# How novice analysts understand supply chain process models: experimental study of using diagrams and texts

Joerg Leukel and Vijayan Sugumaran

*Faculty of Business, Economics & Social Sciences, University of Hohenheim, Stuttgart, Germany*
*Department of Decision and Information Sciences, School of Business Administration, Oakland University, Rochester, Michigan, USA*
*corresponding author: joerg.leukel@uni-hohenheim.de*

**Purpose:** Process models specific to the supply chain domain are an important tool for the analysis of interorganizational interfaces and requirements of IT systems supporting supply chain decision-making. The purpose of this study is to examine the effectiveness of supply chain process models for novice analysts in conveying domain semantics compared to alternative textual representations.
**Design/methodology/approach:** A laboratory experiment with graduate students as proxies for novice analysts was conducted. Participants were randomly assigned to either the diagram group, which worked with 'thread diagrams' created from the modeling grammar 'Supply Chain Operation Reference (SCOR) model', or the text group, which worked with semantically equivalent textual representations. Domain understanding was measured using cognitively demanding information acquisition tasks for two different domains.
**Findings:** Diagram users were more accurate in identifying product-related information and organizing this information in a graph compared to those using the textual representation. We found considerable improvement in domain understanding, and using the diagrams was perceived as easy as using the texts.
**Originality/value:** The study's findings are unique in providing evidence for supply chain process models being an effective representation for novice analysts. Such evidence is lacking in prior research because of the evaluation methods used, which are limited to scenario, case study, and informed argument. This study adds the diagram user's perspective to that literature, and provides a rigorous empirical evaluation by contrasting diagrammatic and textual representations.
**Keywords:** Conceptual modeling, Process model, Requirements analysis, Supply chain, Laboratory experiment

## 1. Introduction

Many firms increasingly use information technology (IT) to integrate their business processes into the processes of their suppliers, customers, and other parties involved in the supply chain (Büyüközkan and Göçer, 2018). By utilizing supply chain data and process knowledge, organizations can improve their visibility and streamline their operations to gain efficiency, which greatly contributes to the overall sustainability of the supply chain (Ganbold *et al.*, 2021; Saleem *et al.*, 2021). This operational efficiency has been amplified by the advent of digital services and digital platforms providing some well-defined reusable functionality through standardized protocols (Tiwana *et al.*, 2010; Williams *et al.*, 2008). For documenting the common understanding of activities, products, and stakeholders of a supply chain, process models are frequently used. The role of these supply chain process models is to assist individuals in acquiring a realistic understanding the domain of interest and facilitate communication about the domain between domain analysts, IT analysts, developers, managers, and end-users of IT systems. The models are typically diagrammatic representations including some textual description, and are created using a modeling grammar that defines visual constructs for representing domain phenomena.

With the focus of process analysis moving from an organizational scale to the supply chain, specific modeling grammars for supply chain processes have been proposed (Lambert and Cooper, 2000; Verdouw *et al.*, 2011; Zhang *et al.*, 2009), which complement domain-independent modeling grammars, such as the *Business Process Model and Notation (BPMN)* (OMG, 2014). By focusing on the product flow, supply chain process models are different from business process models concerned with the control flow. The representational focus is on activities realizing the flow of goods and services from upstream suppliers to the downstream customers. The diagrammatic representations particularly target novice analysts who have some experience with interpreting process models but are not modeling experts.

Given the importance of supply chain process models for the analysis of interorganizational interfaces and requirements on supply-chain IT, relatively little is known about their effectiveness in conveying domain semantics to novice analysts. Although various modeling grammars are documented in the literature, evidence for their usefulness is scarce. This deficit can be attributed to the types of evaluation methods used in prior research, which include: (1) constructing scenarios around the representation (Long, 2014), (2) reporting how the representation has been applied in a business environment (Verdouw *et al.*, 2011), and (3) arguing for the representation's usefulness (Chandra and Grabis, 2016; Millet *et al.*, 2009). Even less is known about whether diagrams will be at least as useful as alternative textual representations. If users of the diagram would acquire lower levels of domain understanding compared to users of the text, then using diagrams would be meaningless. Although prior research provides some empirical support for process models created from domain-independent grammars being equally useful as textual representations (Boritz *et al.*, 2012; Ottensooser *et al.*, 2012; Trkman *et al.*, 2019), the diagram-versus-text comparison is missing for grammars specific to the supply chain domain.

Against this backdrop, the objective of our study is to empirically examine the extent to which trained novice analysts acquire domain semantics from using supply chain process models compared to using alternative textual representations. Specifically, we report on a controlled laboratory experiment in which we manipulated the type of representation (diagram vis-à-vis text) and administered information acquisition tasks for two different domains. The tasks were cognitively demanding, and thus allowed us to assess a deep-level of domain understanding. To scope our work, we focus on the so called *SCOR thread diagrams* created from adopting a process modeling grammar defined in the *Supply Chain Operations Reference (SCOR) model* (APICS, 2017). SCOR was first introduced in 1997 and is often regarded as the industry-standard for process modeling in a supply chain context (Bolstorff and Rosenbaum, 2012). By collecting experimental data and conducting quantitative analysis, our research contributes to the literature by providing evidence for supply chain process models being an effective representation for novice analysts.

The remainder of this article is structured as follows. We first discuss the literature related to domain understanding from representations of supply chain processes. Then, we present the design of our controlled experiment and report the results. We discuss the findings from our study before concluding the article.

## 2. Literature Review

### *2.1 Supply chain process models*

Supply chain process model is a particular type of diagrammatic model representing the logic of product flow within a supply chain. The model describes how the supply chain transforms products provided by upstream suppliers across various stages into final products delivered to downstream customers (Mentzer *et al.*, 2001). Essential model elements include representations of: (1) the products being dealt with in the supply chain, (2) activities for handling and transforming products (e.g., receiving, manufacturing, delivering), and (3) entities that perform these activities (e.g., suppliers, manufacturers). Such models are often used for the analysis of interorganizational interfaces (e.g., within supply chain design) and requirements on supply-chain IT (Daneshvar Kakhki and Gargeya, 2019).

Models can be created using modeling grammars, which define the visual constructs for representing domain phenomena and the rules for how to combine these constructs (Wand and Weber, 2002). Because the constructs are specific to the supply chain domain, the grammar used can also be referred to as supply chain grammar (Leukel and Sugumaran, 2013; Pentland, 1994). Various grammars have been proposed in the literature, which differ with respect to graphical notation, coverage of domain phenomena, and theoretical foundation. Irrespective of such differences, the key idea of supply chain grammar is to organize supply chain-specific information in a spatial dimension and link related pieces of information visually to facilitate understanding by diagram users.

