

Towards Outcome-Based Regulatory Compliance in Aviation Security

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Abstract—Transport Canada is reviewing its Aviation Security regulations in a multi-year modernization process. As part of this review, consideration is given to transitioning regulations where appropriate from a prescriptive style to an outcome-based style. This raises new technical and cultural challenges related to how to measure compliance. This paper reports on a novel approach used to model regulations with the Goal-oriented Requirement Language, augmented with qualitative indicators. These models are used to guide the generation of questions for inspection activities, enable a flexible conversion of real-world data into goal satisfaction levels, and facilitate compliance analysis. A new propagation mechanism enables the evaluation of the compliance level of an organization. This outcome-based approach is expected to help get a more precise understanding of who complies with what, while highlighting opportunities for improving existing regulatory elements.

Keywords—aviation; compliance; Goal-oriented Requirement Language; indicators; security.

I. INTRODUCTION

Transport Canada develops policies, regulations and services designed to make the Canadian transportation system safe, efficient, affordable, integrated, and environmentally friendly. Its Aviation Security directorate's mandate is to safeguard the integrity and security of Canada's aviation transportation system through 1) awareness and education, 2) the establishment and implementation of policies, regulations, and standards, and 3) monitoring and enforcement [8].

Regional inspectors from the aviation security inspection program have a responsibility to promote compliance through awareness, education, and enforcement, in particular by: monitoring, inspecting, and enforcing compliance against legislative requirements; conducting inspections; conducting tests (e.g., of facilities and restricted areas); following-up to ensure deficiencies are corrected; and providing security advice and guidance to regulated communities [8].

Most of the legislative security requirements on airlines, airports, and other regulated parties are currently formulated as *prescriptive* policies and regulations. This means that:

- These regulations are about *how* things are to be done. Defining a prescriptive regime that applies equally well across a non-homogeneous group of regulated parties is challenging;
- Inspection activities assess compliance to specific regulations in a binary way (yes/no), which means it is hard to determine how close/far an organization is from being compliant, and how significant this is from a performance or effectiveness point of view.

In order to ease the compliance burden on regulated parties and address some of the above issues, Transport Canada is reviewing its aviation security regulations in a multi-year modernization process [9]. In particular, some of the new regulations are *outcome-based* and focus more on *what* should be achieved than on how to do things. Since regulated parties are not being told how to achieve desired outcomes, such regulations can help promote innovation and enterprises can find ways to comply while satisfying their own business objectives. This transition involves cultural and technical changes impacting policy makers, regulated parties, and inspectors who do the compliance assessments.

In this paper, we report on the exploration of a new approach where we model outcome-based regulations with the *Goal-oriented Requirement Language* (GRL), generate questionnaires for the regional inspection activities where some of the questions target compliance and performance with a qualitative scale (rather than a binary assessment as in prescriptive regulations), and input the information collected by the inspection activities back into the model for compliance analysis. To enable this process, we have extended GRL with *qualitative indicators* and appropriate evaluation algorithms.

The paper is organized as follows. Section II gives an overview of our goal-oriented approach, then compliance

modeling and analysis are introduced in Section III. Section IV presents lessons learned, followed by conclusions and future work in Section V. Note that, given confidentiality constraints and the sensitive nature of the application domain discussed here, all the illustrative examples are actually either very generic or artificial. However, the experience report is based on the use of real regulations and models.

II. APPROACH OVERVIEW

A. Goal Modeling for Compliance and Performance

Recent literature surveys have shown that goal-oriented languages are often used to model regulations and compliance [7], or enterprise performance [16]. Few approaches combine both, but several do for documenting *safety cases*, which provide arguments based on collected evidence that the safety objectives of a system are being met. The Goal Structuring Notation (GSN) community standard [12] helps construct safety goal models and link informal evidence, but the notation lacks a formal representation enabling automated analysis. Other goal languages such as *i** and KAOS are also used for safety compliance. Sabetzabeh *et al.* [15] notably propose Modus, an add-on to a commercial UML tool, to model KAOS goals, obstacles, and (probabilistic rather than quantitative) evidence, which can be analyzed through Monte Carlo simulations based on experts' opinions. The focus here is more on the agreement on evidence than on observable and quantifiable measures. Rifaut [14] proposes a method for modeling regulations and the arguments for claiming compliance where he uses GRL in a generic measurement model based on ISO/IEC 15504 [11]. Silveira *et al.* [18] also suggest a compliance governance dashboard, with key indicators used to measure the compliance level of processes, but they do not address the compliance level of organizations.

