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# <<Software Configuration Management in Mixed Risk Environments>>

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**Abstract**

Software Configuration Mangement is becoming more important so that organizations can save time by preventing downtime by standardizing the configurations of the computers for end users. The ANP model was used in this study to simulate a variety of mission critical computers mixed in with non mission critical computers to determine the best conditions for deploying software configurations based on the maximum amount of risk, availability of IT staff for support should something go wrong, and the potential downtime that may result. In the future it is hoped that this decision model will be implemented as a feature in future software so that users can input their qualitative weights and criteria in order to determine whether it is safe to deploy software configurations.


**Introduction**

Information technology managers are in a constant search for way to save time that benefits their department as well as their customers. As, there are many methods to do this, it is best to focus on the ones that require a low risk and a high reward. Examples of this include process improvement, standardization, scheduling, documentation, and enhanced communication. Counter examples of this which are high risk and low reward include the installation of new software suites with a minimal improvement of features compared to existing systems, hiring additional staff for tasks that have not yet been optimized, making changes to critical systems without understanding their dependencies or when their support staff is unavailable. By taking these aforementioned low and high risks into consideration, we must ask the question of how to find low risk problems and then identify the ones that high rewards associated with them.

The examples shown above were mentioned not only because of the commonly known rewards and risks that they offer, such as enhanced features for customer satisfaction or a unexpected and disastrous lack of functionality, but more importantly, to see how they save the organization the organization time. This is especially important, as time is becoming the new currency of what makes a company competitive (Stern, 2006). Time produces groundbreaking innovations that provide a competitive advantage, and timing introduces these innovations at the most favorable moments. Time with experience introduces the experience curve that accelerates an organizations productivity such that their competition will probably never catch up (Stern, 2006).

Although we have introduced the topic of time and innovation in order to explain some of their fruits, our study is primarily concerned with time enhancement and preventing time disasters as they relate to changing the configuration of microcomputer workstations in a business environment, which we will refer to more generically as computers. The examples explained earlier can used as analogies in that the correct configuration of these computers at the right time will result in rewards such as enhanced or continuing productivity, however the incorrect configuration will produce a time deficit resulting in lost productivity and will require additional maintenance from the IT department. More importantly, it is hoped that this mistiming is not the result of a chain reaction, which would cause multiple computers to be configured incorrectly.

Software vendors have recognized the low risk, high reward, opportunities as they relate to configuring computers and have created various software suites that are known as “software configuration management (SCM)” products (Leon, 2005). These SCM products are able to scan a computers to see what their current configuration is so that IT staff can make decisions on how they wish to the configure the computers. It must also be mentioned that SCM products also can implement these configurations on the computers they have been targeted to using processes, standards, and schedules that IT staff create.

Although qualified IT staff are usually the ones who implement these configurations, being human, they are prone to reasonable mistakes, and when these probabilities of error are applied to a massive scale, such as an organization of 50,000 computers, the results can be disastrous. However, with the correct processes and technical competency in place, it can be assumed that the benefits will be great and the mistakes will be minimal to the point of being negligible in the total scheme of business.

There are three methods to deploy these software configurations. The most commonly known can be referred to as the “big-bang” (Coupaye & Estublier, 2000, p.1), in which the configuration is deployed to all computers in the organization. However as mentioned in the prior paragraph, this has a very high risk associated it, and thus is usually relegated to low risk configurations that will result in negligible or no downtime for the end user. The second method is know as “incremental” (Coupaye & Estublier, 2000, p.1), in which configurations are deployed to small groups of computers in a linear fashion in hopes that that problematic configurations will be tested and recognized before they reach the entire organization. The third method of deployment is known as “continuous” (Coupaye & Estublier, 2000, p.1) (Limoncelli, 2017) which is similar to incremental, however there is an assumptions that the IT department does significantly play the role of a middle-man between the vendor of the configuration and the organizations computers. An example of this would be the deployment of Microsoft Windows updates without the IT department manually approving. This definition can also be extended to the IT department also not setting a schedule for which these updates will be deployed.

This web of risk and complexity requires a continuous effort to work with, however there are two alternatives to it, and their explanations will reveal why highly efficient IT departments do not use them. The first alternative is to not configure the computers, for example, not deploying updates for software used by the organization, however after a few years, this will result in the software crashing or a virus/malware infection that will cause the computer to become a time burden on the organization because of lost productivity and costly maintenance. The second alternative is to encourage the users to do the updates themselves, however this will also cause a time burden due to some lost productivity, and some users may never install the updates, leading to the results of the first alternative.

Current SCM software supports continuous deployment, however, it must be recognized that continuous deployment involves many decisions that sometimes involve a web of decisions that must be created by a competent IT staff member, whose position is commonly referred to as a “Configuration Manager” (Limoncelli, 2017). As computer technology becomes more widespread and complex, the scope and complexity of configurations that the Configuration Manager must work with will increase. In addition to this the count of security vulnerabilities reported annually appears to be increasing at a rate of around 15% (Weinburg, 2015, p.13), resulting in more demand for configurations in the form of software patches to plug security holes.