### *2.2 Understanding of supply chain process models*

In discussing the literature on how individuals understand supply chain process models, we introduce a taxonomy based on three dimensions of diagram understanding: (1) the modeling grammar, (2) evaluation criteria, and (3) evaluation method used. We begin our discussion with non-SCOR representations, before turning to SCOR-based representations.

Grammars based on Petri nets (PN) have been proposed for representing supply chain processes. For instance, in the grammar developed by Blackhurst *et al.* (2005), products are represented by places, activities by transitions, and product instances by tokens that move via transitions from one node to other nodes. The rationale for using PN is the graphical representation, which is supposed to be effective in communicating domain semantics to managers as model users. In a similar vein, Zhang *et al.* (2009) proposed an adaptation of colored Petri nets (CPN), in which colored tokens stand for products and places represent organizations, and asserted that such models would be easy to understand. Both studies defined applicability to real-word supply chains as the validation criterion. However, no empirical evaluation of the understandability of the proposed representations have been carried out, but the studies only provide illustrations of how to use the grammar (evaluation method: case study). Moreover, their assumptions about the understandability of representations are in contradiction to empirical evidence for novices perceiving PN-based process models being more difficult to understand compared to Event-driven Process Chain (EPC) diagrams (Sarshar and Loos, 2005).

The *Business Process Model and Notation (BPMN)* is the most used grammar for business process modeling (OMG, 2014). Therefore, it is not surprising that adaptations of BPMN to the context of supply chain processes have been proposed. Chandra and Grabis (2016) demonstrated how the constructs and rules defined in the BPMN grammar can be mapped onto recurring phenomena of supply chains. Blecken (2010) put forward a BMPN-based grammar specifically for humanitarian supply chains. Although the grammar's applicability was examined using the case study method, the evaluation only assessed coverage of domain phenomena observed in that case but not understandability of the created models by individuals.

SCOR is a widespread modeling approach and provides constructs and rules for describing supply chains at different levels of abstraction (Bolstorff and Rosenbaum, 2012; Stephens, 2001). At the center of SCOR lies the 'thread diagram', which focuses on product flows. The grammar includes constructs for representing supply chain activities (symbol: arrow-shaped rectangle), actors (symbol: label), tiers (symbol: vertical swimlane), and product flows (symbol: arrow connecting rectangles) as well as a two-dimensional classification of activities (symbol: 2-digit code). For instance, S1 stands for sourcing (S) of stocked products (1), M2 for manufacturing (M) of make-to-order products (2), and D3 for delivering (D) engineer-to-order products (3). Product flow has comprehensive coverage including raw materials, intermediate goods, final goods, and services as well as reused, repaired, refurbished, and recycled goods; hence, SCOR can also be used for representing reverse and circular supply chains (Upadhyay *et al.*, 2019; Upadhyay *et al.*, 2021). It is important to note that thread diagrams convey a relevant share of domain semantics through symbols rather than individual labels, which may exhibit great variation in other types of diagrams.

Prior research examined SCOR for developing solutions to managerial problems in supply chains, in particular, performance measurement (Yadav *et al.*, 2020) and risk management (Rotaru *et al.*, 2014). Another stream of research is characterized by integrating SCOR constructs into modeling approaches for simulation, enterprise information systems, and specific domains. Persson and Araldi (2009) proposed an integration of SCOR constructs into discrete-event simulation, and provided two examples demonstrating how models can be created using a modeling software; hence, applicability had been the evaluation criterion, and scenario was the evaluation method. Long (2014) combined SCOR with agent-based simulation and demonstrated the applicability of their approach using an example scenario. Medini and Bourey (2012) proposed a SCOR-based grammar for enterprise architecture modeling, which has been applied in an industrial project (evaluation method: case study).

All of the studies discussed above have a common theme that effectiveness of diagrams is defined by their ability to represent domain phenomena, and this ability was demonstrated by some exemplar diagrams. However, no study reports on the extent to which individuals were able to understand these diagrams. In previous research, the unit of analysis is either the organization, such as a focal company, or the supply chain. The evaluation methods used are limited to scenario, case study, and informed argument, which are inadequate to provide evidence for supply chain process models being effective in communicating domain semantics to model users. We address this limitation by assessing the understanding of SCOR thread diagrams by individuals and compare their understanding with individuals who use textual representations. How far users understand a given diagram can be measured by tasks that ask for deriving information from that diagram. One's understanding of the diagram is defined as the extent to which the domain semantics articulated by the user corresponds with the actual domain semantics conveyed by the diagram. If users of the diagram acquire higher levels of domain understanding compared to users of a semantically equivalent text, then using the diagram would be more effective than using the text. Therefore, the unit of analysis is the individual for which we adopt an experimental method.

## 3. Method

### *3.1 Experimental design*

We employed the method of laboratory experiment to collect empirical data from participants who solved information acquisition tasks using different representations of supply chains under highly controlled conditions. Given the exploratory nature of our research, we chose an experiment to focus on internal validity rather than generalizability to different contexts, such as modeling experts. Figure 1 provides an overview of the research process.

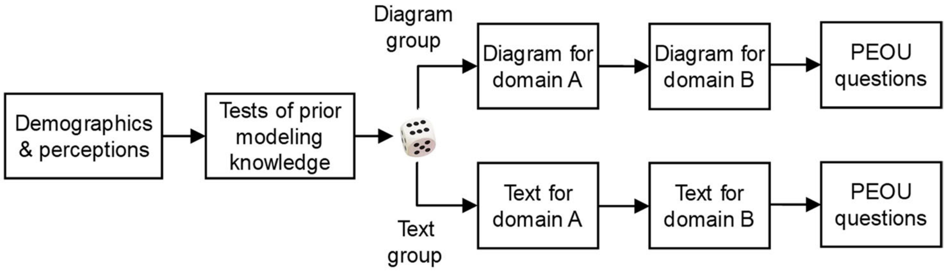



**Figure 1.** Overview of the research process.

We conducted a between-group experiment in which participants were randomly assigned to either the diagram or the text group. After answering questions about their background and completing tests of prior modeling knowledge, participants were given representations of two domains (A, B) using which they had to information acquisition tasks. For each domain, the diagram and text were semantically equivalent with respect to our dependent variable for measuring participants' understanding of the domain semantics conveyed by the representation. In the final step, participants indicated their perceived ease-of-use in the tasks. Overall, this design enabled us to collect objective data about participants' task performance and compare it between the diagram (treatment) and text (control) groups. To mitigate the risk of biases in the collected data, we implemented the following procedures: participants were drawn from a homogeneous target group and randomly assigned to groups; we tested the effectiveness of randomization; we adopted validated measurement instruments for all variables and verified assumptions of the statistical tests used. We have also clearly outlined the specific design choices of our experiment and provided a detailed description to allow researchers to replicate our evaluation.

