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Supporting Vehicle Option Change Management Through a Graph-Based Visualization Tool

When implementing configuration management methods, the amount of data required can be problematic when validating changes to the database. This is especially true for rule-based configuration management techniques. This paper presents a graph visualization tool to assist in validating changes to the rule database. The development and implementation of the tool is presented, along with the execution and results of two user studies designed to test specific aspects of the support tool. The paper then presents how the visualization tool was implemented for four ongoing configuration changes at the original equipment manufacturer (OEM) to prove the effectiveness of the tool in assisting in validating configurations changes. [DOI: 10.1115/1.4034472]

Keywords: graph visualization, change management, configuration management

Introduction

In order to remain relevant in the global economy, manufacturers are compelled to focus increasingly on the needs of the individual customer. Previous research [1] has shown that the configuration management methods currently in place to satisfy these needs can be problematic, especially when validating changes to complex systems. When managing large amounts of data, as is the case in the rule-based reasoning methods at a major automotive OEM, the use of an information management system becomes necessary [2]. Data visualization is one method of increasing the user's ability to understand and manage large amounts of data. Specifically, graph visualization is useful when attempting to understand the relationships between components. Based on this, a graph visualization support tool has been developed to assist in configuration change management at a major automotive OEM.

The purpose of this paper is to present a graph visualization tool to support configuration change management at an automotive OEM. The section "Background: Data Visualization" provides background information on data visualization and its potential use in understanding configuration changes and the potential relationships between change components. The researchers then discuss the development and implementation of the visualization tool. Finally, a series of use cases are provided where the visualization tool was successfully used to validate ongoing configuration changes at the OEM.

Background: Data Visualization

As the amount of available data increases, it is necessary to be able to understand and interact with the data and communicate it to others in a meaningful way [3]. Previous research has shown that implementing a data visualization method can be useful in increasing the ability to understand complex data systems [4–6].

After considering the types of visualization that could be most beneficial for use in managing configuration rules, graph visualization was selected. Graph visualization, using a series of nodes and edges to describe relationships, is applicable and in certain instances, ideal, for any dataset where relationships between entities are a key focus of the data [7]. Graph visualizations have been shown to be useful when identifying both direct and indirect relationships between entities in a system [8–11], which is a key application of the proposed visualizations for use in configuration management. Node-link graphs are particularly useful when considering path finding, which is essential to understanding possible propagation pathways [12].

While graph visualizations have not previously been used to support configuration management, they have been used in a variety of other instances where understanding the change propagation or network relationships is essential. In the most similar instance to the one in question, Keller et al. used a combination of design structure matrices (DSMs) and node-link graphs to understand change propagation pathways in physical product components [13]. Schaub et al. considered how graph visualizations can be developed to support enterprise architecture management despite regularly changing data models [14]. Kurtoglu and Tumer used graphs to understand and identify functional failures and their propagation pathways in complex engineering systems [15]. Other examples of using graph visualizations to understand and interact with data networks are shown in Refs. [16] and [17].

Though graph visualizations are useful in portraying network relationships and information, many factors can affect the readability of the graph itself. Previous research has looked at the readability of graphs based on a variety of different factors. Others considered how the use of curved versus straight edges to connect components in the graph affected the overall aesthetics of the

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Table 1 Software platform selection overview

	D3	Processing	Gephi
Familiarity	HTML-based	Java-based High level of familiarity	Have used extensively
Availability	Open-source Many examples/shells available	Open-source Tutorials available Largely build-to-suit	Open-source Software is complete Difficult to modify
Functionality	Capable of displaying and interacting with graphs	Capable of displaying and interacting with graphs	Capable of displaying/minor interaction

graph [18]. Numerous researchers have focused on the aesthetics of graph visualizations [19–21]; however, these studies focused on just the numerical aspects of the data (shortest path length, number of edges, etc.) rather than on understanding indirect relationships between components. A series of graph visualizations were used over time to explore whether the "difference maps" were useful in understanding change to a network over time [22]. Lastly, researchers have considered how varying the drawing of edges in a directed graph affected the readability of the graph [23].

Additionally, multiple researchers have provided guidelines on the use of color on the effectiveness of visualizations as a whole and the potential effects of poor or ineffective implementation [24–26]. Further, a series of studies on the effects of using different graph layout algorithms [21,27] demonstrated that it was difficult to show that any one algorithm provided the "best" result; however, it was shown that the use of an algorithm, particularly one that minimizes crossing paths, is more effective for improving graph readability. This sentiment is echoed in the review of graph visualization layout techniques by Gibson et al. [28].

Development of the Visualization Tool

Platform Selection. Three platforms were considered for the development of the graph visualization that will provide the foundation for the visualization method. These platforms are Gephi [29], Data-Driven Documents (D3) [30], and Processing [31].

Gephi. Gephi is a visualization tool used for exploring networks, systems, and graphs [29]. Unlike the other platforms being considered, Gephi is a fully functional software package for importing node and edge data and displaying interactive network graphs. Gephi was used to create the graph layouts in a previous user study [32]. The major benefits of Gephi are that it already exists, is open-sourced, and can be modified through the use of plugins. The major drawbacks of Gephi are that many of its functions are unrelated to the goals of this research, the development of new plugins would require learning a new programming language, and does not provide, even with additional plugins, some capabilities for data encoding that may be necessary for this research.

Data-Driven Documents (D3). D3 is a JavaScript library that is used to visualize data in meaningful ways [30]. Because D3 is a JavaScript library, much of the desired functionality for the visualization support tool is already available, but would require the supporting programming code for interacting with the data and displaying the results properly. This leads to the major benefit, and also drawback, of using D3. On the one hand, the required functionality already exists and D3 is capable of a wide range of possibilities with respect to visualizing graph-based data. The drawback is that D3 is run in HTML, which would require a better understanding of data recovery and programming in HTML.

Processing. Processing is an open-source programming language that was designed specifically to assist in adding a visual context to data [31]. Processing is a widely used language within data visualization and has over 100 libraries to extend the capabilities of the original software. The main positive of using processing as the platform is that the software is completely build-to-suit, meaning that the resulting tool can be programmed to be exactly what is required. Other benefits are that the large number of libraries can assist in developing the necessary functions and the researcher is already familiar with the programming language. The largest drawback is that the graph visualization software would have to be built from scratch.

Summary. The level of familiarity, availability, and functionality for each of the possible platforms is shown in Table 1. Due to the low level of familiarity with programming with D3, as a result of it being HTML-based, D3 is rejected from the possible platforms. Additionally, Gephi is excluded because it is not capable of some of the required functionality for the visualization support method. As a result, processing is chosen as the platform for the development of the visualization support method.

User Study: Defining Graph Layout Requirements. The first step in developing a visualization method for configuration management is to understand the information requirements for the user interface, what the user needs to see when applying the method. In this way, it is possible to backtrack from the required information to the available information provided in the current organizational systems to determine the additional requirements of the visualization method. In order to better understand what information best assists the user in identifying relationships between configuration components (options, parts, and configuration rules), a user study is conducted using different variations on the layout and available information provided to the user. The user study was designed in accordance with the benchmark task method proposed in Ref. [33]. The remainder of the section provides additional details regarding the design and execution of the user study. A more complete write-up of the experimental procedure can be found in Ref. [32].

Research Questions. Research has shown that different types of data representation may be more accommodating for answering different types of questions about the system being represented. Additionally, the manner in which the data are represented can have a significant impact on the user's ability to answer said questions. This led to the following research questions:

- How does the layout or coloring of the data representation graph affect the ability of the user to successfully answer questions about the system being represented?
- Does an increase/decrease in the amount of information being represented affect the user's ability to answer questions about the system?

It is hypothesized that layout will have minimal effect, while increasing the color-coding will increase the ability to correctly answer questions. This hypothesis is made because the color-coding will increase the user's ability to easily identify different types of interactions. Additionally, the authors hypothesize that limiting the amount of information will increase the accuracy of responses for those questions that are still answerable, while making it impossible to answer the questions regarding the missing information. This hypothesis is made because limiting the amount of information will remove clutter from the graph and more easily highlight where the interactions take place. This hypothesis also takes into account the concept of cognitive load and the effect it can have on the effectiveness of visualization [34].

Variables. In order to answer the above research question, a user study was developed and executed. The user study consisted of four variables: the geometry of the graph used for data visualization, the coloring of the interactions between the nodes in the graph, the amount of information available to the user, and the order in which the questions were asked. The first variable consisted of two levels: the graph is arranged with the vehicle option nodes on the outside in a circle, or the vehicle option nodes arranged based on the functionality of the option. The purpose of this variable was to see if the layout of the graph allowed for easier identification of interactions or if the shape did not matter and any shape would result in the same accuracy of the responses. Admittedly, with only two layouts, it is possible that no influence might be found while for a different two layouts, a different influence may be found. Therefore, inferences should be tempered. The second variable included two levels: interactions regarding parts were red, all other interactions were gray; or interactions were color-coded based on whether they were inclusions, exclusions, or "either/or" relationships between elements. The purpose of this variable was to determine whether the coloring allowed for easier identification of different types of interactions. The third variable included two levels: all information (parts and vehicle options) or reduced information (just vehicle options). The purpose of this variable was to determine if removing some of the information increased the user's ability to answer the remaining questions with greater clarity. The final variable consisted of two different orders in which the questions were asked and was simply used to ensure the question order did not affect which questions were answered correctly.