Taking into consideration this increasing scope and complexity, current SCM software has some automated decision-making tools embedded in it, however they are basic and only quantitative rather than qualitative. For example, as mentioned above, the creation of scheduling and standard processes is available, and these can be triggered by the presence of given system conditions such as an old version of software being detected on a system, or a computers coming back online after being offline during the last scheduled deployment of a configuration. This aforementioned gap in the availability of qualitative tools that assist the Configuration Manager in deciding the timing of deploying configurations is an opportunity to choose the best decision model, criteria and weights, which should be implemented in future SCM products.

## **Methodology**

The Analytic Network Process was chosen for this research because unlike the Analytical Hiearchy Process (AHP), which commonly used to make decisions, ANP is different in that it encourages the user to ask questions and explore their options. Also, it allows criteria to be placed into groups that can be weighed as a whole and/or compared with one another, which is known as “inner dependence” (Saaty, 2016), to determine additional weights. Another one of its popular reasons for its use is that its final outcomes otherwise known as “alternatives”, can also affect the criteria. Put more succinctly, AHP is can be described as prescriptive, i.e. telling the user what to do, while ANP is descriptive, i.e. telling the user how their weights and resulting alternative(s) affect the entire system. In Figure 1 show below, we see the AHP model on the left and the ANP model on the right.

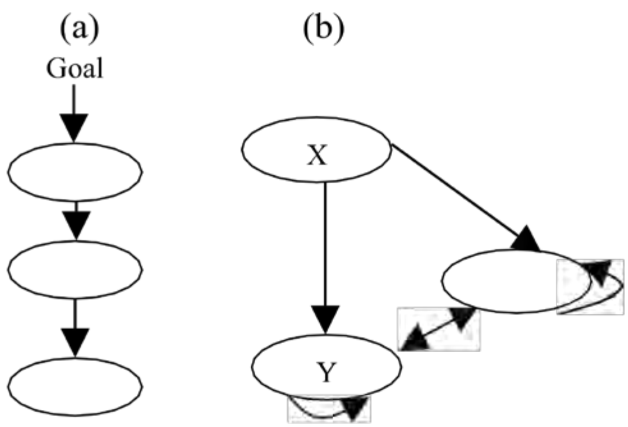



*Figure 1 (Gencer & Gurpinar, 2007)*

The software chosen to build this model is SuperDecisions (Saaty, 2016). The aforementioned clusters and their criteria in **Appendix C** were built into an ANP model as shown in **Appendix E**.

**Data and Data Sources**

In order to test the qualitative model that was created, a group of experts was assembled, all of whom had worked with the responsibility of being a Configuration Manager with various levels of scope of responsibility and knowledge of computing in an enterprise environment. The results of their interviews also caused the author of this paper to categorize their job functions into two groups, namely “strategic” and “tactical”. The tacticians tended to be functional engineers who implemented management policy, while the strategists tended to be managers and coordinators. As will be shown in the discussion section, the results between the two groups were significant. Also, these experts work in the same IT department in an organization of 2,000 employees with a total organizational budget of around $500 million.

| Participant ID | Title | Tactical vs Strategic | Experience (years) | Expertise |
|---|---|---|---|---|
| Participant 1 (P1) | Technical Support Analyst | Tactical | 5 | Software Configuration Management |
| Participant 2 (P2) | System Engineer | Tactical | 10 | System Administration |
| Participant 3 (P3) | Technical Support Technician | Tactical | 5 | Technical Support |
| Participant 4 (P4) | System Analyst | Strategic | 2 | Systems Engineering |
| Participant 5 (P5) | System Engineer | Tactical | 10 | System Administration |
| Participant 6 (P6) | Technical Support Supervisor | Strategic | 4 | Technical Management |

The participants were interviewed individually and were asked to fill out a comparison chart as shown in **Appendix B** per the comparison rules of AHP by showing their favor for one of each alternative on the left or right of the chart by choosing the number associated with the importance that they placed on it. Explanations of the meaning of the criteria are shown in **Appendix C**. The ANP decision model is shown in **Appendix E** while a table of the nearly 100 weighted connections are shown in **Appendix G**. The total weight of each criteria is shown by the value of the limiting matrix shown in **Appendix F** and the weight of each criteria within its own cluster is shown by the "Normalized by Cluster" column in **Appendix F**. Also individuals clusters were assigned weights which are shown in **Appendix H**. Most importantly, the supermatrix is shown in **Appendix D** which shows the weights of all criteria. A complete synthesis of the model is shown in **Appendix I**.

## Discussion

One of the features of ANP is that values that have a weight in the supermatrix less than 3% can be counted as insignificant. The three most significant values can also be seen as highlighted in Appendix D.