### *3.2 Participants*

The experiment was targeted at novice analysts who have some practical experience with developing and interpreting SCOR thread diagrams. The participants should have knowledge of the constructs and rules defined in the modeling grammar. Prior knowledge of the application domain was not required to succeed in the experiment. This setting is similar to previous experiments that evaluated the usefulness of process representations for novices (Dikici *et al.*, 2018).

We recruited thirty-three graduate students (twenty females and thirteen males) from an international bio-economy program, which focuses on all aspects of supply chains for bio-based products. Their mean age was 25.69 years ($SD$ = 3.18). All participants were enrolled in a second semester course on modeling and simulation. The course provided an introduction to process modeling and SCOR thread diagrams through four classroom sessions, 90 minutes each. Students learned how to develop process models, analyze the syntactic correctness of diagrams, and solve tasks similar to those administered in the experiment. Because our research deals with understanding representations of organizational processes, rather than process design, students from this specific program and course are a suitable surrogate for trained novice analysts (based on the course materials and the training provided in the class). Students provided written informed consent and their participation was voluntary. Participants were awarded extra credit equivalent to five percent of their total grade in the course.

### *3.3 Measurements*

#### *3.3.1 Dependent variables*

We measured domain understanding through performance in two information acquisition tasks, which we presented to participants as product-modeling tasks. The tasks asked the participants to sketch an image that best represents the structure of the final product described in either the diagram or text. Each task could be solved by first identifying the various elements of the final product from the representation and then arranging them in form of a graph. The graph is made of nodes for products and arcs for relationships between products. Solving the tasks required a thorough analysis of the representation by identifying relevant information and organizing this information in the form of a graph. For each correctly identified product (i.e., nodes of the graph), we assigned a score of one. A product was regarded as correct, if it had been appropriately connected within the graph. We summed up the scores for the two domains (maximum scores of six and eight, respectively, and total score of fourteen). This type of task and the measurement of task performance have been introduced and validated in previous research (Leukel and Hubl, 2018).

We complemented the objective measurement of domain understanding by assessing the *perceived ease-of-use (PEOU)*, which is defined as the extent to which an individual believes that using a particular representation would require less cognitive effort. We measured this perceptual variable by adapting a validated three-item instrument from previous research (Shanks *et al.*, 2008). Item definitions are provided in Appendix C.

#### *3.3.2 Control variables*

We considered variables to control for individual factors, which might affect domain understanding (Dikici *et al.*, 2018). These factors allowed us to assess whether our randomized assignment of participants to groups worked as expected. Variables included age (years), graduate credits (0-120 scale), class attendance (0-4 scale), self-reported modeling knowledge (1-5 scale), perceived usefulness (1-5 scale), grammar test score (0-6 scale), and diagram test score (0-5 scale). Measurement instruments are provided in Appendix A.

*Self-reported modeling knowledge* was measured by a three-item instrument adopted from previous research (Mendling *et al.*, 2010). Participants indicated their familiarity with SCOR diagrams (1-5 scale).

*Perceived usefulness (PU)* was defined as the extent to which a person believes that using a particular representation would enhance their job performance. Again, we adopted a validated three-item instrument (Maes and Poels, 2007), and adjusted the items to our study setting. The first item of our PU instrument specifically assessed the extent to which participants perceived SCOR diagrams as more useful than textual representations. We examined this particular perception in our data analysis.

*Grammar test score* was defined as the number of correct answers to six multiple-choice (MC) questions about the SCOR grammar. Participants had to validate statements adopted from previous research (Leukel and Hubl, 2018). We included this variable to measure participants' actual modeling knowledge.

*Diagram test score* also measured participants' actual modeling knowledge by providing an exemplar diagram for which participants had to answer five MC questions (four answer options each). We adopted the diagram and questions from a previous experiment (Leukel and Sugumaran, 2018).

### *3.4 Materials*

The materials included three parts. In the first part, we captured the participants' background through questions on age, graduate credits, class attendance, self-reported modeling knowledge, and PU, which were complemented by the two tests of modeling knowledge (materials provided in Appendix A). The second part of our materials provided the actual task materials through two domain representations and one product-modeling task each (Appendix B). In the last part of our materials (Appendix C), participants had to answer the PEOU question.

We first developed the SCOR thread diagrams, and then derived textual descriptions that were semantically equivalent with respect to our performance variables. The diagram and text provided sufficient information to complete the tasks correctly. Each text began with stating the final product and its manufacturer, and then proceeded with describing the supply chain by referring to actors, tiers, and products. The words used for denoting actors, tiers, and products were exactly the same as in the corresponding diagram. Domain A described the supply chain of a window manufacturer, in which five other companies were taking part by delivering products such as round timber, sawn timber, wood protection, glass, and window panes. The diagram included 17 processes, which were arranged across 3 tiers (Figure B.1), and the length of the corresponding text was 116 words. Domain B was concerned with a supply chain for urban roads, in which city administrations, general contractors, and various suppliers were involved. Products included asphalt, traffic lights, aggregates, and polymers among others. The diagram represented 9 actors, 20 processes, and 5 tiers (Figure B.3), and the word count of the corresponding text was 103.

### *3.5 Procedures*

We organized the experiment as a class room exercise. One of the three instructors explained the procedures. Participants were randomly assigned to either the diagram or the text group. To prevent copying, every second seat and every second row were left empty, and every two participants next to each other were assigned to different groups. Instructors distributed the materials on paper in a single document, and the experiment started simultaneously for all participants. Participants were given 45 minutes to work through the document (the maximum time required was 36 minutes). The instructors made sure that there was no collaboration between participants. Once a participant had answered the final PEOU question, an instructor collected the document. Because the procedures were similar to previous experiments from which we also adopted validated measurement instruments, pilot testing of the procedures was not necessary.

### *3.6 Data analysis plan*

Our data analysis began with two validation steps. First, we assessed the reliability of our reflective measurements by using the Cronbach's alpha measure. We found an acceptable level of internal consistency for self-reported modeling knowledge (.772), and good levels for PU (.858) and PEOU (.846), respectively (Nunnally and Bernstein, 1994). Second, we verified whether our metric dependent variables followed normal distribution. Because there were departures from normality, we choose to use non-parametric tests for examining between-group differences in the dependent variables. All quantitative analyses were conducted using IBM SPSS Statistics 25.