Experimental Design. The participants for this user study consisted of 78 industrial engineering students enrolled in the junior level industrial engineering operational research course. The students had varying levels of work experience, but it was assumed that prior work experience was outside the scope of the research. The user study was conducted in a single 1-h session during a normally scheduled class period of the junior operational research course. The setting for the experiment was the classroom in which the course usually met.

In developing the survey to be used in the experiment, the first step was to determine the type of questions that may be asked of the visualization during the change evaluation process. During the course of the motivating case study [1], numerous types of questions were identified that are commonly considered during a change to the configuration system. For the purposes of this experiment, the list of questions was further expanded through additional interviews with *Launch and Change Control* personnel at the OEM.

Before conducting the experiment, it was necessary to ensure that each type of question was being asked in multiple ways. Triangulating the questions to ensure each type is covered in multiple ways is important when attempting to understand the relationship between the independent and dependent variables within a study [35,36]. The triangulation of questions for the user study is shown in Table 2.

The groups (1–12) were assigned such that each group would test a different set of variables. For this experiment, it was not necessary to conduct a full-factorial experiment because the group that did not receive any part information could not receive the graph with coloring based on part interactions. The assignment of the variables to the groups is shown in Table 3.

The materials that each participant received with their packet depended upon which group they were in, which was assigned randomly during distribution of the packets. However, every student from all of the groups received one questionnaire with 13 questions about the system being represented, and two data visualization graphs (one representing U.S. models and one representing European models). An example of one of the data visualization graphs is shown in Fig. 1. The depicted graph is the European graph received by groups 1 and 7.

Table 2 Survey question triangulation

Triangulation	Question												
Question type	1	2	3	4	5	6	7	8	9	10	11	12	13
Option availability	X								X				
Option–part interaction		X		X	X					X	X	X	
U.S. versus Europe availability		X											
Effect of adding rule/option			X										
Using options to choose a part				X						X			
Finding option errors			X			X	X						
Option–option interaction							X	X					
Finding part errors											X	X	X
Effect of removing a part													X

Table 3 Group-variable assignment

		Group											
	Condition	1	2	3	4	5	6	7	8	9	10	11	12
Graph geometry	Functional	X	X	X				X	X	X			
	Circle				X	X	X				X	X	X
Information available	Full	X		X	X		X	X		X	X		X
	Reduced		X			X			X			X	
Coloring	Interaction-based	X	X		X	X		X	X		X	X	
	Part-based			X			X			X			X
Question order	Order A	X	X	X	X	X	X						
	Order B							X	X	X	X	X	X

Evaluation Metrics. The metrics that were used for evaluation are correctness and confidence. These metrics were chosen because it was not only important to determine which set of variables produced the most accurate responses, but also to determine the confidence of the users in selecting those answers. As such, it was necessary to include a method for measuring the participants' confidence levels for each individual question.

Determining the correctness for each questionnaire response was to determine the total number of correct responses, along with the number of possible correct answers (in the case where only partial information was presented in the data visualization graphs). The confidence for each response was collected using a modified 100 mm scale [37,38]. A similar rating method was used in previous studies on confidence [39]. To simplify the process, the line used in this study was graduated at 10% intervals, from 0 to 100. An example of the scale with a tick mark is shown in Fig. 2. An example mark is shown in gray and encircled.

Experimental Procedure. The students arrived for the normally scheduled class and sat at tables of their choice. Once all of the students had arrived and were seated, the user study packets were distributed to the students. Each packet contained a questionnaire and two visualization graphs. The assignment of groups and the contents of each packet will be discussed in the section "Availability of Information." The students were grouped only in that a group received the same packet information. All work was conducted individually. Once the packets were handed out, the

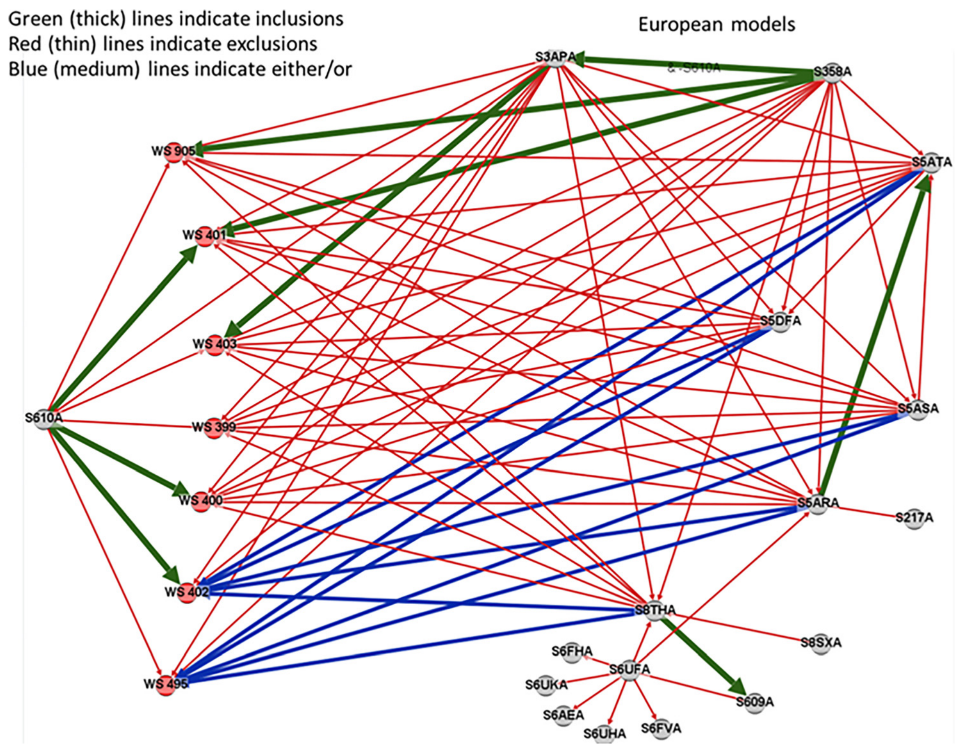


Fig. 1 Example of a visualization graph (provided to groups 1 and 7)

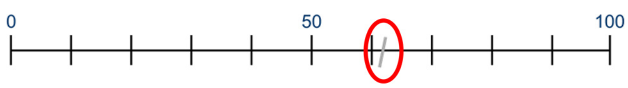


Fig. 2 Modified 100 mm confidence scale

instructions were provided to the participants. Additionally, a brief class instructing the students on the data visualization techniques was conducted. This was necessary because none of the participants had prior experience with the data visualization method being used to represent the system discussed in the questionnaire. Following the instructional period, the students were allowed to ask any questions regarding the survey or the data visualization technique. The participants were then given 40 min to conduct the experiment.

Results. A total of 78 questionnaires were collected from the participants and evaluated during the user study. The questionnaires were evaluated by a single grader, as previously discussed, and the data were tabulated into spreadsheets for ease of analysis.

For correctness, the results were consolidated according to the different variable levels. For instance, all of the groups of individual participants that received the full information in the graph (1, 3, 4, 6, 7, 9, 10, 12) were in one consolidation, while the groups receiving reduced information (2, 5, 8, 11) were consolidated separately. This was conducted for each variable in order to see how the different variables affected the accuracy of the responses. The results for each group and the consolidated results are shown in Tables 4 and 5, respectively. Blank spaces in Table 4 represent questions that were unanswerable due to a lack of available information.

Table 5 also includes the percent difference between the variable levels, with those questions indicating a significant difference between the variables highlighted in yellow.

For confidence, the level of confidence for each question was estimated using the graduated scale on the confidence indicator line. This was done for each question and then consolidated for each group. The average confidence levels for each question for each group are shown in Table 6.