1. The value of 0.9 in the alternatives cluster with a potential downtime of none infers that deployment with no downtime is the most favored option
2. The value of 0.9 when reducing potential downtime shows that any downtime over an hour must be reduced in order for the proposed deployment to be significant
3. The value of 0.41 for safety regarding potential downtime means that safety is the top priority of the agency, but since it only accounts for only nearly half the weight, other factors have a significant chance of being worked into its high priority probably in a cooperative fashion.

In the sensitivity analysis in appendix J, it is seen that deployment and reduction of potential downtime are inversely related and this accelerates quickly as the priority reaches past a weight of 0.5.

## Future Research

For future research when using a small population, using the median instead of the mean may be more favorable. Also, it may be interesting to create separate results for the tacticians and the strategists. Also, at the moment, chaning the weights of the model is difficult due to the current limitations of the software, so that fastest way to test the model is simply to delete an entire criteria. For example, to synthesize the model to see if a deployment will be accepted if the safety criteria is not in its scope, the best way is to delete the safety criteria and then synthesize the model. Doing this for future desired combinations has proved effective.

## Conclusion

This study was written in hopes to integrate automated decision making into a commercially available configuration management software by continuously exporting the synthesis of the alternatives from superdecisions into a file or database that is queried via a script to determine whether to deploy packages based on their deployment scope, potential downtime, and staff availability (time of day). If the conditions are met, the script would trigger the configuration management software, via command line, to run the given deployments. This nearly Realtime decision making and subsequent execution is needed because scheduling and targeting must be precise and synchronized (Coupaye & Estublier, 2000, p.1).

The results of this study have confirmed assumptions that IT staff in this organization about their priorities but also brought up new insights showing the configurations that require one minute or less of potential downtime are the only ones that are reasonably acceptable.

## References


Chung, Shu-Hsing, Lee, Amy H.I., & Pearn, W.L. (2005). Analytic network process (ANP) approach for product mix planning in semiconductor fabricator.(Author Abstract). *International Journal of Production Economics, 96*(1), 15-36.

Coupaye, T., & Estublier, J. (2000). Foundations of enterprise software deployment. *Software Maintenance and Reengineering, 2000. Proceedings of the Fourth European,* 65-73.

Gencer, & Gürpinar. (2007). Analytic network process in supplier selection: A case study in an electronic firm. *Applied Mathematical Modelling, 31*(11), 2475-2486.

Leon, A. (2005). *Software configuration management handbook* (2nd ed., Artech House computing library). Boston: Artech House.

Limoncelli, T., Hogan, Christina J., & Chalup, Strata R. (2017). *The practice of system and network administration. Volume 1* (Third ed.). Boston: Addison-Wesley.

Saaty, Thomas (1996). The Analytic Network Process. . RWS Publications, Pittsburgh

Saaty, W. Rozann (2016). Decision Making in Complex Environments. SuperDecisions. Web. 29 May 2017. <superdecisions.com>.

Stern, C., Deimler, Michael S, & Boston Consulting Group. (2006). *The Boston Consulting Group on strategy* (2nd ed.). Hoboken, N.J.: John Wiley & Sons.

Weinberg, Bill. (2015) Open source hygiene – Mitigating Security Risks from Development, Integration, Distribution and Deployment of Open Source Software. Retrieved from: https://www.slideshare.net/blackducksoftware/rv4sec-bill-weinberg-open-source-hygiene-presentation

## Appendix A

| Participant ID | | | (P1) | (P2) | (P3) | (P4) | (P5) | (P6) | Average | Median |
|---|---|---|---|---|---|---|---|---|---|---|
| **cluster - potential downtime** | | | | | | | | | | |
| fifteen minutes | 3.0 | five minutes | 1 | 3 | 2 | 3 | 1 | 6 | 3.0 | 3.0 |
| fifteen minutes | 6.0 | none | 3 | 9 | 2 | 9.5 | 3 | 9.5 | 6.0 | 6.0 |
| fifteen minutes | (6.5) | one day | -7 | -8 | -4 | -9.5 | -3 | -9.5 | -6.5 | -7.0 |
| fifteen minutes | (4.3) | one hour | -2 | -4 | -3 | -7 | 1 | -8 | -4.3 | -4.0 |
| fifteen minutes | 5.1 | one minute | 2 | 4 | 2 | 9.5 | 1 | 8 | 5.1 | 4.0 |
| fifteen minutes | 5.4 | seconds | 3 | 9 | 2 | 9.5 | 1 | 9 | 5.4 | 5.4 |
| fifteen minutes | (5.0) | six hours | -6 | -9.5 | -3 | -9.5 | 2 | -9.5 | -5.0 | -6.0 |
| fifteen minutes | (9.4) | three days | -9.5 | -9.5 | -9 | -9.5 | -9.5 | -9.5 | -9.4 | -9.5 |
| fifteen minutes | (4.8) | three hours | -7 | -7 | -2 | -7 | -2 | -8 | -4.8 | -7.0 |
| five minutes | 4.1 | none | 3 | 1 | -1 | 5 | 3 | 9.5 | 4.1 | 3.0 |
| | 0.0 | | | | | | | | | |
| **cluster - risk ceiling** | 0.0 | | | | | | | | | |
| administrative | 5.0 | customer attention | 5 | 7 | 5 | 5 | 2 | 8 | 5.0 | 5.0 |
| administrative | 5.8 | operational | 4 | 3 | 7 | 7 | 2 | 7 | 5.8 | 5.8 |
| administrative | 7.9 | safety | 9 | 9.5 | 9.5 | 9.5 | 3 | 9.5 | 7.9 | 9.5 |
| customer attention | (0.5) | operational | -4 | -8 | 2 | 2 | -2 | -4 | -0.5 | -2.0 |
| customer attention | 5.9 | safety | 3 | 6 | 5 | 9.5 | 3 | 6 | 5.9 | 5.9 |
| operational | 5.5 | safety | 5 | 9 | 4 | 7 | 3 | 8 | 5.5 | 5.5 |
| | 0.0 | | | | | | | | | |
| **cluster comparisons** | 0.0 | | | | | | | | | |
| staff availability | (1.3) | Deploy | 4 | 6 | | -6 | -3 | 5 | -1.3 | 1.3 |
| staff availability | 0.7 | Reduce potential downtime | 2 | 8 | | 2 | -2 | 2 | 0.7 | 2.0 |
| staff availability | 5.5 | Reduce worst risk | 4 | 4 | | 9.5 | 3 | 4 | 5.5 | 4.0 |
| potential downtime | (1.3) | Deploy | -2 | 5 | | -4 | -2 | 2 | -1.3 | -1.7 |
| potential downtime | 5.3 | Reduce worst risk | -5 | 3 | | 9 | 3 | 4 | 5.3 | 3.5 |
| Reduce worst risk | (5.5) | Deploy | -3 | 4 | | -9.5 | -3 | -4 | -5.5 | -3.5 |