Shamsaei *et al.* showed that GRL supplemented with indicators [13] can be used to model regulations and organizational objectives, and to measure the compliance of these organizations and their processes against regulations [17]. This is relevant to the context of Transport Canada and its desire to provide a goal-oriented framework to enable decision-makers to model and evaluate the impact of decisions on outcomes in the aviation security system. GRL is also a good fit given this is an independent, international standard (as part of the *User Requirements Notation* [2][10]) that supports the concept of evaluation strategies as well as extension mechanisms for tailoring the language to particular domains. URN/GRL has also been selected in this project because local expertise on the language and on its free modeling and analysis tool, namely *jUCMNav* [3], is readily available.

B. Process Overview

Within Transport Canada, our team is working towards an *Operational Performance Framework* (OPF), whose purpose is (among others) to help develop performance-based standards, define measurable and traceable compliance objectives, and define and assess performance expectations.

In our work on the modeling of outcome-based regulations, we are exploring the process illustrated in Figure 1.

Starting from regulations in natural language, we first build (step 1) a generic GRL model that integrates a family of related regulations targeting different types of organizations (e.g., different classes of airports). Such a generic model is useful to minimize maintenance of smaller but highly overlapping models. These models use GRL concepts such as *actors* (⊖, e.g., an aerodrome operator) that include different types of intentional elements such as *softgoals* (⊖, e.g., for high-level outcomes like perimeter security), *goals* (⊖, e.g., display signs), and *indicators* (⊖, also known as KPIs – Key Performance Indicators, e.g., the number of signs that are not visible enough), as well as various decomposition and weighted contribution links connecting these elements.

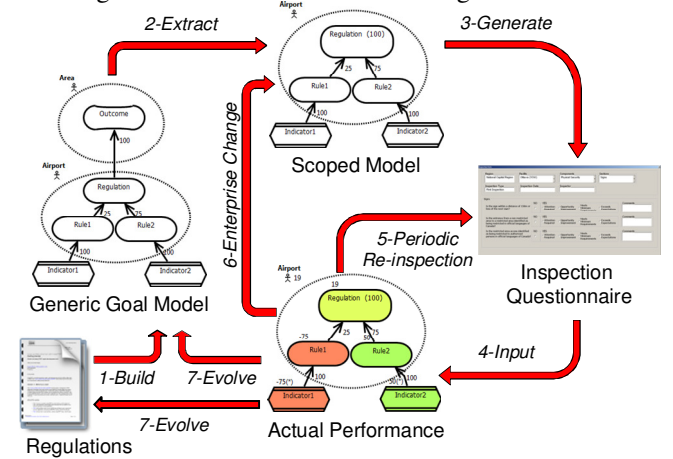


Figure 1. Process for Managing Outcome-Based Regulations

From the generic model, we extract (step 2) a GRL model scoped to the enterprise (e.g., airport) to be inspected. This scoping also guides the automatic generation of questionnaires for the inspection activities (step 3), where individual questions come from a database. These questionnaires are documents that are to be filled during the inspection activities. This is not unlike the model-driven approach to safety assessment questionnaire construction of Falessi *et al.* [6], but in our case decisions about how to assess compliance are already present in the goal model, in the form of indicators.

The information so collected is fed to the indicators of the scoped GRL model (step 4), which then uses GRL evaluation algorithms [1][3] to assess the compliance and performance of the enterprise assisted with colour-coded feedback. The questionnaire answers and performance results, once aggregated, can be used to determine whether the enterprise (or part thereof) needs to be re-inspected sooner than usual (step 5), and/or whether the enterprise should improve its processes and ways of doing business (step 6). These aggregated results may also have an impact on the regulations and its generic GRL model (step 7). For example, across many enterprises, one security requirement might be more onerous than needed to be effective. Another interesting case is when enterprises are compliant with a requirement, and yet they consider it to be insufficient performance-wise. This can trigger the evolution of regulations in ways that are currently difficult to do with prescriptive (yes/no) regulations.