Discussion. It should first be noted that there are limitations in the analysis due to the responses of the participants. From evaluating the responses, it was identified that some of the participants

Table 4 Number of correct responses for each question by group

Question		1 Right	2 Right	3 Right	4 Right	5 Right	6 Right	7 Right	8 Right	9 Right	10 Right	11 Right	12 Right	13 Right
Version	1	2	5	6	3	7	1	5	3	6	7	7	1	2
	2	7						6	6				6	
	3	1	5	5	2	5	0	4	2	4	6	5	1	4
	4	4	3	4	1	6	0	6	6	5	7	6	4	1
	5	3	5	3	1	3	1	5	6	6	3	4	3	2
	6	6						5	6				4	
	7	3	3	5	2	5	0	3	2	3	6	4	1	1
	8	7						6	7				7	
	9	3	3	3	0	5	0	4	3	5	3	2	3	1
	10	2	3	6	2	3	0	5	0	6	6	4	1	0
	11	3	4	3	2	4	0	4	3	5	5	3	0	2
	12	4						5	5				4	

Table 5 Percent of correct responses by variable

Question	1	2	3	4	5	6	7	8	9	10	11	12	13
Parts (%)	41	61	69	25	75	4	71	49	78	84	69	27	25
No parts (%)	89	0	0	0	0	0	81	89	0	0	0	78	0
% Diff	54	100	100	100	100	100	13	45	100	100	100	65	100
Circle (%)	56	58	62	23	62	4	77	67	85	81	65	41	19
Function (%)	59	64	76	28	88	4	72	59	72	88	72	49	32
% Diff	4	10	19	18	30	4	−7	−13	−18	8	9	16	40
Colored (%)	54	36	54	21	54	3	74	56	51	67	54	38	10
Red/gray (%)	62	44	36	13	44	3	74	69	51	44	36	51	23
% Diff	13	18	−50	−60	−24	0	0	19	0	−53	−50	25	56
Set A (%)	55	64	64	25	75	7	74	69	75	82	79	45	32
Set B (%)	61	57	74	26	74	0	75	56	83	87	57	44	17
% Diff	10	−14	13	4	−1	100	2	−24	9	6	−39	−2	−85

Table 6 Average confidence for each question by group

	Question	1	2	3	4	5	6	7	8	9	10	11	12	13
1	7	63%	64%	71%	71%	88%	81%	59%	59%	63%	63%	78%	69%	81%
2	7	64%						61%	46%				50%	
3	7	57%	86%	65%	44%	77%	71%	52%	29%	125%	74%	49%	64%	71%
4	7	49%	85%	67%	39%	79%	79%	66%	58%	70%	67%	69%	54%	79%
5	7	55%	79%	71%	38%	62%	78%	51%	32%	49%	71%	59%	61%	78%
6	7	57%						63%	42%				57%	
7	6	75%	84%	82%	77%	80%	85%	68%	28%	62%	67%	83%	38%	49%
8	7	66%						76%	56%				80%	
9	5	68%	87%	61%	55%	64%	66%	61%	37%	60%	64%	62%	30%	56%
10	6	69%	73%	66%	68%	80%	77%	68%	63%	68%	68%	51%	66%	53%
11	6	56%	76%	63%	63%	74%	72%	52%	40%	49%	54%	53%	31%	50%
12	6	75%						75%	53%				68%	

did not take the experiment seriously or were confused by the instructions. This conclusion was made due to a number of responses being unsuitable based on the question being asked and/or instructions provided to the participants. Additionally, a number of students turned in their completed questionnaires after only 15 min of work. During a pilot study, the fastest completion times were 20 min or higher, so it is unlikely that multiple participants were able to finish that quickly. It is more likely that the students rushed through the questions in order to be released early. Fortunately, the above situations were in small minority and should not significantly affect the outcomes.

Availability of Information

When considering the availability of part information, a definite trend existed where the accuracy of the answerable questions greatly increased when the part information was removed from the data visualization graph. Figure 3 illustrates the percentage of correct responses for each question for both the full information and reduced information (part versus no parts) groups.

In the questionnaires, the only questions that remained answerable after the removal of the part information were questions 1, 7, 8, and 12. In the above graph, all other questions are shown as having 0% correct responses for the "No Parts" group. However, for the answerable questions, the percentages of correct responses were significantly higher in almost all situations. The percentages for the answerable questions ranged from 78% to 89%, whereas the range for the same questions for the "Parts" group was 27–71%. This corresponds with the hypothesis that decreasing the amount of information presented will increase the ability to answer correctly for those questions that are still answerable.

Color-Coding of Interactions

There appears to be little correlation between the method for color-coding the interactions between the components and the user's ability to accurately answer the questions. Figure 4 depicts

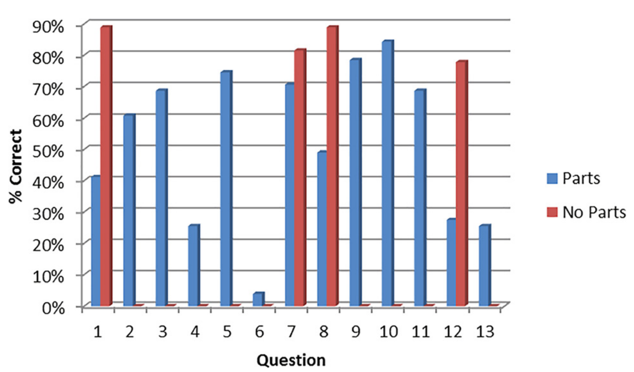


Fig. 3 Graph of the correctness for each question based on availability of information

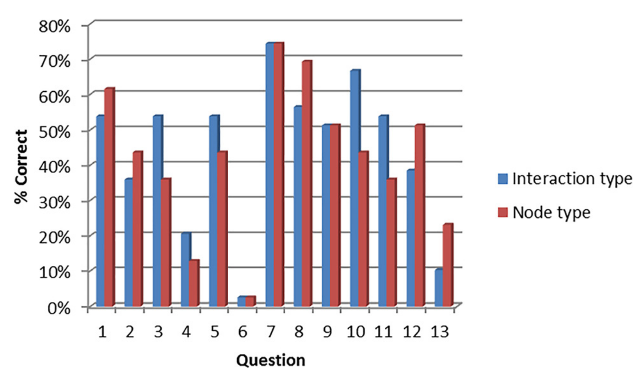


Fig. 4 Graph of the correctness for each question based on color-coding

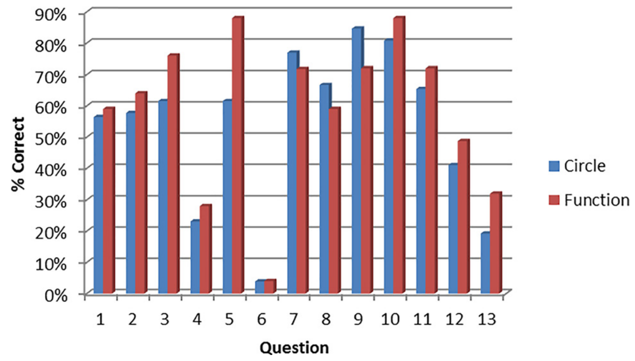


Fig. 5 Graph for the correctness of each question based on layout

the percentage of correct responses for each question for the groups based on the type of color-coding used to identify interactions.

As seen in the graph, the percentage of correct responses for each question does not differ significantly based on the type of color-coding used to identify the interactions.

Confidence

An ANOVA was conducted for the confidence ratings for the different groups. The analysis showed no statistically significant difference in the confidence of the users based on which type of graph they were given. Due to differences in the way the confidence was understood by the participants and a lack of variation in the results for confidence, no conclusions were able to be made regarding the resulting confidence levels of the participants for individual questions.

Graph Geometry

No correlation was found between the geometry of the data visualization graph and the accuracy of the responses. Figure 5 illustrates the percentage of correct responses for each question for the groups based on the graph geometry.

As seen in the graph, the percentages of correct responses for each question are almost the same, regardless of the geometry of the graph.

Question Order

To ensure that question order did not play a factor in the accuracy of the responses, two different orderings of the questions were used. Figure 6 illustrates the percentage of correct responses for each question for the groups based on the order of the questions.

As seen in the graph, there is no trend for response accuracy based on the order of the questions. Therefore, it can be concluded that the ordering of the questions did not impact the results.

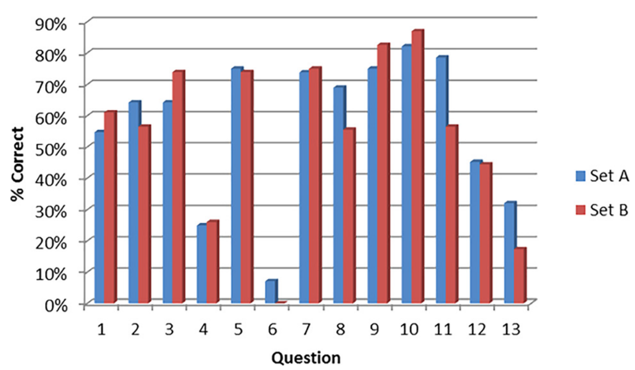


Fig. 6 Graph of the correctness for each question based on order

Findings. The results generally showed an increase in the percentage of correct answers for those questions that could still be answered when the amount of information presented was reduced. On the other hand, the color-coding scheme did not seem to have any identifiable effect on the results. The most significant limitation in this study was the possibility for variations in the amount of effort put forth by the participants. It was clear, based on the results, that some of the students did not put forth their best effort or follow the instructions of the experiment.

Tool Requirements Identification. Through the course of the case study, a need was identified for support tools to assist in the configuration management process, to include managing the effects of proposed configuration changes. In order to address the identified issues, the following requirements are proposed:

- able to easily visualize the interactions between configuration components (including parts)
- able to highlight specific problem areas to assist in simplifying the rule database
- able to check for errors in the existing rule database
- able to show how proposed configuration changes would affect the existing rule database

These requirements were identified through the interviews to address specific issues experienced by the automotive OEM in their current configuration management process.