## Appendix B

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **chosen downtime allowance** | | | | | | | | | | | | | | | | | | | | |
| fifteen minutes | 9.5 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9.5 | five minutes |
| fifteen minutes | 9.5 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9.5 | none |
| fifteen minutes | 9.5 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9.5 | one day |
| fifteen minutes | 9.5 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9.5 | one hour |
| fifteen minutes | 9.5 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9.5 | one minute |
| fifteen minutes | 9.5 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9.5 | seconds |
| fifteen minutes | 9.5 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9.5 | six hours |
| fifteen minutes | 9.5 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9.5 | three days |
| fifteen minutes | 9.5 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9.5 | three hours |
| five minutes | 9.5 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9.5 | none |
| **risk ceiling** | | | | | | | | | | | | | | | | | | | | |
| administrative | 9.5 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9.5 | customer attention |
| administrative | 9.5 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9.5 | operational |
| administrative | 9.5 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9.5 | safety |
| customer attention | 9.5 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9.5 | operational |
| customer attention | 9.5 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9.5 | safety |
| operational | 9.5 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9.5 | safety |
| **cluster comparisons** | | | | | | | | | | | | | | | | | | | | |
| staff availability | 9.5 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9.5 | Deploy |
| staff availability | 9.5 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9.5 | Reduce potential downtime |
| staff availability | 9.5 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9.5 | Reduce worst risk |
| reduce potential downtime | 9.5 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9.5 | Deploy |
| reduce potential downtime | 9.5 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9.5 | Reduce worst risk |
| Reduce worst risk | 9.5 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 9.5 | Deploy |

**Appendix C**

| | **Potential Downtime (PD)** | |
|---|---|---|
| **UID** | **Criteria** | |
| PD1 | none | |
| PD2 | seconds | |
| PD3 | one minute | |
| PD4 | five minutes | |
| PD5 | fifteen minutes | |
| PD6 | one hour | |
| PD7 | three hours | |
| PD8 | six hours | |
| PD9 | one day | |
| PD10 | three days | |

| | **Staff Availability (SA)** | |
|---|---|---|
| **UID** | **Criteria** | **Description** |
| SA1 | 5am-2pm – morning | staff available for six hours |
| SA2 | 8am-5pm – office hours | staff available for the entire work day |
| SA3 | 2pm-10pm – swing shift | staff available for three hours |
| SA4 | 10pm-6am – graveyard shift | only oncall staff are available |