Questions:					
Are there signs in all required languages?	No			Yes	
	No (0)	Attention Required (1)	Opportunity to Improve (2)	Meets Minimum (3)	Exceeds (4)
Are the signs installed within a distance less than or equal to X meters?	Not even most signs are installed within X meters.	Most signs are installed within X meters.	With the exception of a few signs, all signs are installed within X meters.	All signs are installed within X meters.	Meets minimum plus some signs are installed even closer than X meters.
Are the signs visible?	The signs are not visible.	The signs are obstructed most of the time (e.g., behind a corner).	The signs are not obstructed and visible at all times except from a few angles.	The signs are not obstructed and visible at all times from all angles.	Meets minimum plus the signs cannot be obstructed even temporarily.

Figure 2. Sample (Artificial) Questions with Binary and Qualitative Scales for an Outcome-Based Regulation

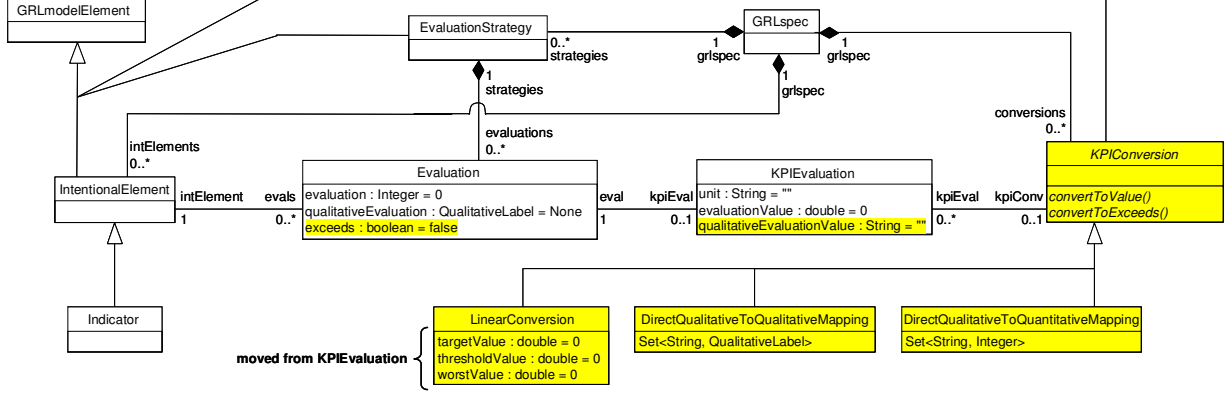


Figure 3. GRL Metamodel Extensions for Qualitative Indicators

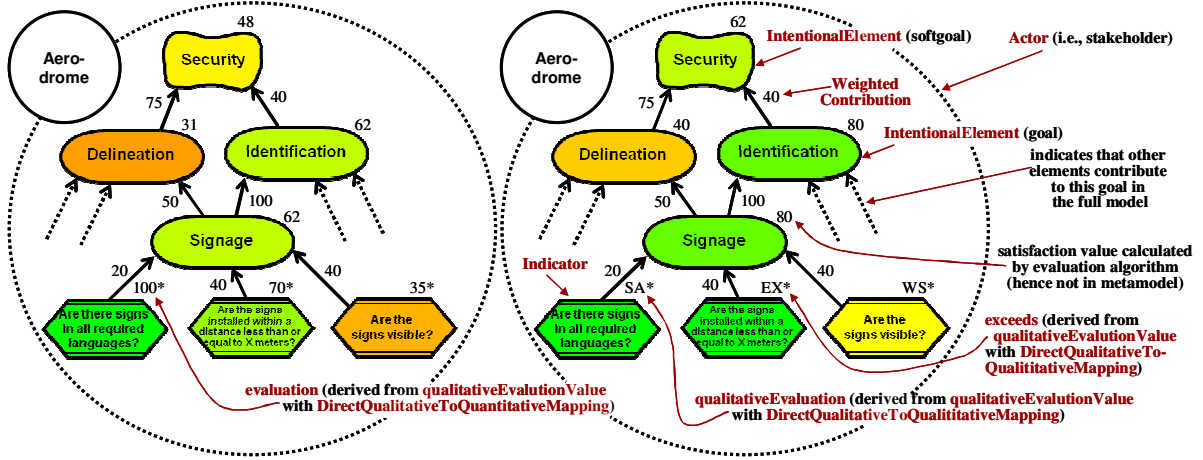


Figure 4. Two Evaluations of a Sample (Artificial) GRL Model – Reduced Complexity

III. COMPLIANCE MODELING AND ANALYSIS

A. Goal Modeling and Question Generation

In our experiment with OPF, a generic GRL model was built iteratively with the teams involved in the review of regulations. Expected outcomes for each of the regulations were defined by the teams and mapped to a set of qualitative indicators to aid inspection and compliance assessment activities.