Tool Implementation

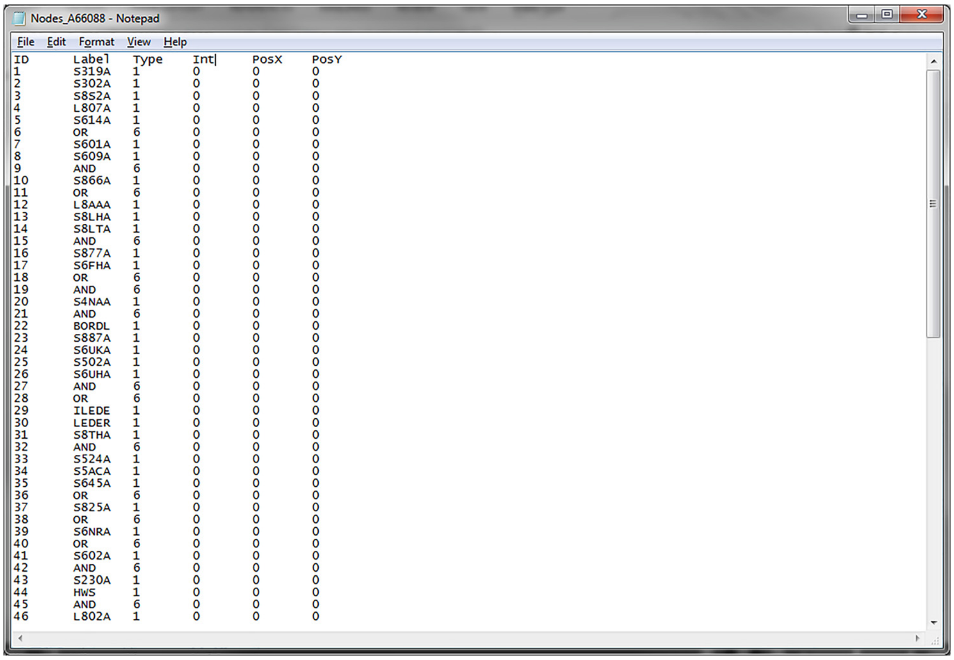
Data Organization and Source. In order to create each graph visualization, two sets of inputs are required: the nodes (items of interest) and the edges (relationships) of the graph. Both of these inputs are created through the additional software tools used to support the configuration management process at the OEM.

Graph Nodes. The graph nodes, or items of interest, consist of the vehicle options, parts, and packages that exist in the configuration rule database. Also, the researchers created "AND" and "OR" nodes to assist in representing rules that are not strictly binary. In addition to the node label, the following information is recommended for capture in the input file: a unique ID number for easy recall and data storage, the type of node, the lowest level of interaction from the specified nodes, and the *X*/*Y* coordinates for the nodes position in the graph.

Specifying the type of node increases the amount of information that can be visually stored in the graph and allows for easier understanding of what a specific node entails. The lowest level of interaction from the specific nodes identifies the number of interactions required to move from the original nodes to a specific node (for example: in A->B->C, where "A" is a node specified in the change document, the level of interaction for "C" would be 2). This information is useful in that it can assist the user in determining the likelihood of a change propagating to other components. Lastly, the *X*/*Y* coordinates are useful if any prepositioning of the nodes is used for an initial layout of the graph. An example node input file is shown in Fig. 7.

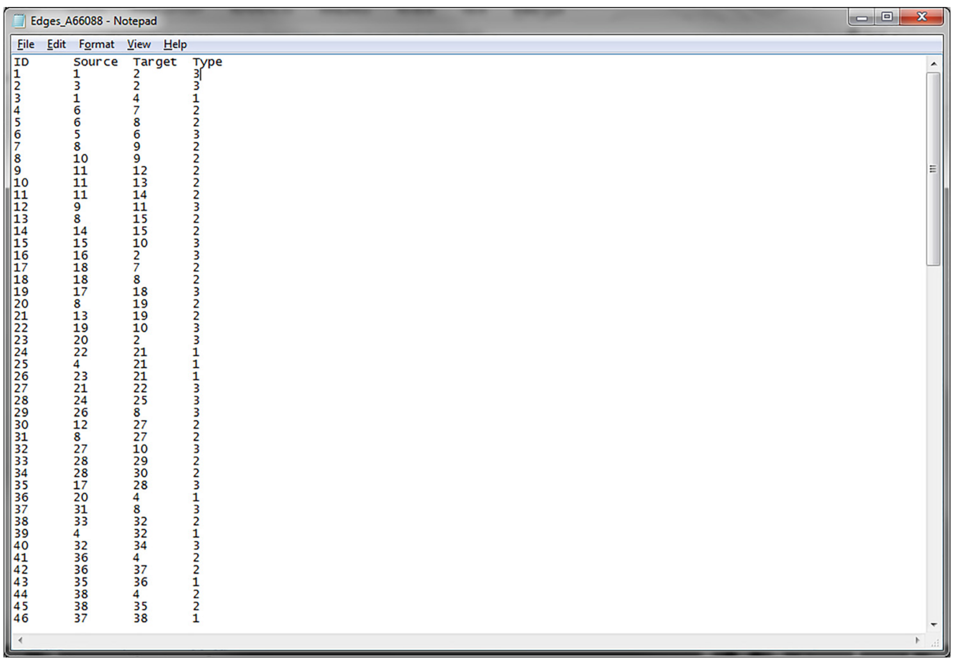
Graph Edges. The graph edges, or relationships between the nodes, consist of the rules that govern how the different components interact. These relationships include all of the rules as specified in the option and part rule databases, as well as function class information. It is also possible to use new rules as created in the conflict detection tool as relationships. While it may be useful to label the edges on the graph, a label is not currently included in the information provided in the edge input file. The information provided for each edge is a unique ID number of easy data storage and recall, the source node of the edge, the target node of the edge, and the type of edge.

The source node of the edge refers to the "If" portion of the rule in a binary rule, while the target node refers to the "Then" portion of the rule. In more complex rules (nonbinary), a more comprehensive grammar must be used. The edge type represents



ID	Label	Type	Int	PosX	PosY
1	S319A	1	0	0	0
2	S302A	1	0	0	0
3	S8S2A	1	0	0	0
4	L807A	1	0	0	0
5	S614A	1	0	0	0
6	OR	6	0	0	0
7	S601A	1	0	0	0
8	S609A	1	0	0	0
9	AND	6	0	0	0
10	S866A	1	0	0	0
11	OR	6	0	0	0
12	L8AAA	1	0	0	0
13	S8LHA	1	0	0	0
14	S8LTA	1	0	0	0
15	AND	6	0	0	0
16	S877A	1	0	0	0
17	S6FHA	1	0	0	0
18	OR	6	0	0	0
19	AND	6	0	0	0
20	S4NAA	1	0	0	0
21	AND	6	0	0	0
22	BORDL	1	0	0	0
23	S887A	1	0	0	0
24	S6UKA	1	0	0	0
25	S502A	1	0	0	0
26	S6UHA	1	0	0	0
27	AND	6	0	0	0
28	OR	6	0	0	0
29	ILEDE	1	0	0	0
30	LEDER	1	0	0	0
31	S8THA	1	0	0	0
32	AND	6	0	0	0
33	S524A	1	0	0	0
34	S5ACA	1	0	0	0
35	S645A	1	0	0	0
36	OR	6	0	0	0
37	S825A	1	0	0	0
38	OR	6	0	0	0
39	S6NRA	1	0	0	0
40	OR	6	0	0	0
41	S602A	1	0	0	0
42	AND	6	0	0	0
43	S230A	1	0	0	0
44	HWS	1	0	0	0
45	AND	6	0	0	0
46	L802A	1	0	0	0

Fig. 7 Example graph node input file



ID	Source	Target	Type
1	1	2	3
2	3	2	3
3	1	4	1
4	6	7	2
5	6	8	2
6	5	6	3
7	8	9	2
8	10	9	2
9	11	12	2
10	11	13	2
11	11	14	2
12	9	11	3
13	8	15	2
14	14	15	2
15	15	10	3
16	16	2	3
17	18	7	2
18	18	8	2
19	17	18	3
20	8	19	2
21	13	19	2
22	19	10	3
23	20	2	3
24	22	21	1
25	4	21	1
26	23	21	1
27	21	22	3
28	24	25	3
29	26	8	3
30	12	27	2
31	8	27	2
32	27	10	3
33	28	29	2
34	28	30	2
35	17	28	3
36	20	4	1
37	31	8	3
38	33	32	2
39	4	32	1
40	32	34	3
41	36	4	2
42	36	37	2
43	35	36	1
44	38	4	2
45	38	35	2
46	37	38	1

Fig. 8 Example graph edge input file

the type of relationship between the nodes. Three different types of relationships are currently used: inclusive, exclusive, and multiple-inclusive relationships. An inclusive relationship means that the source requires the target to also be present. Similarly, exclusive requires that the target must not be present. The multiple-inclusive relationship is used in conjunction with OR and AND nodes to help delineate that the relationship is not binary. Multiple-exclusive could also be represented separately, but has not been used in the current implementation. An example of an edge input file is shown in Fig. 8.

Methods. Two major functions of the visualization tool are described: graph creation and graph manipulation.

