Regulation-Based Dimensional Modeling for Regulatory Intelligence

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***Abstract*—Regulations are a source of evolving requirements for products and organizations. As regulatory institutions shift towards outcome-based regulations, they increasingly adopt legislation performance modeling, at the basis of regulatory intelligence. In this context, performance modeling refers to the measuring of important business aspects in a coordinated manner and the use of these measurements for improved decision making. Considering that in many cases regulatory texts already exist, it is necessary to build a performance model based on existing regulations that may be still prescriptive rather than outcome-based. The process of turning the underlying textual legislation into a formal performance model that can be assessed by Business Intelligence (BI) tools is complicated due to organizational, cultural, and technological reasons. In this paper, we present a methodology from a technical perspective that enables regulatory institutions to reason about regulations and compliance with regulations as new dimensions. We demonstrate the methodology using traffic law as an example regulation, jUCMNav for performance modeling, and IBM Cognos for BI reporting.**

***Index Terms*—goals, indicators, business intelligence, regulations, compliance, performance modeling, Goal-oriented Requirement Language, User Requirements Notation.**

I. Introduction

In recent years, *Regulatory Intelligence* (RI) has started attracting substantial attention. RI is often defined from the viewpoint of regulated parties as the act of gathering and analyzing regulatory information for impact or changes in laws, regulations, directives, and guidance documents, in order to support decision making. In this paper, we extend this common view on RI to include that of *regulators* in charge of evolving their regulatory requirements based on feedback from regulated parties and compliance reports.

Regulations are an important source of requirements on organizations and their systems and products, even when they are not directly requirements themselves. Assessing compliance with regulations is key when enforcing such regulations. Furthermore, it is difficult to enhance regulations if compliance is not being measured consistently across regulated parties. For example, regulations that are not measurable and organizations without the ability to capture appropriate measurements make it difficult to evolve regulations. This may lead to situations where an organization complies with irrelevant or out-of-date regulations or is in non-compliance with regulations even though the organization performs regulated tasks effectively.

In some domains, regulators have started to focus on the intention of regulations rather than following a prescriptive regulatory compliance approach (which imposes on regulated parties specific actions to achieve compliance). An approach based on the intention of a regulation, commonly called an *outcome-based* approach, is centered on the goals a regulation attempts to achieve rather than prescribing how the goal should be achieved. This gives the regulated parties the freedom to choose operations and strategies that fit their specific context. Hence, regulators must ensure that solutions chosen by regulated parties effectively satisfy the intention of the regulations, e.g., by measuring whether the outcome is satisfactory, which typically entails the adoption of legislation performance modeling.

Business Intelligence (BI) provides means for analyzing large quantities of data and enables stakeholders of organizations to make informed decisions. BI can be seen as a technological enabler for many RI activities. Typically, data analysis in BI tools takes place along *dimensions* [22]. Dimensions represent important axes (e.g., time, location, departments, products) for which stakeholders would like to measure the changes in performance metrics. The nature of these dimensions fits well in a database environment where the structure of entities is well formulated. For example, in the context of a company, a typical modern BI application enables on-the-fly dashboards that facilitate rapid analysis of a company's performance by aggregating data in summary reports and offering the ability to drill-down to very detailed reports across the previously mentioned dimensions. Examples of these dimensions include time (from years to quarters to months), geographic location (from countries to regions to cities), organizational structures (from companies to departments to work teams or even individuals), and products (from product categories to individual products).

Even though an important responsibility of regulatory institutions is the monitoring of compliance of regulated parties, regulations have not been utilized as a dimension for BI reporting for many reasons. First, regulations are written with little regard for strict structures required by database management systems. Second, regulations sometimes overlap, may be subjective, and may be written in a prescriptive or outcome-based way. Finally, regulations are associated with other, typically implicit, attributes such as importance, means of assessments and enforcements, violation severity, and so forth. Such properties make it difficult to organize regulations in well-structured database schemas, let alone being used as a dimension within the BI domain.

To effectively use regulations as a dimension, regulations must be well-structured and measurable, and *relative* importance must be explicitly defined. As an example, consider a driver who has 15 parking violations and another driver who has run a red light twice. If one wants to evaluate both drivers' compliance with driving regulations, the evaluation has to take into consideration the number of violations, but more importantly, the relative weight of the regulations that have been violated. Clearly in this example, the red light regulation has more weight than the parking regulation and, hence, the second driver's compliance with driving regulations is worse than the first driver's.