As an artificial, much simplified but illustrative example (we have models about a hundred times larger than the one discussed here), let us consider the issue of signage at a regulated party.

In the prescriptive regulation approach, the regulated party must have all signs in all required languages and all signs at the most X meters from each other. An inspector must indicate non-compliance regardless of whether two signs or many more signs are more than X meters from each other. It is reasonably obvious that two non-compliant signs

should not be treated the same way as many such signs, leading to the need to measure degrees of non-compliance.

Questions with degrees of non-compliance use five qualitative compliance levels: “No (0)”, “Attention Required (1)”, “Opportunity to Improve (2)”, “Meets Minimum (3)”, and “Exceeds (4)”. The first three levels indicate non-compliance at different levels. The fourth level means compliance, and the fifth level exceeds compliance. Such a scheme enables the regulator to assess trends, identifying those regulations which are routinely exceeded by the majority of the regulated parties and may hence be candidates for change.

To assess the degree of non-compliance, it was necessary to clearly define the goal of a regulation. In the case of signage, the goal is to alert people to a restricted area. This, however, means that a sign should not only exist every X meters but also be visible. If the sign is not visible, the goal of the regulation is not met and therefore the sign is not effective.

In our first attempt at modeling the regulation with GRL, we modeled the existing material as provided, i.e., often compound questions were used to assess compliance of the regulated party with a specific regulation. However, the granularity of the initial GRL model was not sufficient to obtain accurate compliance results. Reorganization resulted in a series of questions about the regulation as shown for signage in Figure 2. It turned out that each question belonged to one of the following three categories: existence-type, implementation-type, and effectiveness-type questions.

This new style of questionnaire allows inspection activities to assess how well a regulated party complies with the regulation. For example, “Are there signs in all required languages?” is an existence-type question that requires a simple Yes/No answer. “Are the signs installed within a distance less than or equal to X meters?” is an implementation-type question (i.e., how well is the regulation implemented). For such a question, limiting the answer to Yes or No is not appropriate in the context of an outcome-based approach. Instead, the five compliance levels are used for this question. The third question “Are the signs clearly visible?” is about effectiveness (i.e., is the goal of the regulation achieved) and hence also uses the five compliance levels.

Further thought was put into how to ensure consistency across several inspections in a way that eases the burden and allows consistent analysis of the collected data across the whole country. Hence, in addition to consistent compliance levels, descriptions were added for each possible answer of a question to aid in making a choice. Sample descriptions for the issue of signage can be found in Figure 2.

The responses to the questionnaire are used to populate indicator values in the reorganized GRL model, which now accurately assesses the outcomes, the degree of non-compliance, and the exact source of non-compliance, and gives regulated parties alternatives for compliance with a regulation. Furthermore, the GRL model gives an assessment of overall effectiveness in addition to compliance.

B. GRL Analysis Enhanced with Qualitative Indicators

An extract of the GRL metamodel [10] is presented in Figure 3. In GRL, a goal model can be evaluated with the help of an *EvaluationStrategy*, which defines the initial val-

ues for each goal model element (i.e., *IntentionalElement*). The initial value can be quantitative or qualitative (evaluation or qualitativeEvaluation, respectively). These values are then propagated, using evaluation algorithms [1], to the other model elements through their weighted links.

For a KPI (i.e., Indicator), an initial value is based on a conversion of a real-world KPI evaluationValue. GRL and jUCMNav support a single, basic conversion mechanism [13]. It converts a *quantitative*, real-world value by mapping linearly the worst, threshold, and target real-world values to quantitative evaluations from -100 to +100.

In the context of modeling outcome-based regulations (MOBR), the current support for KPIs in GRL needs to be expanded to *qualitative* KPI evaluation values that support exceeding expectations. New additions to the GRL metamodel are highlighted in Figure 3. The real-world KPI qualitativeEvaluationValue is added to KPIEvaluation. A new GRLmodelElement called KPIConversion is also added. KPIConversion is an abstract class that provides the framework to specify explicitly how a real-world value in KPIEvaluation is converted/mapped to a quantitative or qualitative value in Evaluation as well as the new exceeds value.