Graph Creation. In graph creation, the data from the input files are read and displayed on the screen in a node-link diagram. In order to accurately depict the different types of rules/relationships between nodes, a visualization grammar was required. For binary rules, the grammar consists of an arrow pointing from one node to another. An example of an inclusive, binary rule is shown in Fig. 9. In the figure, P5A3A is the source node, and S5ACA is the target node, meaning that if P5A3A is present, S5ACA must also be active. The green arrow is being used to represent the inclusivity of the relationship.

On the other hand, an exclusive, binary relationship is shown in Fig. 10. In this instance, the presence of S5A1A requires that P5A3A not be present for the configuration to work.

O	If-Part of rule	Then-part of rule
Z	& + P5A3A	/ + S5ACA

Fig. 9 Rule and corresponding graph for an inclusive, binary relationship

O	If-Part of rule	Then-part of rule
A	& + S5A1A	/ + P5A3A

Fig. 10 Rule and corresponding graph for an exclusive, binary relationship

O	If-Part of rule	Then-part of rule
A	& + S645A	/ + L807A / + S825A

Fig. 11 Rule and corresponding graph for a relationship requiring an OR node

O	If-Part of rule	Then-part of rule
A	& + L807A & + S6VAA	/ + S6AEA

Fig. 12 Rule and corresponding graph for a relationship with an AND node

When considering relationships that are not binary, OR and AND nodes are used to assist in representing the rules. An example of a rule with an OR node is shown in Fig. 11. In this graph, the OR node is created as the target for the If part of the rule and the source for the Then part of the rule. The meaning of the following graph is that if S645A is present, then neither S825A nor L807A must be present.

An AND node is represented in a similar manner to the OR node and is shown in Fig. 12. The following graph shows that if both L807A and S6VAA are present, then S6AEA cannot be present.

Another example of an AND node is shown in Fig. 13. In this example though, one of the source nodes has a negative attached to it, changing the type of relationship between the node and the AND node. The resulting interpretation is that if L807A is not present, but S552A is present, then S5ACA must be present.

Colors were chosen to represent the types of relationships instead of either size or dash lines because in a more complex graph, it is more difficult to distinguish between or trace different line thicknesses or different types of dashed lines [40]. While green (light), red (medium), and blue (dark) were chosen for the colors of the mapping, a different set of colors could be used in their place (see figure online for color). An example of a completed graph is shown in Fig. 14.

Graph Manipulation. While it is possible to explore a static graph visualization, the ability to interact with the data greatly

O	If-Part of rule	Then-part of rule
Z	& + S552A & - L807A	/ + S5ACA

Fig. 13 Another rule and corresponding graph for a relationship with an AND node

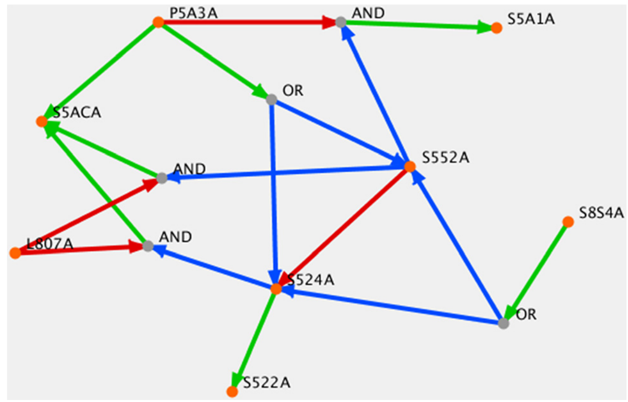


Fig. 14 Graph visualization for a specific change

increases the user's understanding of the system. As such, the software tool supports graph manipulation. The current level of interaction includes the ability to move nodes on the existing graph, to create new nodes and edges, to remove nodes, to highlight a specific node and all of its interactions, and to rearrange the layout of the graph to increase readability. Additional options are for the user to save the existing visualization or to reset the visualization to its original state.

At the most basic level of interaction is the ability of the user to move the existing nodes. This is necessary as it allows the user to manually position items of interest or to cluster specific nodes based on some criteria. As the edges are directly linked to the nodes, as the nodes are moved, the edges change to accommodate the placement of the nodes.

As one of the required tasks of the visualization is to assist in the evaluation of potential changes to the system, it is necessary for the user to be able to add and remove nodes and edges. At present, the current system allows the addition of both nodes and edges. When a specific node is removed, however, all of the associated edges are removed as well. When adding a node or edge, the user must also have the ability to specify which type of node or edge is being created, along with entering in any information that is to be stored in the associated data file.

When evaluating the potential propagation pathways from one node to another, it is useful to be able to select a specific node for highlighting. When a node is selected, all of its interactions are highlighted, while any relationships not directly related to the node are dimmed slightly. These represent the first-order interactions for the node. It may also be possible to allow the user to change the order of interaction for this highlighting for increased user specificity. To show the full relationship, the path between nodes should not be between two components (options/parts/packages) and not AND or OR nodes, but should pass through the intermediate nodes. An additional extension of this is that when two nodes are selected, the shortest path between them (or all unique paths) is highlighted to show the level of interaction between the two nodes.

Results from the user study suggest that while using a specific layout, algorithm is not essential. Further study is required to determine whether other layouts not experimentally explored can have an influence on usability. Despite this, it is important to use some algorithm for arranging the nodes. This helps to alleviate clutter and greatly increases the readability of the graph. For this visualization, a force-directed algorithm is used and will be discussed further.

In addition to the ability to save the current visualization (which captures the current image of the graph), it is also useful to be able to output the current data files that go with the graph. The data files could be outputted in the data file or in the form of rules that could then be merged with the existing rule database.

Force-Directed Graph Layout

The force-directed algorithm is a basic graph layout algorithm that uses a repulsive force between all nodes and an attractive force along all edges. To apply the algorithm, a repulsive force is determined between the nodes and a movement value is created for each node. Then the attractive force determined for each edge's and node's movement value is adjusted accordingly. After both forces have been applied, the nodes are moved according to their final movement values. This process is repeated until the user is satisfied with the dispersion of the nodes. It is also important that outer boundaries are set for the nodes to ensure that the graph does not grow continually, but rather reaches a steady-state.

User Study: Evaluating Rule Implementation

Research Questions. Research has shown that different types of data representation may be more accommodating for answering different types of questions about the system being represented. Additionally, the use of a graphical user interface (GUI) for making changes to a system or for implementing changes is a common method for simplifying data maintenance. This led to the following research questions:

- How does the use of a graphical method for rule implementation affect the user's ability to accurately author rule changes in a system?
- How does the use of a graphical method for rule implementation affect multiple users' abilities to consistently author rule changes in a system?

It is hypothesized that the use of a graphical representation for rule implementation will increase both the accuracy and consistency for making changes to the rule database. This hypothesis is made because the graphical representation has been shown previously to increase the user's ability to understand the system better, and a better understanding should lead to increased accuracy when implementing the changes.

Based on the initial results, which showed a marked decrease in the effectiveness using the visualization method, the following research question was added:

- How does the amount of training and familiarity with the visualization method affect the user's ability to implement rules in the system?

It is hypothesized that implementing a small training period will greatly increase the familiarity of the participants with the method and will result in increased effectiveness in implementing the rules. A more complete review of the user study procedure and results can be found in Ref. [41].

Experimental Design. In order to answer the above research question, a user study was developed and executed. The user study consisted of two variables: the method for implementing the rule changes and the amount of training on the new visualization method. The first variable consisted of two levels: implementation of changes through a graphical representation or implementation using a text-based representation. The purpose of this variable was to see if using a different method increased the user's ability to accurately and consistently implement the changes. The second variable had two levels, and only applied to the group assigned the visualization method: a minimal amount of training on what the new method is and a slightly increased training period (approximately 5 min) showing how the new method can be used to show changes to the system. This variable was developed based on concerns during the initial results that a lack of familiarity with the new method was resulting in decreased scores, as opposed to the actual effectiveness of the new method.

The participants of the user study were 74 senior, undergraduate, mechanical engineering students at Clemson University. The students were chosen for the experiment because, as seniors, they have a similar level of experience to new employees at a company. Additionally, selecting the participants from this course ensured that the students would have a similar educational background.

The user study was conducted in two sessions during a normally scheduled class period of the senior mechanical engineering design course, with each group only attending a single session. The control group and the experimental group with minimal training attended the first session and the experimental group with additional training attended the second session. The setting for the experiment was the classroom in which the course usually met (for two groups) or in a nearby classroom with a slightly different setup (for the third group). While the classroom layouts were different for the groups, the researchers did not believe this would be a factor in the results as all environments were standard classroom types, with which the participants were familiar.

Experimental Procedure

For the first session, the students arrived for the normally scheduled class and sat at tables of their choice. Once all of the students had arrived and were seated, the user study packets were randomly distributed to the students. Each packet contained a set of documents according to whichever group the participant was assigned. Once the packets were handed out, the participants were separated based on the packet that they had received. Once in separate classrooms, each group was given a brief class instructing the students on the background of the research and the specific instructions for their part of the research. The presentations were developed to provide similar levels of detail regarding the study and to take a similar amount of time to complete. Following the instructional period, the students were allowed to ask any questions regarding the survey or the data visualization technique. The participants were then given 40 min to conduct the experiment. While the participants were assigned to groups, the grouping was only conducted to control variables; all work during the study was conducted individually.