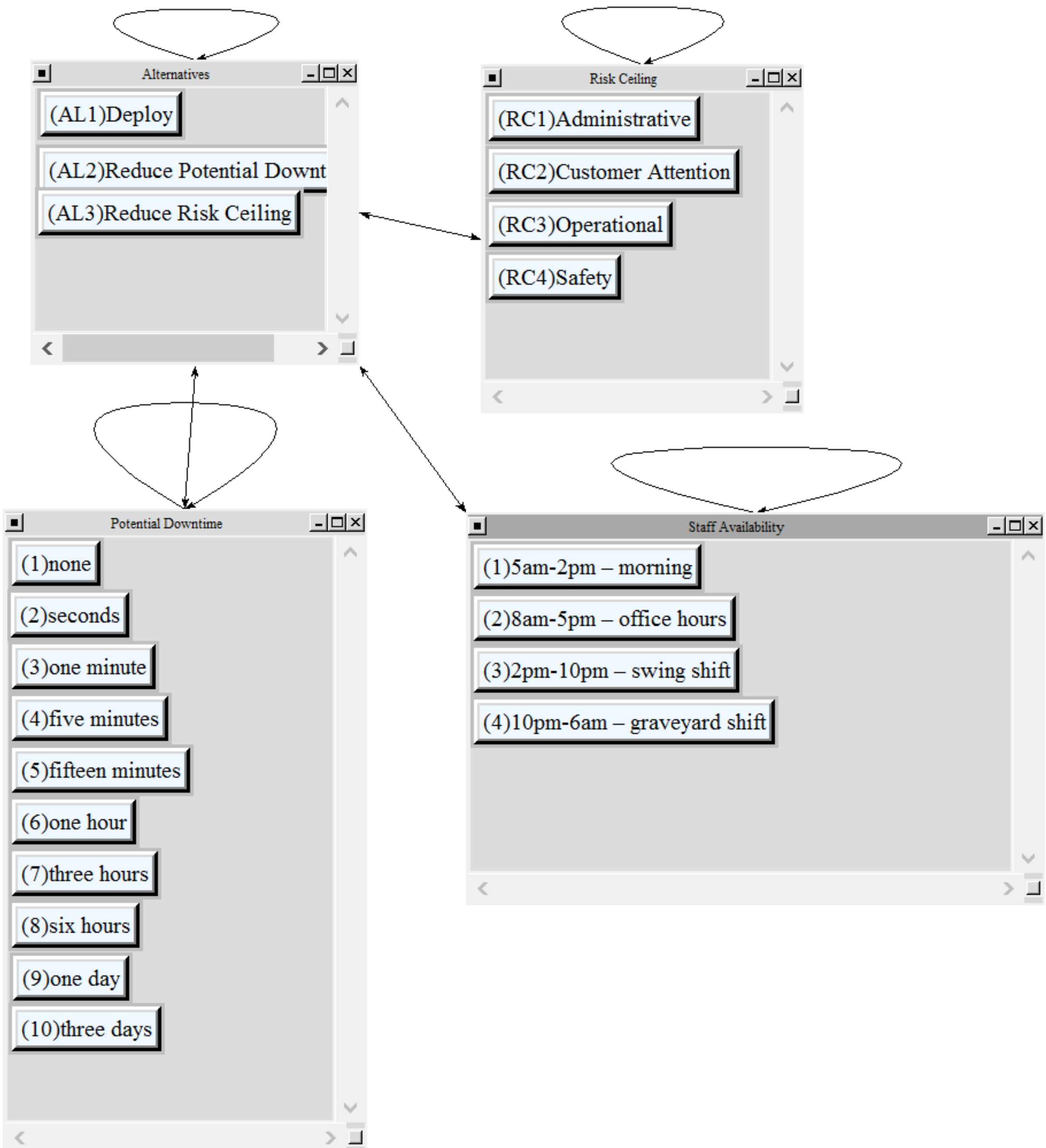
| | **Risk Ceiling (RC)** | |
|---|---|---|
| **UID** | **Criteria** | **Description** |
| RC1 | Administrative | planning, coordination, strategy |
| RC2 | Customer Attention | customer service, retail sales |
| RC3 | Operational | engineering, repair shops, vehicle operato assignment |
| RC4 | Safety | vehicle dispatch and physical security |

| | **Alternatives (AL)** | |
|---|---|---|
| **UID** | **Criteria** | **Description** |
| AL1 | Deploy | send software package to computers for automated execution |
| AL2 | Reduce Potential Downtime | find ways to reduce the potential downtim of the package or deploy during more favorable staff availability |
| AL3 | Reduce Risk Ceiling | reduce downtime or find a more favorabl staff availability time, otherwise contact managers for a special request |