The abstract KPIConversion class defines that any subclass must provide a *convertToValue()* method that takes a real-world value and converts it into either a quantitative or qualitative evaluation value. This provides greater flexibility than the existing approach. A subclass of KPIConversion may define any attributes as needed to perform the conversion as shown in Figure 3. For example, the *LinearConversion* subclass handles the existing, basic conversion, while the *DirectQualitativeToQualitativeMapping* subclass and the *DirectQualitativeToQuantitativeMapping* subclass are examples of new conversions needed in the MOBR context. Note that a different conversion may be used for a different evaluation strategy or for a different KPI in the same evaluation strategy. Similarly, the method *convertToExceeds()* must be implemented by all subclasses of KPIConversion.

Finally, the evaluation of a goal model now has to take into account that a KPI may exceed expectations and that the evaluation value of a KPI may be qualitative instead of quantitative. The boolean *exceeds* attribute is propagated separately from the evaluation values. In an AND-decomposition context, a parent node exceeds expectations only if all its child nodes also exceed expectations while in an OR-decomposition context, a parent node exceeds expectations only if at least one child node also exceeds expectations.

If a KPI has a qualitative evaluation value, then the GRL evaluation mechanism will try to propagate qualitative values for as long as possible using the standard evaluation mechanism for qualitative values [1][10]. The qualitative value is transformed into a quantitative value using the standard rules of the GRL evaluation mechanisms for mappings between qualitative and quantitative values, only when the qualitative value needs to be combined with a quantitative value. If propagation of qualitative KPI values is not desired, then the selected KPI conversion should immediately result in a quantitative evaluation value.

An artificial but illustrative example of a GRL model is shown in Figure 4. The complexity of the model is reduced

to highlight the typical structure of such GRL models. KPIs are found at the bottom of the model, represent the questions, and contribute to a regulation goal (e.g., Signage). The regulation itself contributes to higher level goals such as Delineation, Identification, and finally Security. Two evaluations are shown, where assessment results have been fed into the KPIs and propagated upwards. The example on the left shows the case where the answers “Yes”, “Opportunity to Improve (2)”, and “Attention Required (1)” to the three questions have been converted into the quantitative values 100, 70, and 35, respectively. In the example on the right, the answers “Yes”, “Exceeds (4)”, and “Attention Required (1)” to the three questions have been converted into the qualitative labels Satisfied (SA), Satisfied plus the Exceeds flag (EX), and Weakly Satisfied (WS), respectively. Note that the Exceeds flag is not propagated upwards as only one of the three KPIs contributing to the Signage goal exceeds expectations.

IV. LESSONS LEARNED

Improved accuracy – Two reasons contribute to accuracy. First, the act of building the model from existing regulations formulates the intent of the regulations more precisely, highlighting omissions and ambiguities, which can then be resolved. Second, the model is the basis of derived questionnaires, which alleviates consistency problems.

Modeling is essential – In an outcome-based context, a model much more adequately captures the interactions of potential solutions than natural language regulations. Furthermore, the model is an essential tool in discovering which measurements are needed to ensure compliance. This raises questions whether the currently implemented process for writing regulations can be improved in an outcome-based context, which we will investigate in future work.

Exceeding expectations – In a goal-oriented reasoning environment, there is always a maximum evaluation value (100 in our case). In a compliance assessment, the target for being compliant must be the maximum value, while other values must denote degrees of non-compliance. If the target for compliance were less than the maximum value, something that exceeds expectations could offset a deficit somewhere else. However, this is not desired as it does not accurately reflect how compliance must be assessed in our context. Nevertheless, inspection activities may want to indicate that compliance exceeds expectations for a specific regulation. Hence, this is modeled as an orthogonal concern, i.e., if expectations are exceeded, then the exceeds flag is set in addition to the maximum evaluation value.

Greater flexibility in handling real-world values – OPF places requirements on goal-oriented modeling that requires changes to the GRL metamodel, introducing greater flexibility when converting real-world values into GRL evaluation values (i.e., KPIConversion). Inspection activities often use a qualitative scale to rate the degree of compliance to regulations. Such discrete inputs, however, do not lend themselves to the existing, basic, linear conversion of quantitative real-world values into GRL evaluation values. Furthermore, the conversion may not always follow the same rules for all considered regulations or for all types of questions. Hence, support for various conversions from a qualita-

tive or quantitative real-world value to a qualitative or quantitative GRL evaluation value is desired, allowing conversions to be selectively applied to a set of KPIs. An integral step in the modeling of regulation selects a conversion for each KPI in the model, thus defining the type of question and consequently the allowed answers. Two types of questions are shown in the example in Figure 2. The first type is a Yes/No question and the required conversion into quantitative/qualitative GRL evaluation values is 100/Satisfied for Yes and 0/None for No. The second type of question uses a five-point Likert scale. The desired conversion in this case is 0/None for “No (0)”, 35/WeaklySatisfied for “Attention Required (1)”, 70/WeaklySatisfied for “Opportunity to Improve (2)”, 100/Satisfied for “Meets Minimum (3)”, and 100/Satisfied for “Exceeds (4)”. This approach strikes a good balance between the existing solution with a single conversion and a completely open solution where conversions could be defined by arbitrary functions. The proposed approach presents a set of useful and usable conversions that can be easily selected by a modeler.