The second session mirrored the first session, except only one group was present, so the participants did not have to be divided. Additionally, the second session included the increased training period during the presentation. The increased training period consisted of providing an example (from a different rule database and product) of how a change could be implemented to the system. The increased training period took less than 5 min to conduct.

Packet Contents. The materials that each participant received with their packet depended upon which group they were in. Both groups received change documents for three independent configuration changes. The control group, which implemented the changes using a text-based representation, received materials suitable to their assigned method. Both experimental groups, which implemented the changes using a graphical representation, received the same materials, with the addition of a set of configuration graphs (Fig. 15), which would be modified by the participant according to the corresponding configuration change document. The configuration changes chosen for the study were

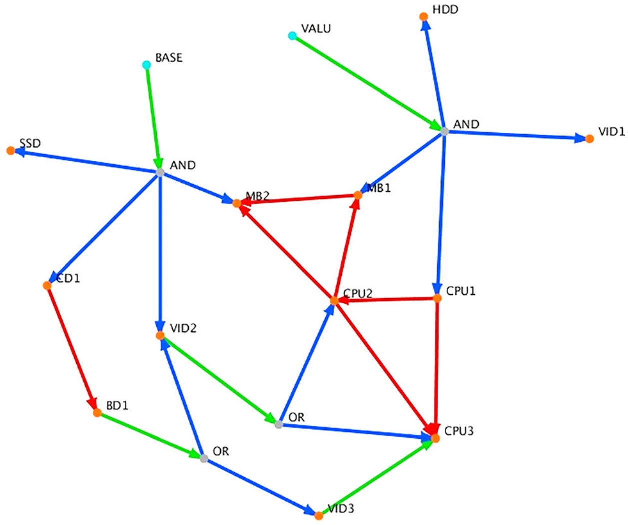


Fig. 15 Rule system graph provided to the experimental groups

developed based on the types of changes that occur at a local automotive manufacturing facility. Additionally, the documents were created to mirror the change documents used at the OEM.

Evaluation Protocol. The resulting rule systems were evaluated as to whether or not the resulting system accurately portrayed the changes specified in the configuration change documents. To assist in identifying the effectiveness of each method, the changes were broken down into components of the change. For example, adding a package to the system requires adding the package and adding the individual rules that apply to the package. A single grader was used to evaluate all of the results.

Results. A total of 74 results (three configuration changes per result and four components per change) were collected from the participants and evaluated during the user study. The results were evaluated by a single grader, as previously discussed, and the data were tabulated into spreadsheets for ease of analysis.

For accuracy, the results were consolidated according to which group the participants were in (control, experimental, and experimental w/training). This was done in order to see how the rule implementation method affected the accuracy of the resulting rule sets. The results for each group for changes 1, 2, and 3 are shown in Tables 7–9, respectively.

Table 7 Number and percent of correct responses by group for change 1

Change 1	1.1		1.2		1.3		1.4	
Group	#	%	#	%	#	%	#	%
Experimental	26	100	15	58	26	100	25	96
Control	25	100	21	84	24	96	25	100
Training	23	100	20	87	22	96	23	100

Table 8 Number and percent of correct responses by group for change 2

Change 2	2.1		2.2		2.3		2.4	
Group	#	%	#	%	#	%	#	%
Experimental	25	96	15	58	18	69	17	89
Control	25	100	25	100	25	100	19	79
Training	23	100	22	96	22	96	17	85

Table 9 Number and percent of correct responses by group for change 3

3	3.1		3.2		3.3		3.4	
Group	#	%	#	%	#	%	#	%
Experimental	26	100	23	88	9	35	9	35
Control	23	92	23	92	25	100	25	100
Training	23	100	19	83	12	52	12	52

Discussion. It should first be noted that there are limitations in the analysis. While the participants had no previous experience with either method for rule implementation, the use of spreadsheets and the basic logical grammar used in if-then statements is commonplace. However, the use of node-link graphs to visually

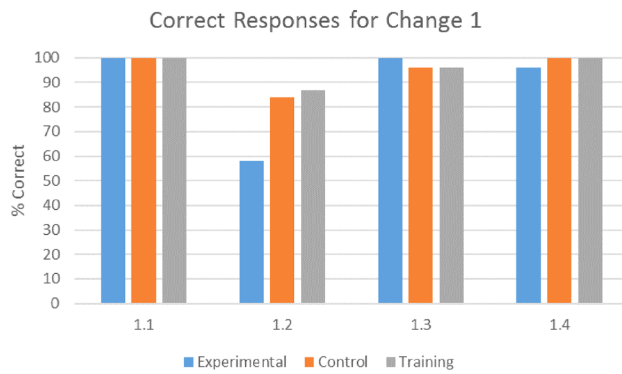


Fig. 16 Percent correct responses for change 1

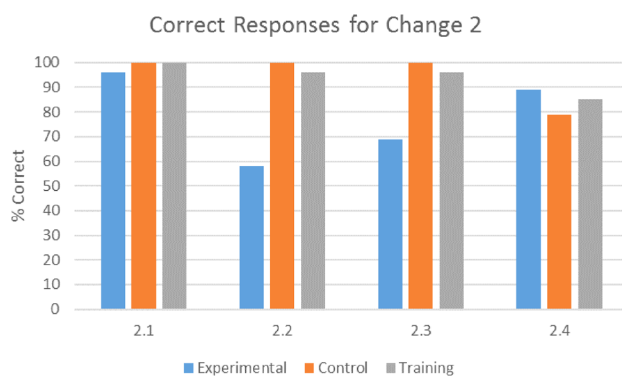


Fig. 17 Percent correct responses for change 2

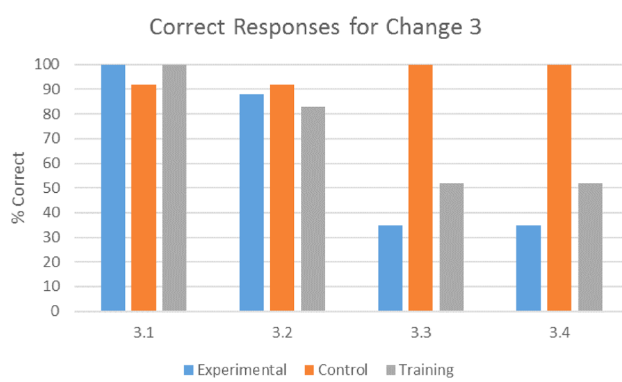


Fig. 18 Percent correct responses for change 3

represent configuration rules, and the grammar that is associated with it, is something the participants were unlikely to have any experience with at any level. While a similar amount of training was provided to the control and experimental groups, the experimental group that was given the graphs was less likely to fully understand and become familiar with the process during the brief training period. This likely caused the decrease in the capabilities of the graph visualization method for rule implementation and was the reasoning for the second session with an increased training period for the training group.

When considering the accuracy of the results based on the method of rule implementation, a definite trend existed where the accuracy of the answerable questions greatly increased with the use of the text-based (control) method. However, a brief training session with the second experimental group significantly decreased the gap. Figures 16–18 illustrate the percentage of correct responses for each question for all of the groups.

From the above graphs, it is clear that, in each situation, the text-based method for rule implementation surpassed the visualization-based method for accuracy, when the groups received the same amount of training. This was especially true for changes 2 and 3, the changes that involved the addition or modification of packages. Because package declarations are the most complicated rules in the database, it is likely that the participants were not familiar enough with the visualization method to accurately convey the correct relationships in the more complicated rules.

With the additional training period, the accuracy of the responses for the second experimental group increases significantly and only lags behind the control group for the third change. After reviewing the third change, the authors realized that an issue with the wording in the question resulted in confusion as to how directionality in the visualization was applied. This is likely the cause of the significant drop in accuracy for both of the visualization groups for parts 3.3 and 3.4

Tool Validation

In order to test the visualization tool throughout its development, the researcher used the software to assist in validating in-progress configuration changes at the OEM. How the visualization tool is used to assist in the analysis of ongoing changes at the OEM is illustrated through four cases.

Case 1: Windshield Option Change. The first change for which the visualization tool was implemented involved changing the rules that governed the relationships between two vehicle options. Previously, the presence of option 358 required that option 3AP also be present. However, this led to an issue in assigning parts for the vehicle, so a change was made that made the presence of option 358 require the absence of option 3AP.