## 4 Results

### *4.1 Data screening*

Table 1 shows participants' data for the two groups. On average, participants rated their SCOR modeling knowledge as in the middle (*M* = 2.83, *SD* = 0.78, on a 1-5 scale). They regarded SCOR thread diagrams as being rather useful (*M* = 3.70, *SD* = 0.77, on a 1-5 scale). Specifically, they expected diagrams to be more useful than textual representations (*M* = 3.88, *SD* = 0.86; first item of the PU instrument). Participants performed moderately in the grammar test (relative mean scores of 58% and 55%, respectively) but better in the diagram test (67% and 77%, respectively). There were no statistically significant differences in the variables shown in Table 1, suggesting that the assignment of participants to groups was effectively randomized.

**Table 1.** Participants' data for the diagram and text groups.

| Variable | Scale | Diagram (n = 15) | Text (n = 18) | Test results | | |
|---|---|---|---|---|---|---|
| | | M (SD) | M (SD) | U | z | p[a] |
| Age | Years | 25.87 (3.66) | 25.53 (2.79) | 125.00 | -0.095 | .924 |
| Graduate credits | 0-120 | 38.40 (22.52) | 33.24 (8.71) | 127.50 | 0.000 | >.999 |
| Class attendance | 0-4 | 3.07 (0.88) | 2.94 (1.16) | 133.00 | -0.077 | .939 |
| Self-reported modeling knowledge | 1-5 | 2.84 (0.83) | 2.82 (0.75) | 132.50 | -0.091 | .927 |
| Perceived usefulness | 1-5 | 3.73 (0.69) | 3.67 (0.85) | 133.00 | -0.074 | .941 |
| Grammar test score | 0-6 | 3.47 (1.46) | 3.28 (1.45) | 122.50 | -0.461 | .645 |
| Diagram test score | 0-5 | 3.33 (1.59) | 3.83 (1.10) | 114.00 | -0.787 | .431 |

[a] Significant at $p < .05$ (Mann-Whitney U-test, asymptotic, two-tailed).

Next, we assessed correlations between the independent and dependent variables (Spearman's rank correlation test, two-tailed). Product-modeling performance increased with higher scores in the grammar test ($r_s = 0.45$, $p < .001$). PEOU was correlated with self-reported modeling knowledge ($r_s = 0.37$, $p = .034$), PU ($r_s = 0.43$, $p = .013$), grammar test score ($r_s = 0.45$, $p = .009$), and diagram test score ($r_s = 0.62$, $p < .001$). Those who performed better in the product-modeling tasks reported higher PEOU ($r_s = 0.47$, $p = .006$).

### *4.2 Testing for differences in the dependent variables*

Table 2 presents the means, standard deviations, and statistical comparisons for each dependent variable and for each group. Participants using diagrams performed considerably better in the product-modeling tasks than participants using text, as indicated by the mean relative scores for the diagram group (65%) and the text group (38%) as well as other test results. We assessed the magnitude of the effect using *absolute r* as an effect size measure for the Mann-Whitney U-test (Cohen, 1988). This analysis revealed that the observed difference in product-modeling performance corresponds to a medium-sized effect ($| r | = 0.36$). Participants perceived diagrams and texts as rather easy to use ($M = 3.53$ and $M = 3.44$, respectively, on a 1-5 scale). The difference in the PEOU was statistically non-significant ($p = .755$), and the effect size measure ($| r | = 0.05$) was below the threshold of 0.10 for a small-sized effect.

**Table 2.** Results of testing for differences in the dependent variables.

| Variable | Scale | Diagram (n = 15) | Text (n = 18) | Test results | | | |
|---|---|---|---|---|---|---|---|
| | | M (SD) | M (SD) | U | z | p[a] | Effect size[b] |
| Product-modeling | 0-14 | 9.13 (5.82) | 5.28 (5.38) | 79.00 | -2.076 | .038 | Medium (0.36) |
| Perceived ease-of-use | 1-5 | 3.53 (0.66) | 3.44 (1.07) | 126.50 | -0.313 | .755 | None (0.05) |

[a] Mann-Whitney U-test, asymptotic, two-tailed.

[b] Absolute r: ≥ 0.1 small, ≥ 0.3 medium, ≥ 0.5 large (Cohen 1988).

## 5. Discussion

### *5.1 Contributions to literature*

Our research examines how diagrammatic vis-à-vis textual representations of supply chain processes impact novice analysts' domain understanding. We find that using diagrams enhances domain understanding measured by performance in solving information acquisition tasks. Based on the empirical results obtained from a controlled experiment, our research makes the following three specific contributions.

First, our study contributes to the literature by providing evidence for SCOR thread diagrams being more effective representations for novice analysts than textual representations. Despite the importance of SCOR, such evidence is yet lacking in the modeling literature.

Second, by administering information acquisition tasks that required organizing elements in a product graph, we advance prior research that has examined the understandability of process models derived from domain-independent modeling grammars through MC questions (Boritz *et al.*, 2012; Mendoza *et al.*, 2018; Ottensooser *et al.*, 2012). Because the task is specific to the supply chain domain, it allows ascertaining the user's understanding of supply chain representations precisely. Compared to MC questions, this task format provides a greater degree of freedom, while it rules out guessing as a strategy.

Third, given that prior research on business process models found no differences in the perceived ease-of-use between diagrams and textual representations (Boritz *et al.*, 2012; Czepa and Zdun, 2019), we extend the boundaries of this no-difference observation to the supply chain context.

### *5.2 Implications for research*

Our study results have several implications for research. In our experiment, we considered information acquisition tasks specific for measuring participants' domain understanding. Thus, opportunities exist to administer problem-solving tasks that allow measuring an even deeper level of domain understanding. The problem-solving task describes a problem in the domain and asks the user to provide explanations or solutions (Khatri *et al.*, 2006). Examining problem-solving performance can help establish the boundaries of when diagrammatic representations of supply chain processes will be more useful than textual representations for novice analysts.