## Appendix D

| | | Alternatives | | | Potential Downtime | | | | | | | | | | Risk Ceiling | | | | Staff Availability | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (AL1)Deploy | (AL2)Reduce Potential Downtime | (AL3)Reduce Risk Ceiling | (1)none | (2)seconds | (3)one minute | (4)five minutes | (5)fifteen minutes | (6)one hour | (7)three hours | (8)six hours | (9)one day | (10)three days | (RC1)Administrative | (RC2)Customer Attention | (RC3)Operational | (RC4)Safety | (1)5am-2pm - morning | (2)8am-5pm - office hours | (3)2pm-10pm - swing shift | (4)10pm-6am - graveyard shift |
| Alternatives | (AL1)Deploy | 0 | 0 | 0 | 0.9 | 0.888889 | 0.875 | 0.75 | 0.166667 | 0.1 | 0.111111 | 0.111111 | 0.1 | 0.1 | 0.428571 | 0.166667 | 0.75 | 0.1 | 0.139648 | 0.09596 | 0.191921 | 0.191921 |
| | (AL2)Reduce Potential Dov | 0 | 0 | 0 | 0.1 | 0.111111 | 0.125 | 0.25 | 0.333333 | 0.9 | 0.888889 | 0.888889 | 0.9 | 0.9 | 0.071429 | 0.833333 | 0.25 | 0.9 | 0.332516 | 0.087186 | 0.174371 | 0.174371 |
| | (AL3)Reduce Risk Ceiling | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.527836 | 0.316854 | 0.633708 | 0.633708 |
| Potential Downtime | (1)none | 0.148196 | 0.046492 | 0 | 0 | 0 | 0 | 0 | 0.162685 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | (2)seconds | 0.119769 | 0.037574 | 0 | 0 | 0 | 0 | 0 | 0.139481 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | (3)one minute | 0.08555 | 0.026839 | 0 | 0 | 0 | 0 | 0 | 0.092988 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | (4)five minutes | 0.044226 | 0.013875 | 0 | 0 | 0 | 0 | 0 | 0.062006 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | (5)fifteen minutes | 0.017278 | 0.005421 | 0 | 0 | 0 | 0 | 0 | 0.023376 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | (6)one hour | 0.003424 | 0.001074 | 0 | 0 | 0 | 0 | 0 | 0.005812 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | (7)three hours | 0.002851 | 0.013411 | 0 | 0 | 0 | 0 | 0 | 0.003874 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | (8)six hours | 0.002137 | 0.000671 | 0 | 0 | 0 | 0 | 0 | 0.003874 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | (9)one day | 0.002223 | 0.000671 | 0 | 0 | 0 | 0 | 0 | 0.003321 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | (10)three days | 0.001902 | 0.000597 | 0 | 0 | 0 | 0 | 0 | 0.002583 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Risk Ceiling | (RC1)Administrative | 0 | 0.029351 | 0.032783 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.022091 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | (RC2)Customer Attention | 0 | 0.149466 | 0.1609 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.093783 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | (RC3)Operational | 0 | 0.062898 | 0.09546 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.064923 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | (RC4)Safety | 0 | 0.415356 | 0.480821 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.319203 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Staff Availability | (1)5am-2pm - morning | 0.110775 | 0.029234 | 0.039155 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.084769 | 0 | 0 |
| | (2)8am-5pm - office hours | 0.326561 | 0.010585 | 0.029366 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.312271 | 0 | 0 |
| | (3)2pm-10pm - swing shift | 0.110134 | 0.03399 | 0.044049 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.084769 | 0 | 0 |
| | (4)10pm-6am - graveyard | 0.024972 | 0.122498 | 0.117465 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.01819 | 0 | 0 |

**Appendix E**



Alternatives
(AL1)Deploy
(AL2)Reduce Potential Downt
(AL3)Reduce Risk Ceiling
Risk Ceiling
(RC1)Administrative
(RC2)Customer Attention
(RC3)Operational
(RC4)Safety
Potential Downtime
(1)none
(2)seconds
(3)one minute
(4)five minutes
(5)fifteen minutes
(6)one hour
(7)three hours
(8)six hours
(9)one day
(10)three days
Staff Availability
(1)5am-2pm – morning
(2)8am-5pm – office hours
(3)2pm-10pm – swing shift
(4)10pm-6am – graveyard shift

**Appendix F**

| Name | | Normalized by Cluster | Limiting |
|---|---|---|---|
| (AL1)Deploy | | 0.32377 | 0.154213 |
| (AL2)Reduce Potential Downtime | | 0.47804 | 0.227698 |
| (AL3)Reduce Risk Ceiling | | 0.19819 | 0.094400 |
| (1)none | | 0.33646 | 0.034089 |
| (2)seconds | | 0.27223 | 0.027582 |
| (3)one minute | | 0.19419 | 0.019675 |
| (4)five minutes | | 0.10094 | 0.010227 |
| (5)fifteen minutes | | 0.03940 | 0.003992 |
| (6)one hour | | 0.00786 | 0.000796 |
| (7)three hours | | 0.03463 | 0.003509 |
| (8)six hours | | 0.00492 | 0.000498 |
| (9)one day | | 0.00502 | 0.000509 |
| (10)three days | | 0.00434 | 0.000440 |
| (RC1)Administrative | | 0.04399 | 0.009999 |
| (RC2)Customer Attention | | 0.22068 | 0.050160 |
| (RC3)Operational | | 0.10551 | 0.023982 |
| (RC4)Safety | | 0.62982 | 0.143157 |
| (1)5am-2pm – morning | | 0.17574 | 0.034282 |
| (2)8am-5pm – office hours | | 0.41401 | 0.080762 |
| (3)2pm-10pm – swing shift | | 0.18315 | 0.035728 |
| (4)10pm-6am – graveyard shift | | 0.22710 | 0.044302 |

