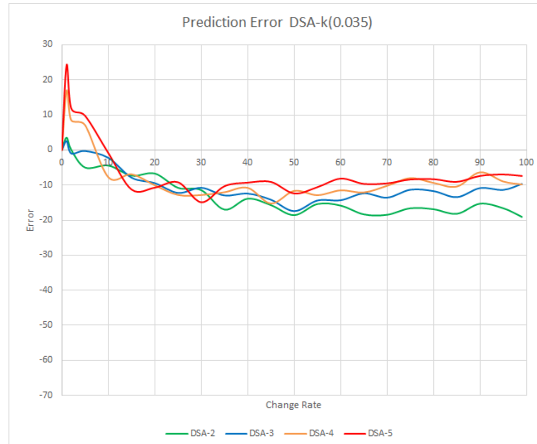

Figure 2: Comparison of predicted versus actual equilibrium points for DSA-k taking into account information stagnancy

in the protocol's information processing. The key difference lies is how often the agents takes cost function changes into consideration. This is controlled by a parameter value we call k. To evaluate the proposed model, we ran an empirical test using the DSA-k protocol where we varied the value for k from 2 through 5. These tests were conducted using $n = 100$ variables, $|D| = 3$, $p_1 = 0.035$, $< c_i = 5 >$ and a $rate$ that varied from 0 to 99. For each setting of k and $rate$, we conducted 30 experiments, each of 1000 steps, where the cost functions were altered, but not added or removed. The results of these tests can be seen in Figure 1. The results clearly show the impact that stagnant information has on the protocol. As the value of k is increased, a noticeable increase in the error can be seen.

With these results in mind, we revisited the equation for the change in energy caused by work. This equation has two principle components, the convergence rate, A and the convergence point, B. By definition, the convergence point is unaffected by delays in information because it represents the solution that the protocol will eventually obtain assuming infinite time. However, it should be clear that delays in processing updates would cause changes to the speed at which a protocol could reach that solution.

Using this reasoning, we speculated that the convergence rate is changed by a factor k. To include this finding, we altered the change work equation by multiply the convergence rate by the value k, which has the impact of slowing convergence. This can be seen in the equation $\frac{dE_W}{dt} = \frac{B-E}{kA}$. Then by combining the equations we reach a new equation to create a new equilibrium point equation that factors in the impact of information stagnancy. This is seen in the equation $E_0 = \frac{kAD+\frac{CB}{rate}}{kA+\frac{C}{rate}}$ In fact, the error for all of the values of k is nearly constant indicating that the error that does remain is probably caused the by order of the simulation cycle.

4 CONCLUSIONS

In this study we showed that the primary cause of prediction error for the equilibrium point of a protocol operating on a DynDCOP is information stagnancy. This error is created by the method used to characterize the converge rate of a protocol. However, this error can be corrected for by altering the equilibrium prediction equation. In addition, the error can be used to measure the impact that information delay has on the performance of a protocol.

ACKNOWLEDGMENTS

This work is supported by the National Science Foundation under Grant No.:IIS-1350671

REFERENCES

[1] Rina Dechter and Avi Dechter. 1988. Belief maintenance in dynamic constraint networks. In *Proceedings of the 6th National Conference on Artificial Intelligence (AAAI-88)*. 37–42.
[2] Roger Mailler. 2005. Comparing Two Approaches to Dynamic, Distributed Constraint Satisfaction. In *Proceedings of the Fourth International Joint Conference on Autonomous Agents and MultiAgent Systems (AAMAS)*. 1049–1056.
[3] Roger Mailler and Huimin Zheng. 2014. A New Analysis Method for Dynamic, Distributed Constraint Satisfaction. In *Proceedings of the 2014 International Joint Conference on Autonomous Agents and MultiAgent Systems (AAMAS)*. 901–908.
[4] R. Mailler, H. Zheng, and A. Ridgway. 2017. Dynamic, distributed constraint solving and thermodynamic theory. *Auton Agent Multi-Agent Syst* (2017). https://doi.org/10.1007/s10458-017-9377-5
[5] Pragnesh Jay Modi, Wei-Min Shen, Milind Tambe, and Makoto Yokoo. 2003. An asynchronous complete method for distributed constraint optimization. In *Proceedings of the Second International Conference on Autonomous Agents and Multi-Agent Systems (AAMAS 2003)*. 161–168.
[6] Gerard Verfaille and Narendra Jussien. 2005. Constraint Solving in Uncertain and Dynamic Environments: A Survey. *Constraints* 10, 3 (2005), 253–281.
[7] G. Wang W. Zhang and L.Wittenburg. 2002. Distributed stochastic search for constraint satisfaction and optimization:Parallelism, phase transitions and performance. *In proceedings of the AAAI workshop on probabilistic Approaches in Search*, 53–59.