Further exploration is also required to determine how the complexity in terms of the number of diagrammatic elements and text lengths, respectively, impact domain understanding. Similarly to previous research (Mendoza *et al.*, 2018; Rodrigues *et al.*, 2015), we considered representations of moderate complexity. With respect to process models created from domain-independent modeling grammars, the results of previous research are inconclusive by suggesting negative effects on domain understanding (Sánchez-González *et al.*, 2012), as well as no effect (Reijers and Mendling, 2011). Therefore, future research could extend the design of our study by manipulating the representation size to test whether the observed effect will be attenuated or amplified for larger diagrams. Moreover, the understanding of the cognitive processes as to why SCOR thread diagrams were more effective for novice analysts than texts is still limited. Based on our findings, future research could use other methods (e.g., think-aloud) to explore how users approach product-modeling tasks with supply chain process models.

### *5.3 Implications for practice*

Our study results inform practice about the usefulness of process representations for the analysis of interorganizational interfaces and requirements on supply-chain IT. Our results indicate that SCOR thread diagrams are more useful to novice analysts than textual representations. Novice analysts can effectively acquire domain understanding (operationalized as knowledge about product structures) from such diagrams, even if they received only limited training as the participants in our experiment. This finding is important because it provides an empirical underpinning for using the domain-specific modeling grammar, namely, SCOR. Thus, the training of project personnel should focus on abstract knowledge of supply chain processes and its recurring issues across specific industries. This knowledge can be sufficient for acquiring domain knowledge from diagrams. Developing a clear understanding of the interorganizational processes within the supply chain through the use of accurate SCOR diagrams can contribute a great deal in analyzing the requirements of novel IT systems for improving the sustainability of the supply chain.

### *5.4 Limitations*

The results of the present study should be viewed in light of the following limitations. First, our experiment only administered two domain representations. We had to control for the influence of many individual factors by specific questions, and also wanted to prevent fatigue of participants by setting a time limit of 45 minutes, which is similar to previous experiments (Figl *et al.*, 2013; Mendling *et al.*, 2019). Second, our experiment used graduate students as surrogates for novice analysts. Although our participants lacked professional experience, they are similar to novice SCOR users in industry, who receive limited training in process modeling. Using students allowed us to mitigate confounding effects of prior domain knowledge, but this design limits external validity. Third, we chose a subset of the SCOR grammar, which provides more modeling constructs, e.g., for returning products. The effect observed for the constructs used in our experiment cannot necessarily be generalized to all the SCOR constructs.

## 6. Conclusion

The effectiveness of supply chain process models for novice analysts in conveying domain semantics is an issue that has been largely neglected in conceptual modeling research. Although diagrams, such as SCOR thread diagrams, are often used by novice analysts, it is unclear whether diagrams are more useful compared to alternative textual representations. Our research is the first in providing evidence for the usefulness of SCOR thread diagrams. We conducted a controlled laboratory experiment and observed that diagram users performed better in solving cognitively demanding information acquisition tasks compared to users who worked with semantically equivalent text. Our research suggests that diagrams created from the domain-specific modeling grammar SCOR are more useful than text. Sustainability of supply chains is an important aspect and this research contributes to improving supply chain sustainability through better understanding of the interorganizational interfaces and the requirements of IT systems with proper use of SCOR diagrams.

**References**

APICS (2017), *Supply Chain Operations Reference (SCOR) Model: Version 12.0*, APICS, Chicago, IL.

Blackhurst, J., Wu, T. and O'Grady, P. (2005), "PCDM: a decision support modeling methodology for supply chain, product and process design decisions", *Journal of Operations Management*, Vol. 23 3-4, pp. 325–343.

Blecken, A. (2010), "Supply chain process modelling for humanitarian organizations", *International Journal of Physical Distribution & Logistics Management*, Vol. 40 8/9, pp. 675–692.

Bolstorff, P. and Rosenbaum, R. (2012), *Supply Chain Excellence. A Handbook for Dramatic Improvement Using the SCOR Model,* 2nd ed., AMACOM, New York, NY.

Boritz, J.E., Borthick, A.F. and Presslee, A. (2012), "The effect of business process representation type on assessment of business and control risks: diagrams versus narratives", *Issues in Accounting Education*, Vol. 27 No. 4, pp. 895–915.

Büyüközkan, G. and Göçer, F. (2018), "Digital supply chain: literature review and a proposed framework for future research", *Computers in Industry*, Vol. 97, pp. 157–177.

Chandra, C. and Grabis, J. (2016), "Conceptual modeling approaches," in Chandra, C. and Grabis, J. (Eds.), *Supply Chain Configuration*, Vol. 153, Springer New York, New York, NY, pp. 137–150.

Cohen, J. (1988), *Statistical Power Analysis for the Behavioral Sciences,* 2nd ed., Laurence Erlbaum Associates, Hillsdale, NJ.

Czepa, C. and Zdun, U. (2019), "How understandable are pattern-based behavioral constraints for novice software designers?", *ACM Transactions on Software Engineering and Methodology*, Vol. 28 No. 2, pp. 1–38.

Daneshvar Kakhki, M. and Gargeya, V.B. (2019), "Information systems for supply chain management: a systematic literature analysis", *International Journal of Production Research*, Vol. 57 15-16, pp. 5318–5339.

Dikici, A., Turetken, O. and Demirors, O. (2018), "Factors influencing the understandability of process models: a systematic literature review", *Information and Software Technology*, Vol. 93, pp. 112–129.

Figl, K., Recker, J. and Mendling, J. (2013), "A study on the effects of routing symbol design on process model comprehension", *Decision Support Systems*, Vol. 54 No. 2, pp. 1104–1118.

Ganbold, O., Matsui, Y. and Rotaru, K. (2021), "Effect of information technology-enabled supply chain integration on firm's operational performance", *Journal of Enterprise Information Management*, Vol. 34 No. 3, pp. 948–989.

Khatri, V., Vessey, I., Ramesh, V., Clay, P. and Park, S.-J. (2006), "Understanding conceptual schemas: exploring the role of application and IS domain knowledge", *Information Systems Research*, Vol. 17 No. 1, pp. 81–99.

Lambert, D.M. and Cooper, M.C. (2000), "Issues in supply chain management", *Industrial Marketing Management*, Vol. 29 No. 1, pp. 65–83.

Leukel, J. and Hubl, M. (2018), "The role of application domain knowledge in understanding supply chain process models", in *Proceedings of the 39th International Conference on Information Systems (ICIS 2018)*, San Francisco, CA.

Leukel, J. and Sugumaran, V. (2013), "Formal correctness of supply chain design", *Decision Support Systems*, Vol. 56, pp. 288–299.

Leukel, J. and Sugumaran, V. (2018), "How product representation influences the understanding of supply chain process models", *Enterprise Information Systems*, Vol. 12 No. 10, pp. 1285-1307.