Cultural Change – While there were some technical challenges, a main lesson learned is that introducing a model-based requirement engineering process to regulation drafting requires cultural change from all involved stakeholders. Success of the OPF initiative will require the buy-in from all the parties. The fact that an international, independent standard is used helps in getting buy-in from government parties, as does the fact that local expertise in the application of the standard is readily available.

Iterative knowledge transfer – A significant amount of time was spent initially discovering requirements for the *assessment and data gathering tool* from the teams. Throughout the interaction, differences had to be resolved iteratively and the GRL model had to be validated iteratively against the documented regulations and questions. The process of generating compliance questions using goal-oriented modeling with the collaboration of the regulatory review team and the OPF team was slow at the beginning, because of the steep learning curve for both groups. However, as the OPF team familiarized themselves with aerodrome regulations and the regulatory review team got familiar with using goal models for reasoning about regulations and policies, work progressed much more efficiently.

Tool Support – The *assessment and data gathering tool* was developed and has already been used for training for the inspection activities. Valuable feedback from the training sessions has enabled improvements to the tool. The goal is to have the tool available for use with the new outcome-based regulations in the future.

Availability of Teaching Material – Teaching material is important and needs to be tailored to the domain of aerodrome regulations. The OPF team is in the process of developing tutorials to disseminate the goal-based approach internally.

Difficulties with Terminology – One observation made by multiple stakeholders is that the goal modeling terminology (e.g., softgoals and actors) is not really evocative in an aviation security context. We are considering renaming many of the GRL concepts and adapting the jUCMNav tool

accordingly to better align these concepts with those used in that specific domain, hence contributing to the acceptability and accessibility of the overall framework.

Intuitive Evaluation Values – In MOBR, inspection activities rate the existence or non-existence of elements that contribute to compliance and to what degree such elements are implemented. A GRL scale of $[0, +100]$ is more intuitive in this context than the standard GRL scale of $[-100, +100]$, as 0 easily relates to not implemented at all and 100 to full compliance. This also avoids the situation where a negative evaluation value and a negative contribution weight results in a positive contribution, which turned out to be very counter-intuitive for domain experts in this project.

Note also that the process of generating questions and indicators from goals is akin to the Goal-Question-Metrics (GQM) approach of Basili *et al.* [4]. Some of their guidelines might be applicable in a regulation context as well. In addition, Cyra and Górski [5] propose a way of combining a decision scale (similar to the qualitative scale used in OPF) with a *confidence* scale. OPF and GRL could be extended with this concept to ensure that uncertainty in the data collected through questionnaires can be taken into consideration and reasoned about during compliance analysis.

V. CONCLUSIONS AND FUTURE WORK

A transition to outcome-based regulations with well-defined, measureable performance goals requires cultural change from all stakeholders. Regulations need to be written in a different way, regulated parties have more freedom in choosing how to achieve compliance to regulations, and inspection activities have to adapt to new types of questions.

We present a framework that allows outcome-based regulations to be modeled with GRL goal models and questions for compliance assessments to be generated. This required changes to the GRL metamodel to enable more flexibility when converting real-world data collected during inspections to GRL model values and to support more advanced reasoning about exceeded expectations. We have also provided or enhanced tools for question generation and GRL modeling.

In addition to future work items already mentioned, the outcome-based approach will be deployed to a larger set of regulations. A key challenge in this endeavour is to ensure that all involved stakeholders have adapted to the new mindset, making training and tool support important. Further tool support for goal modeling is also required for feeding data collected by inspections back to the GRL model.

Furthermore, the intention is to apply the outcome-based approach to existing regulations that have not been written with an outcome-based approach in mind. This will require new qualitative scales (and conversions) to be used for inspection activities when assessing compliance of a regulated party. Generality in other domains also needs to be assessed.

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