**Appendix G**

| | Potential Downtime (PD) | Links |
|---|---|---|
| UID | Criteria | |
| PD1 | none | AL1, AL2 |
| PD2 | seconds | AL1, AL2 |
| PD3 | one minute | AL1, AL2 |
| PD4 | five minutes | AL1, AL2 |
| PD5 | fifteen minutes | AL1, AL2, PD1-PD10 |
| PD6 | one hour | AL1, AL2 |
| PD7 | three hours | AL1, AL2 |
| PD8 | six hours | AL1, AL2 |
| PD9 | one day | AL1, AL2 |
| PD10 | three days | AL1, AL2 |
| | | |
| | **Staff Availability (SA)** | |
| **UID** | **Criteria** | **Links** |
| SA1 | 5am-2pm – morning | AL1, AL2, AL3 |
| SA2 | 8am-5pm – office hours | AL1, AL2, AL3, SA1-SA4 |
| SA3 | 2pm-10pm – swing shift | AL1, AL2, AL3 |
| SA4 | 10pm-6am – graveyard shift | AL1, AL2, AL3 |
| | | |
| | **Risk Ceiling (RC)** | |
| **UID** | **Criteria** | **Links** |
| RC1 | Administrative | AL1, AL2, RC1-RC4 |
| RC2 | Customer Attention | AL1, AL2 |
| RC3 | Operational | AL1, AL2 |
| RC4 | Safety | AL1, AL2 |
| | | |
| | **Alternatives (AL)** | |
| **UID** | **Criteria** | **Links** |
| AL1 | Deploy | AL1, AL2, AL3 |
| AL2 | Reduce Potential Downtime | RC1-RC4, PD1-PD10, SA1-SA4 |
| AL3 | Reduce Risk Ceiling | RC1-RC4, SA1-SA4 |

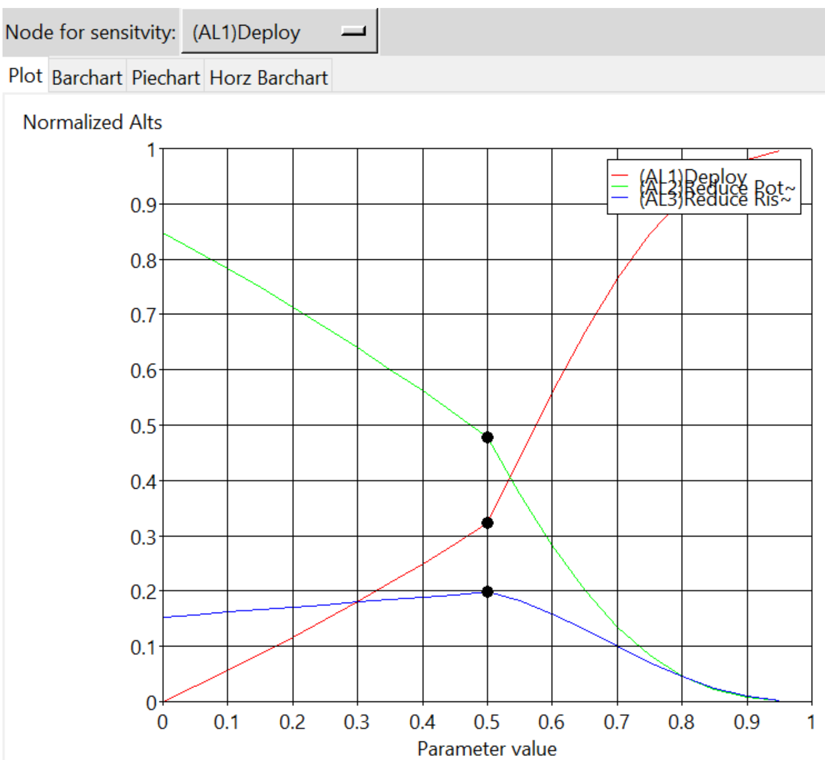
**Appendix H**

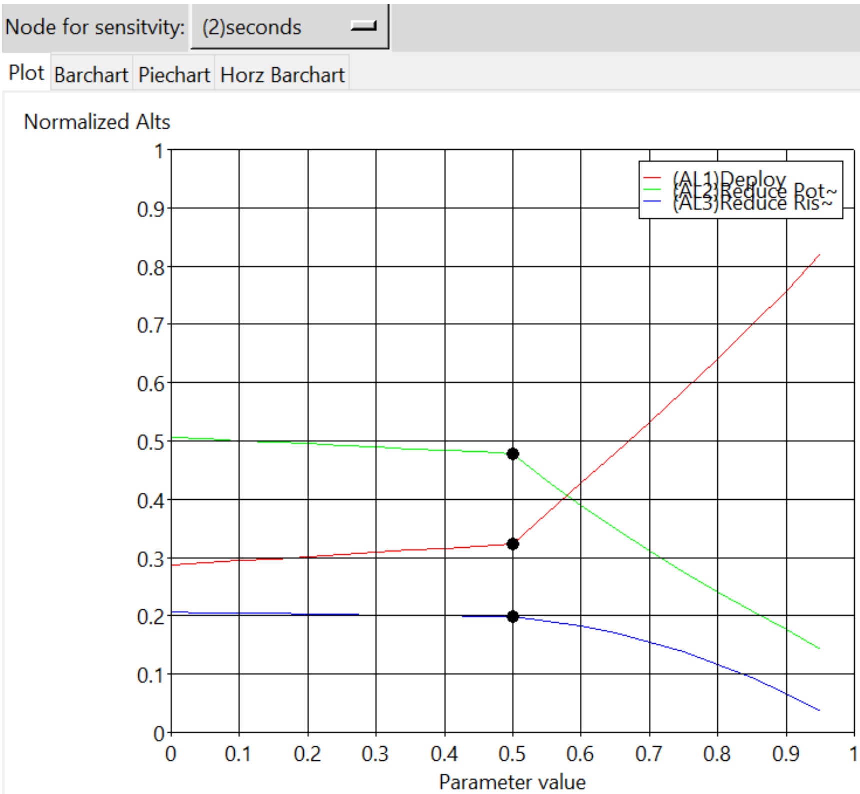
| | |
|---|---|
| Alternatives | 0 |
| Potential Downtime | 0.14662 |
| Risk Ceiling | 0.65707 |
| Staff Availability | 0.19631 |