The implication of the capability to reason about regulations and compliance in such a manner is significant. First, better understanding of compliance is achieved because compliance is directly related to the originating regulatory text. Second, regulations can themselves be analyzed and eventually improved more effectively. In other words, rather than only reason about the regulated entities or compliance, it becomes possible to also reason about effectiveness of regulations and potentially evolve them to, in turn, enhance compliance.

The main contribution of this paper is a tool-supported methodology that guides a regulatory institution through the process of implementing support for analysis of outcome-based regulations with the help of legislation performance models. This methodology combines regulations with associated compliance data and makes them ready for analysis as a dimension in modern BI tools. While we acknowledge that there are important social, organizational, and cultural factors [5] involved in introducing outcome-based reasoning of regulations, the presented methodology focuses on the technical perspective. It is assumed that the regulatory institution is committed to (i) introducing an outcome-based approach for regulation writing and (ii) instituting compliance measurement programs that are aligned with the outcome-based approach.

The steps in the methodology can be summarized as follows. We convert natural language regulatory text to a structured text where parent-child and composition relationships are explicitly identified. Key Performance Indicator (KPI) definitions are identified for regulations, and the regulations and KPIs are assigned values of relative importance. Second, we automatically construct a goal model using the augmented, structured regulatory text. Third, we feed performance measurements collected from real-life operations to the goal model. Fourth, given the performance measurements, we evaluate the goal model to calculate compliance values for all regulations. At that point, these compliance values are ready for consumption in a database system. Finally, BI techniques are deployed to analyze compliance with regulations. In addition to the general steps of the methodology, we also present an implementation of the steps with the help of the goal modeling tool jUCMNav [13] and the BI tool IBM Cognos [10].

The paper is organized as follows. First, we give background information on important aspects of goal modeling for compliance in Section II. In Section III, an overview of the regulation-based dimensional modeling methodology for regulatory intelligence is presented. Section IV introduces our running example based on the Ontario Highway Traffic Act[1]. Sections V to VIII present the steps of our methodology in more detail, i.e., the conversion of natural language regulatory text to a structured text, the generation of a regulation goal model from the structured text, the evaluation of the regulation goal model, and the import of the regulations and evaluation results into a database for analysis using traditional BI tools. Section IX reports on related work, while Section X concludes the paper and discusses future work.

II. BACKGROUND

This work involves the modeling of legislation performance using goal models of regulations to enable BI analysis of compliance. In this section, we briefly present background on the underlying goal modeling notation, i.e., the User Requirements Notation (URN), as well as the concept of Key Performance Indicators (KPIs), and finally regulations modeling.

A. Goal Modeling Notation and Measurements

Goal modeling plays a key role in requirements engineering activities. Goal models capture the intentions of stakeholders and their business objectives and explicitly define the different approaches to achieve such intentions and objectives. In addition, goal modeling typically captures the weighted contributions of goal model elements on each other, allowing the exploration of positive and negative implications of business and technical decisions on high-level stakeholder and system goals.

The Goal-oriented Requirement Language (GRL) is part of URN [1][2], an International Telecommunication Union standard [11] for requirements engineering activities. URN goal models include (i) actors, or stakeholders, (ii) intentions captured with goals (⬭) and their AND/OR/XOR-decomposition structure, (iii) weighted contributions (→), (iv) dependencies, and (v) Key Performance Indicators (KPIs) (⬡).

KPIs are elements that enable the integration of real-world measurements into goal models. A KPI converts a real-world value (e.g., $45,000) to a GRL satisfaction value according to a user-defined conversion function compliant with the structure imposed by the URN standard. Several types of conversion functions are available for URN. A satisfaction value of a goal or a KPI indicates how close an element is to being satisfied. Satisfaction values typically range from –100 (not satisfied at

[1] http://www.e-laws.gov.on.ca/html/statutes/english/elaws_statutes_90h08_e.htm

all) to 100 (fully satisfied). URN's support for KPIs and for evaluation strategies, together with comprehensive tool support available through jUCMNav [13], are three major reasons for using URN as the goal modeling notation of our choice in this context instead of one of many other established goal modeling approaches such as *i** [23], KAOS [21], and Tropos [6].