Long, Q. (2014), "Distributed supply chain network modelling and simulation: integration of agent-based distributed simulation and improved SCOR model", *International Journal of Production Research*, Vol. 52 No. 23, pp. 6899–6917.

Maes, A. and Poels, G. (2007), "Evaluating quality of conceptual modelling scripts based on user perceptions", *Data & Knowledge Engineering*, Vol. 63 No. 3, pp. 701–724.

Medini, K. and Bourey, J.P. (2012), "SCOR-based enterprise architecture methodology", *International Journal of Computer Integrated Manufacturing*, Vol. 25 No. 7, pp. 594–607.

Mendling, J., Recker, J., Reijers, H.A. and Leopold, H. (2019), "An empirical review of the connection between model viewer characteristics and the comprehension of conceptual process models", *Information Systems Frontiers*, Vol. 21 No. 5, pp. 1111–1135.

Mendling, J., Reijers, H.A. and Recker, J. (2010), "Activity labeling in process modeling: empirical insights and recommendations", *Information Systems*, Vol. 35 No. 4, pp. 467–482.

Mendoza, V., da Silveira, D.S., Albuquerque, M.L. and Araújo, J. (2018), "Verifying BPMN understandability with novice business managers", in *Proceedings of the 33rd Annual ACM Symposium on Applied Computing (SAC '18)*, ACM Press, New York, NY, pp. 94–101.

Mentzer, J.T., DeWitt, W., Keebler, J.S., Min, S., Nix, N.W., Smith, C.D. and Zacharia, Z.G. (2001), "Defining supply chain management", *Journal of Business Logistics*, Vol. 22 No. 2, pp. 1–25.

Millet, P.-A., Schmitt, P. and Botta-Genoulaz, V. (2009), "The SCOR model for the alignment of business processes and information systems", *Enterprise Information Systems*, Vol. 3 No. 4, pp. 393–407.

Nunnally, J. and Bernstein, I.H. (1994), *Psychometric Theory,* 3rd ed., McGraw-Hill, New York, NY.

OMG (2014), "Business Process Model and Notation", available at: http://www.omg.org/spec/BPMN (accessed 27 March 2021).

Ottensooser, A., Fekete, A., Reijers, H.A., Mendling, J. and Menictas, C. (2012), "Making sense of business process descriptions: An experimental comparison of graphical and textual notations", *Journal of Systems and Software*, Vol. 85 No. 3, pp. 596–606.

Pentland, B. (1994), “Process grammars: a generative approach to process redesign“, Working Paper Series 178, MIT Center for Coordination Science, Cambridge.

Persson, F. and Araldi, M. (2009), “The development of a dynamic supply chain analysis tool—integration of SCOR and discrete event simulation”, *International Journal of Production Economics*, Vol. 121 No. 2, pp. 574–583.

Reijers, H.A. and Mendling, J. (2011), “A study into the factors that influence the understandability of business process models”, *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans*, Vol. 41 No. 3, pp. 449–462.

Rodrigues, R.D.A., Barros, M.D.O., Revoredo, K., Azevedo, L.G. and Leopold, H. (2015), “An experiment on process model understandability using textual work instructions and BPMN models”, in *Proceedings of the 29th Brazilian Symposium on Software Engineering (SBES 2015)*, IEEE, Belo Horizonte, pp. 41–50.

Rotaru, K., Wilkin, C. and Ceglowski, A. (2014), “Analysis of SCOR’s approach to supply chain risk management”, *International Journal of Operations & Production Management*, Vol. 34 No. 10, pp. 1246–1268.

Saleem, H., Li, Y., Ali, Z., Ayyoub, M., Wang, Y. and Mehreen, A. (2021), “Big data use and its outcomes in supply chain context: the roles of information sharing and technological innovation”, *Journal of Enterprise Information Management*, Vol. 34, No. 4, pp. 1121-1143.

Sánchez-González, L., García, F., Ruiz, F. and Mendling, J. (2012), “Quality indicators for business process models from a gateway complexity perspective”, *Information and Software Technology*, Vol. 54 No. 11, pp. 1159–1174.

Sarshar, K. and Loos, P. (2005), “Comparing the control-flow of EPC and Petri Net from the end-user perspective”, in Hutchison, D., Kanade, T., Kittler, J., Kleinberg, J.M., Mattern, F., Mitchell, J.C., Naor, M., Nierstrasz, O., Pandu Rangan, C., Steffen, B., Sudan, M., Terzopoulos, D., Tygar, D., Vardi, M.Y., Weikum, G., van der Aalst, W.M.P., Benatallah, B., Casati, F. and Curbera, F. (Eds.), *Business Process Management*, Springer, Berlin and Heidelberg, pp. 434–439.

Shanks, G., Tansley, E., Nuredini, J., Tobin, D. and Weber, R. (2008), “Representing part-whole relations in conceptual modeling: An empirical evaluation”, *MIS Quarterly*, Vol. 32 No. 3, pp. 553–573.

Stephens, S. (2001), “Supply Chain Operations Reference Model Version 5.0: A new tool to improve supply chain efficiency and achieve best practice”, *Information Systems Frontiers*, Vol. 3 No. 4, pp. 471–476.

Tiwana, A., Konsynski, B. and Bush, A.A. (2010), “Research commentary—platform evolution: Coevolution of platform architecture, governance, and environmental dynamics”, *Information Systems Research*, Vol. 21 No. 4, pp. 675–687.

Trkman, M., Mendling, J., Trkman, P. and Krisper, M. (2019), “Impact of the conceptual model's representation format on identifying and understanding user stories”, *Information and Software Technology*, Vol. 116, p. 106169.

Upadhyay, A., Akter, S., Adams, L., Kumar, V. and Varma, N. (2019), “Investigating 'circular business models' in the manufacturing and service sectors”, *Journal of Manufacturing Technology Management*, Vol. 30 No. 3, pp. 590–606.

Upadhyay, A., Kumar, A. and Akter, S. (2021), “An analysis of UK retailers’ initiatives towards circular economy transition and policy-driven directions”, *Clean Technologies and Environmental Policy*, Vol. 135 No. 2, p. 917.

Verdouw, C.N., Beulens, A., Trienekens, J.H. and van der Vorst, J. (2011), “A framework for modelling business processes in demand-driven supply chains”, *Production Planning & Control*, Vol. 22 No. 4, pp. 365–388.

Wand, Y. and Weber, R. (2002), “Research commentary: information systems and conceptual modeling—a research agenda”, *Information Systems Research*, Vol. 13 No. 4, pp. 363–376.