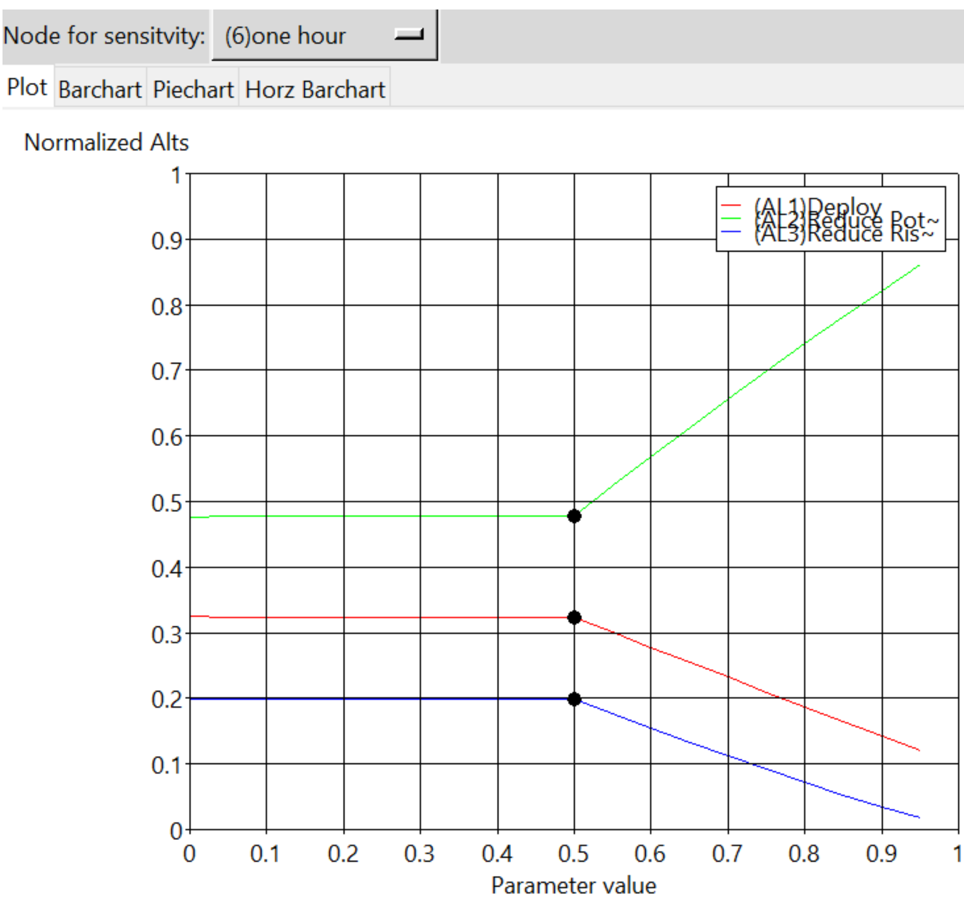
## Appendix I

| Name | Graphic | Ideals | Normals | Raw |
|---|---|---|---|---|
| (AL1)Deploy | | 0.677271 | 0.323766 | 0.154213 |
| (AL2)Reduce Potential Downtime | | 1.000000 | 0.478044 | 0.227698 |
| (AL3)Reduce Risk Ceiling | | 0.414585 | 0.198190 | 0.094400 |

## Appendix J




Node for sensitvity: (2)seconds
Plot
Barchart
Piechart
Horz Barchart
Normalized Alts
(AL1)Deploy
(AL2)Reduce Pot~
(AL3)Reduce Ris~
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Parameter value


Node for sensitvity: (6)one hour
Plot
Barchart
Piechart
Horz Barchart
Normalized Alts
(AL1)Deploy
(AL2)Reduce Pot~
(AL3)Reduce Ris~
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Parameter value