One question that was asked regarding the change was whether it would result in any windshields that were no longer valid. Essentially, were there any windshields that required a configuration that no longer worked due to the change? To assist in answering the question, a visualization graph for the windshields and all options affecting the ordering of windshields was created. The resulting graph is shown in Fig. 19. In the graph, the available

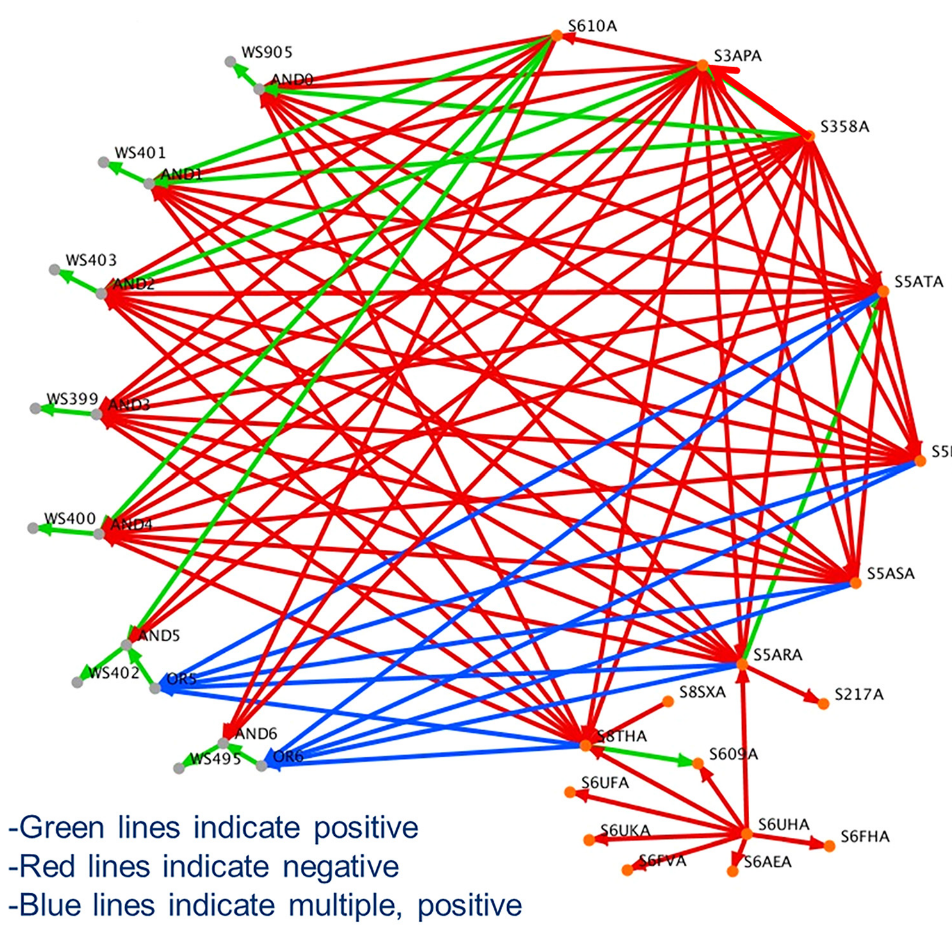


Fig. 19 Visualization graph for windshield option change (case 1)

windshields are found on the left with labels of WS###, while the options are on the right and are represented by S###A. The links between them represent the rules according to the visual grammar described previously. A brief review of the graph shows that no windshield requires both 3AP and 358 to be present. Further, 3AP and 358 are related through a negation rule. Thus, if 358 is present, 3AP cannot be present.

This is the same conclusion that the change control personnel at the OEM came to while working concurrently on the configuration change. In addition, the use of the visualization assisted the researcher in understanding and explaining to the change control personnel as to why the change was written as is and to validate that there were no other configuration conflicts resulting from the implementation of the change.

Case 2: Indian Country Model Change. Another change in which the visualization tool proved helpful involved changing the standard Indian country model for one of the diesel sport utility vehicles from one model to another. The intent of the configuration change validation in this instance was to determine whether any additional rules needed to be added, other than changing the availability of the option code between the two models.

In order to support the validation of this change, two separate graphs were created, one for each model code that was affected. The graph for the model code that currently existed as the model for us in India is shown in Fig. 20. It should be noted that this is an earlier instance of the graph visualization tool and the readability of the graphs has since been improved to increase usability.

The graph for the model that would replace the previous model is shown in Fig. 21 below.

By comparing the two graphs, it was possible to determine if there were any differences between the options and rules for the two models.

A brief inspection of the graphs above shows that a series of rules/options are missing from the middle of the left side of the graph. Essentially, this meant that a change in the engine size (the only significant change between the two model codes) resulted in no longer disallowing a certain emissions standard in the ruleset. When asked if this was intentional, the change control personnel at the OEM were not aware of the inconsistency.

To determine whether it would have been faster to create a list of the options and rules present for each model, an additional study was conducted. In this study, the time measured included the time to create the visualization and then to inspect the graphs to determine where any rule issues may be found. This time was compared to the amount of time it would take to identify the difference using the methods in place at the OEM. It was determined that the use of the visualization graph reduced the required time by 75%.

Case 3: Emissions Standards Option Change. Because the configuration changes are not written by personnel in the change