Williams, K., Chatterjee, S. and Rossi, M. (2008), “Design of emerging digital services: a taxonomy”, *European Journal of Information Systems*, Vol. 17 No. 5, pp. 505–517.

Yadav, S., Garg, D. and Luthra, S. (2020), “Development of IoT based data-driven agriculture supply chain performance measurement framework”, *Journal of Enterprise Information Management*, Vol. 34 No. 1, pp. 292–327.

Zhang, L., You, X., Jiao, J. and Helo, P. (2009), “Supply chain configuration with co-ordinated product, process and logistics decisions: an approach based on Petri nets”, *International Journal of Production Research*, Vol. 47 No. 23, pp. 6681–6706.

**Appendix A**

Self-reported modeling knowledge: (5-point agreement scale; 1=”strongly disagree”, 2=”disagree”, “3=undecided”, 4=”agree”, 5=”strongly agree”)

- Overall, I am very familiar with SCOR thread diagrams.
- I feel very confident in understanding diagrams created with SCOR.
- I feel very competent in using SCOR for supply chain modeling.

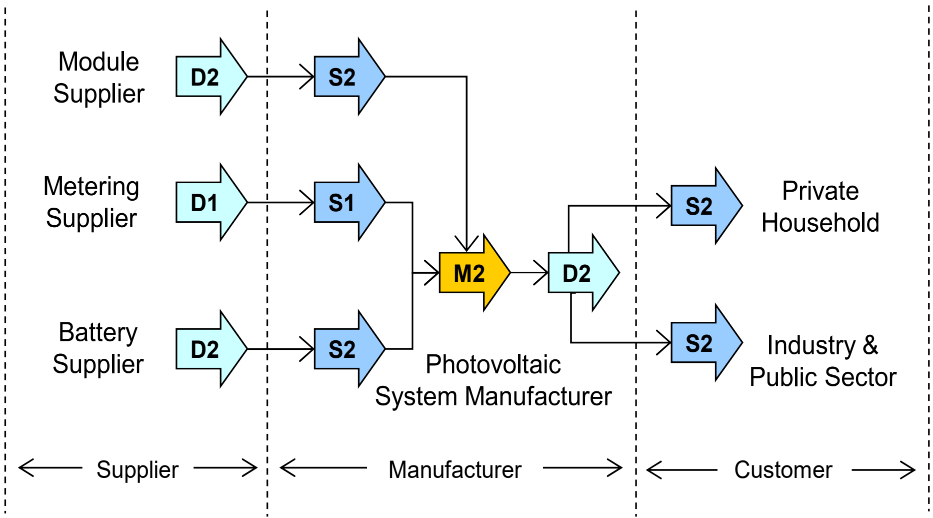
Perceived usefulness: (5-point agreement scale)

- Overall, I think a SCOR diagram would be an improvement to a textual description of the supply chain.
- I find SCOR diagrams useful for understanding the supply chain modeled.
- Overall, I think the SCOR diagram improves my performance when understanding the supply chain modeled.

Grammar test: Please indicate whether the following statements about SCOR diagrams are true or false. *(Three options: True, False, Don’t know; correct answers in brackets.)*

- Each actor must execute at least one process. *(True)*
- A make-to-order product is of higher product specificity than an engineer-to-order product. *(False)*
- Flows may have a label denoting the product. *(False)*
- Tiers can be arranged from right (suppliers) to left (customers). *(False)*
- A D1 process may only be followed by a S1 process. *(True)*
- Actor labels must be chosen from a dictionary provided in the SCOR handbook. *(False)*

Diagram test:

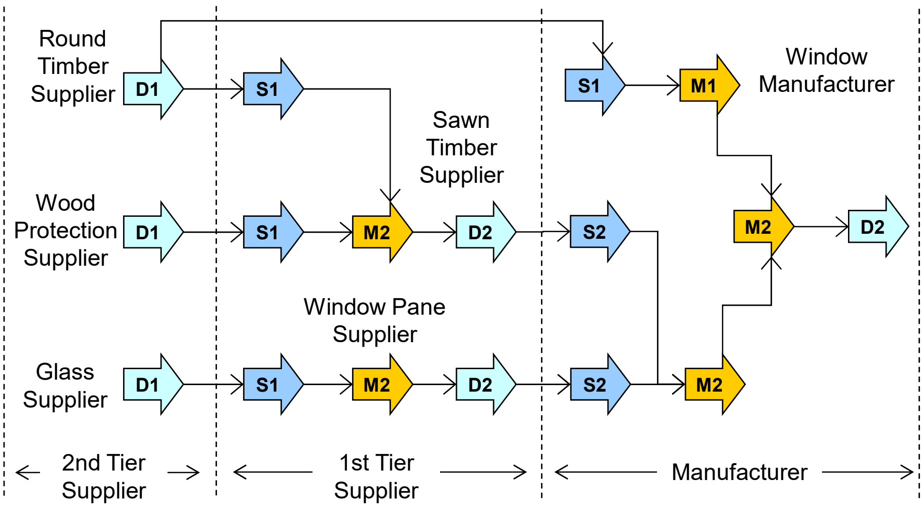



Consider the diagram shown above. Please answer the following multiple-choice questions (there is only one correct answer per question). *(correct answers shown in brackets)*

- Which actor buys products from more than one actor? a) Private Household, b) Photovoltaic System Manufacturer, c) Industry & Public Sector, d) None. *(b)*
- What is the number of actors in this supply chain? a) 3, b) 4, c) 5, d) 6. *(d)*
- Which is the product specificity of the Source processes in the Customer tier? a) Over-the-counter product, b) Make-to-order product, c) Engineer-to-order product, d) Stocked product. *(b)*
- Which statement is correct for the relationship between Module Supplier and Metering Supplier? a) They deliver make-to-order-products, b) They deliver similar products, c) They are competitors, d) They deliver to Photovoltaic System Manufacturer. *(d)*
- Which statement is correct for Private Household? a) Is the most important customer of the manufacturer, a) Is a competitor of Industry & Public Sector, c) Buys products from the manufacturer, d) Neither a, b, and c. *(c)*

## Appendix B

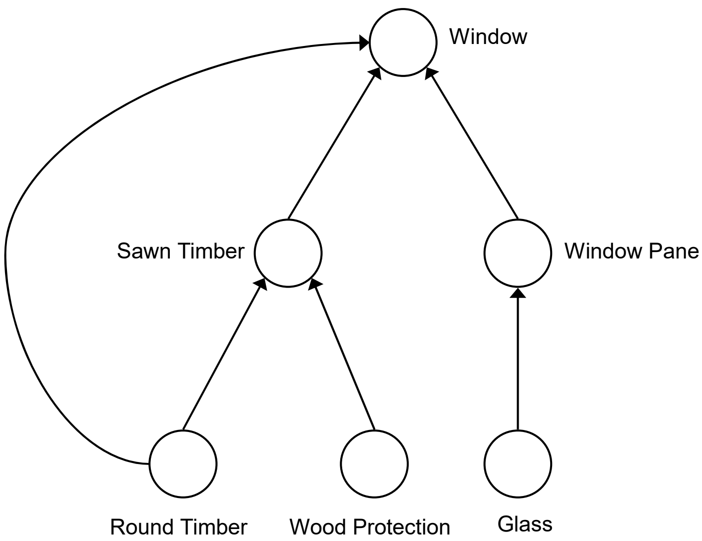
Domain A: Diagram



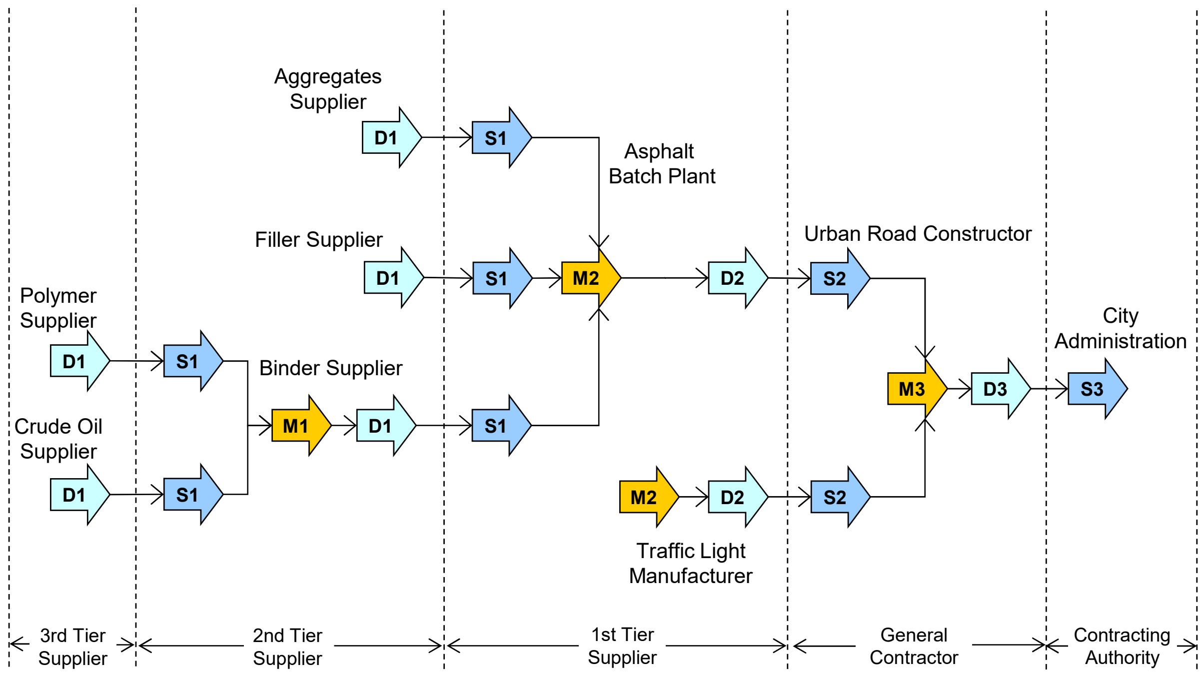

Domain A: Text

*A manufacturer produces windows and then sells them to a broad range of customers based on particular customer orders. However, no further information about these customers is available. The manufacturer buys round timber (available from stock), sawn timber (made specific to customer orders), and window panes (again, made specific to customer orders). The supplier of sawn timber buys round timber from the same company as the manufacturer. In addition, the supplier of sawn timber buys products that preserve wood to ensure a long life of wood (so called wood protection products). Another supplier produces window panes, which are made of glass. This component will be provided by a company taking the role of 2nd tier supplier.*

Domain A: Solution



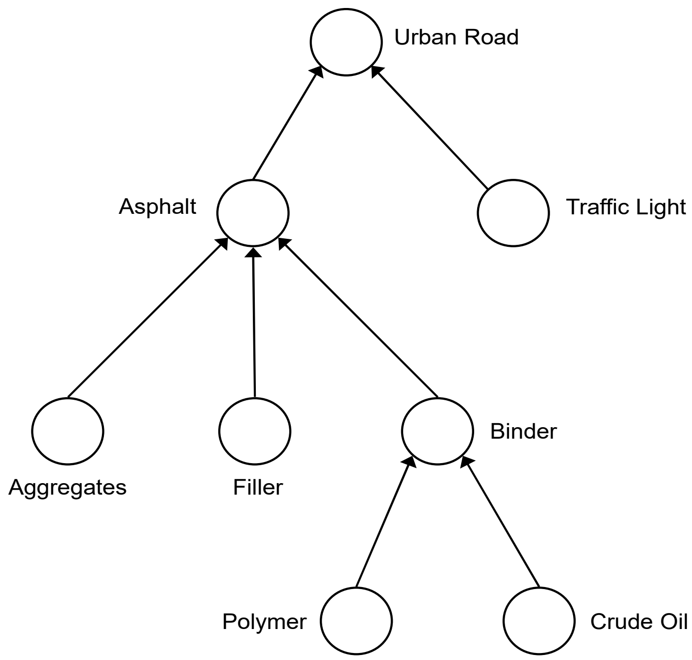

Domain B: Diagram




Domain B: Text

*The city administration wants to build a new urban road. For this purpose, an agreement with a general contractor will be settled. Engineers from the city and the contractor jointly develop the road specification and construction process. Afterwards, the contractor buys asphalt from an asphalt batch plant (1st tier supplier). While this plant produces asphalt specific to the road, it purchases three components that are available from stock: aggregates, filler, and binder from each one supplier (2nd tier). The binder supplier buys polymers and crude oil from each one supplier (3rd tier). Finally, the general contractor sources traffic lights from another company (made-to-order).*

Domain B: Solution




**Appendix C**

Perceived ease-of-use: (5-point agreement scale)

- Overall, I believe it was easy for me to understand what the {diagram | text} was trying to describe.
- Overall, the {diagram | text} was easy to use.
- Understanding the {diagram | text} was difficult. *(item reversed)*