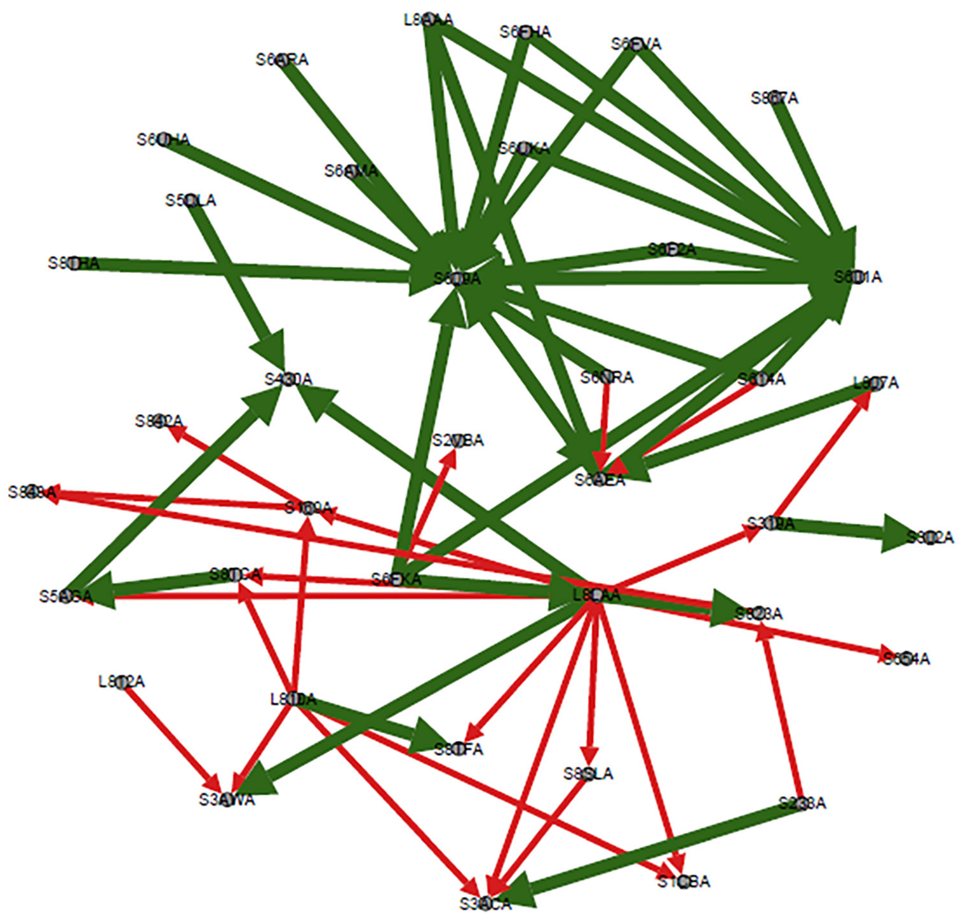


Fig. 20 Visualization graph for existing model

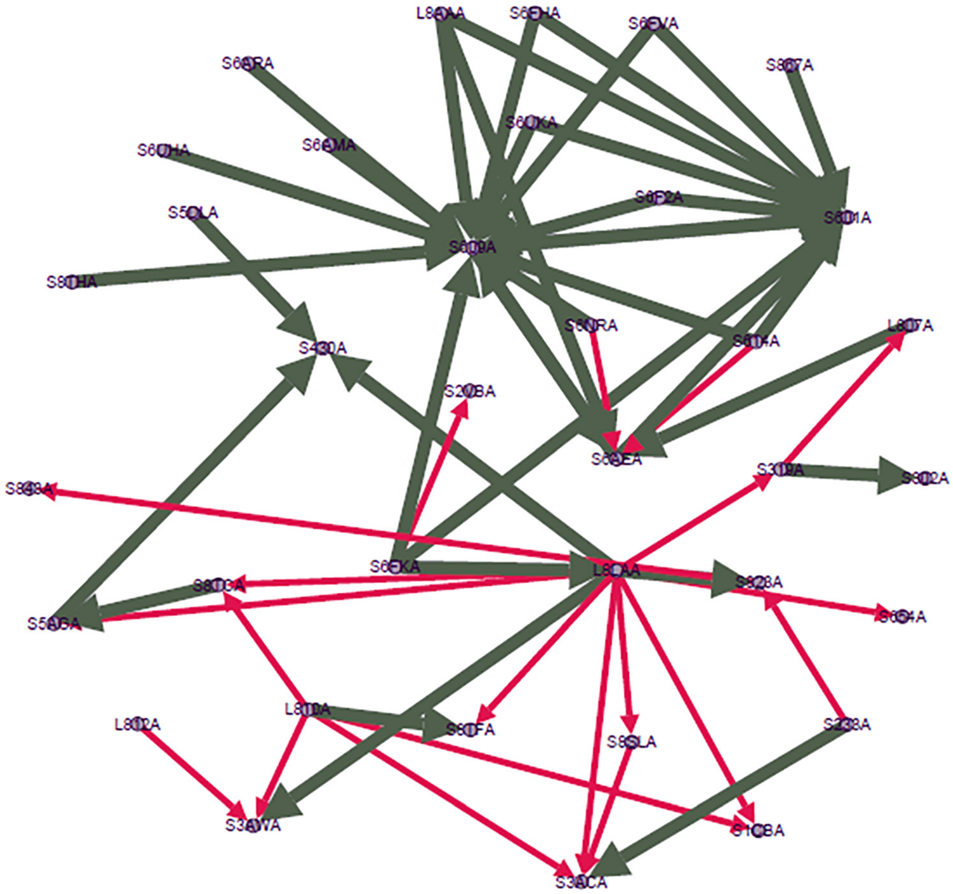


Fig. 21 Visualization graph for replacement model

control group at the OEM, understanding the reasoning and implications behind the change can be difficult when attempting to validate a specific change, even if the validation itself is simple. This was the case with the third configuration change. This change focused on the emissions standard levels (S161A, S167A, and S169A) for four vehicle models (KS01, KS02, LS01, LS02). After the analysis, it was determined that models LS01 and LS02 were being created to allow a specific emission standard (S167A), which was not available for the other two models.

Case 4: Australian Country Option Addition. The final change for which the visualization tool was implemented was the addition of the Australian country option to a current model. Essentially, the OEM wanted to expand its vehicle offerings in Australia.

In order to validate this change, a model was selected that most closely matched the model being changed, but that already included the Australian country option. This mirrored the method used by the change control personnel at the OEM. Two visualization graphs were then created for the models. The first graph showed the model that already had the option, shown in Fig. 22. The second graph showed the model to which the option was being added, shown in Fig. 23. In addition, a blank node (New Node 2) was added to the graph to mimic the option being added to the model. Also, the corresponding rules between the new option and other related options were added to the graph to create a close duplicate to the existing model.

Based on an inspection of the above graphs, no issues were identified to result from adding the Australian country option to the new model. The only changes were that two other options (S2AMA and L8LAA) were not available for the new model and those would not be of concern. An additional application of this tool is that the new options and ruleset that were created using the visualization tool could be exported to provide the written rules/options that needed to be modified in the ruleset to implement the change.

Conclusions and Future Work

The purpose of this paper was to present a graph visualization tool to support configuration change management at an automotive OEM. The graph visualization tool was developed based on the findings of a user study on graph layouts and the requirements identified through a case study in previous research. Following the implementation of the visualization tool, four use cases were presented, through which the tool was proven to be useful in validating configuration changes at the OEM. In addition to identifying potential conflicts or issues when implementing a change, the tool assisted in understanding why changes were implemented the way they were and in decreasing the amount of time required to explore the change.

The primary limitation of the research is that the use cases were conducted by the researcher alongside the change control personnel at the OEM. Though the cases were ongoing configurations changes, the change control personnel were not using the tool themselves, but rather using the information obtained from the researcher's use of the tool. In order to gain a fuller understanding of the usefulness and application of the visualization tool, it is recommended that the tool be implemented completely into the practices of the change control personnel at the OEM.

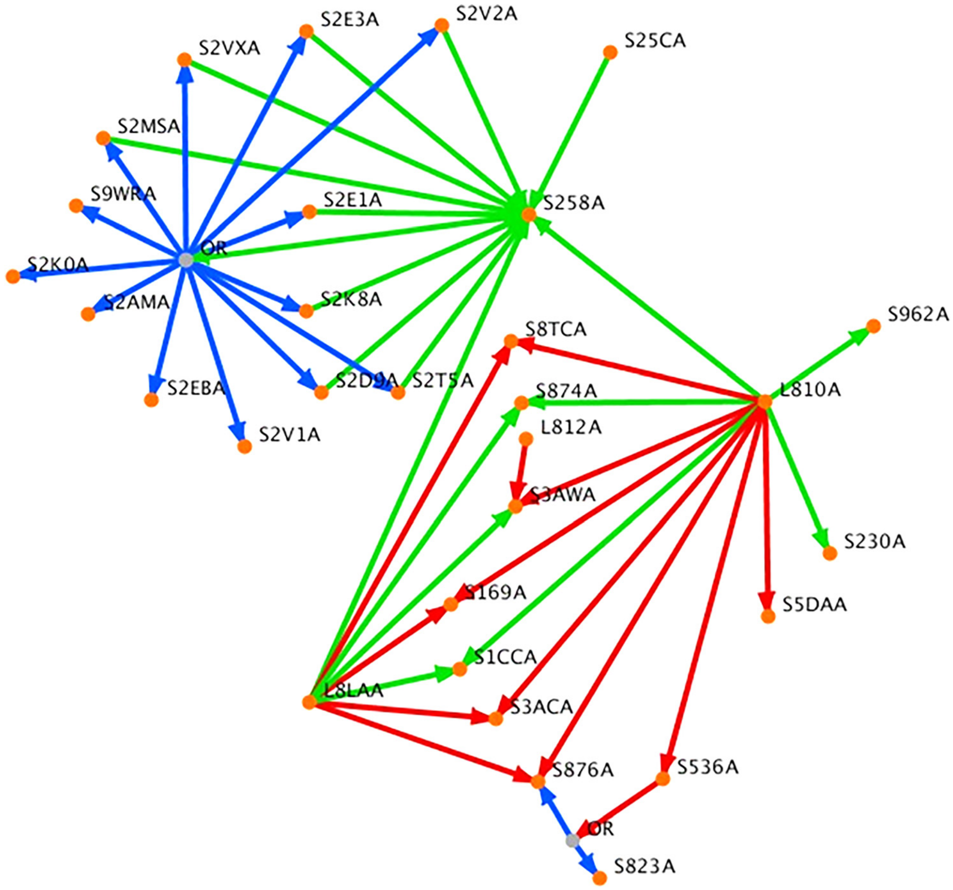


Fig. 22 Existing model graph with the Australian country option already available

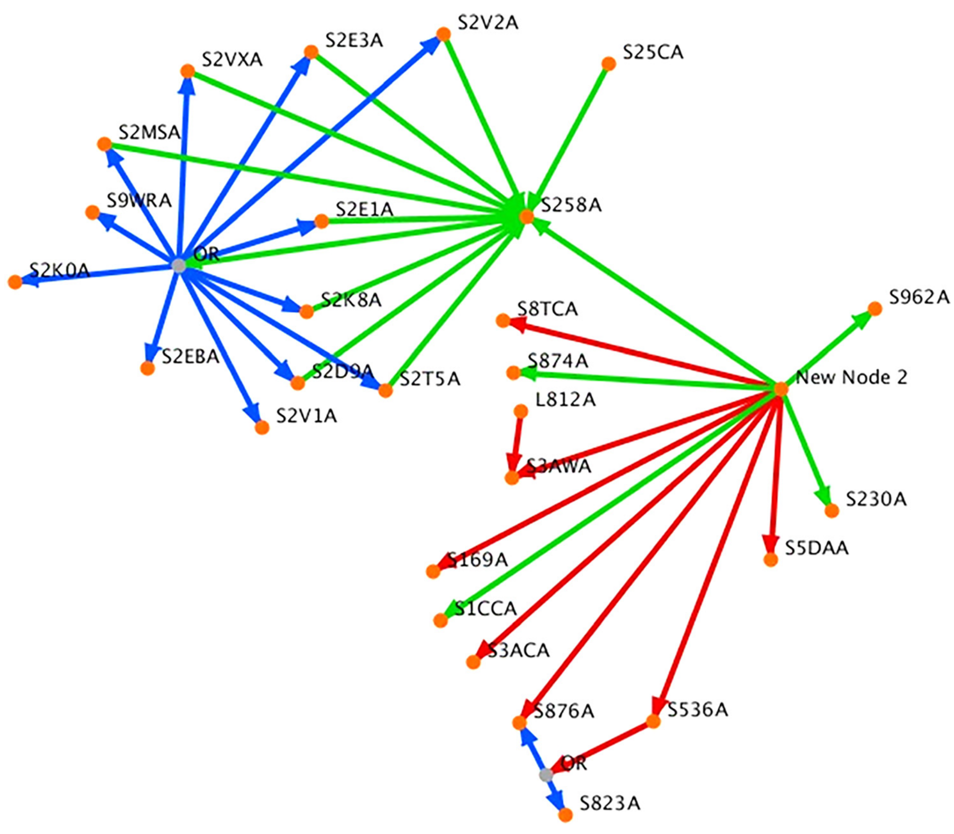


Fig. 23 Graph of the model to which the country option will be added

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