A core concept in goal modeling is the evaluation of goals, i.e., the intentions of stakeholders. This is commonly achieved by providing the goal model with initial real-world values for the KPIs as they are typically found at the bottom of the goal model tree/graph. These values are first converted into GRL satisfaction values and then used along with weighted contributions and the decomposition structure of the goal model to calculate satisfaction values for all goal model elements (by propagating satisfaction values from the bottom up towards the top of the goal model). In this context, URN allows the definition of a GRL strategy, i.e., a set of initial real-world values for KPIs.

In this project, we use jUCMNav [3][13], an Eclipse-based, open source URN modeling and analysis tool that supports the creation of large goal models and their evaluation based on GRL strategies. With jUCMNav, one can initialize a set of real-world values for KPIs with the help of a GRL strategy, either manually or through external data sources.

B. Goal Modeling of Legislation and Regulation

In previous work, we report on how to model outcome-based regulations with URN/GRL goal models [5][20], which requires changes to the URN metamodel, a more advanced reasoning mechanism [17], and improved tool support [3]. The suggested changes are now supported by the latest version of the URN standard [11].

Guidelines for deriving a goal model from regulatory text are available [18]. In this modeling approach, we model regulations with goals to ensure that the complex relationships of different regulations in an outcome-based context can be captured and reasoned with appropriately. Furthermore, we derive KPIs from standardized questions inspectors ask to assess compliance, convert the answers to the questions into satisfaction values of KPIs, and, hence, use the answers as input to goal model evaluation. In this context, GRL satisfaction values of KPIs range from 0 to 100 and signify the level of compliance of a specific regulation associated with the KPI (i.e., 100 = compliant, 0..99 = level of non-compliance), allowing for a more nuanced approach to compliance assessment that goes beyond simple yes/no categorizations. This question/answer-based approach is widely applicable as many institutions have in place a process to measure compliance involving questionnaires. As an example, consider an insurance company. An assessor or inspector that arrives at a scene comes prepared with a set of questions whose answers inform the assessor whether this is a valid insurance claim or not, i.e., whether the insured party complied with all rules (or met all requirements).

An inspector may even indicate that a regulated party exceeds the expectations with respect to compliance with a regulation. In this case, the inspector may want to note that fact to provide further information that can be used to evolve regulations (e.g., are regulations where expectations are routinely exceeded still necessary or well adapted?). The modeling approach presented in [20] as well as the URN standard support the flagging of KPIs as "exceeded", which is then taken into account by the reasoning mechanisms.

III. Overview of the Methodology

This work was initiated in collaborative projects with a national regulator and with a financial institution, whose names cannot be disclosed due to the classified nature of the projects. However, and without loss of generality, we describe the methodology illustrated in Fig. 1 without referring to specific regulations or entities.

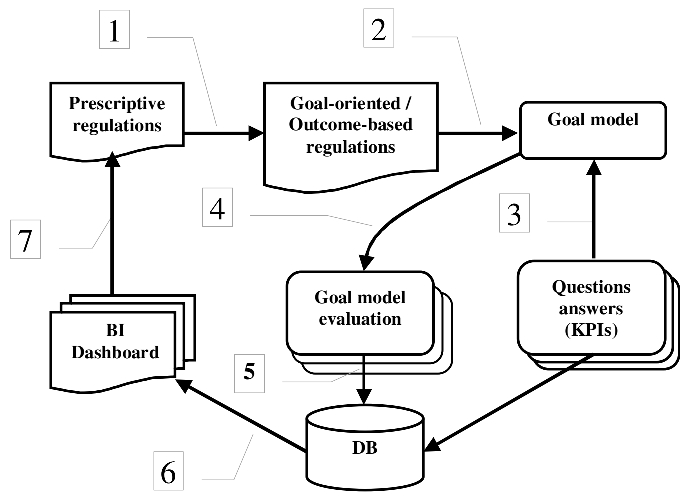

Fig. 1. Overview of Regulatory Intelligence Methodology

Starting from prescriptive regulatory text, in step 1, domain experts (e.g., lawyers, policy analysts, inspectors, and operations specialists) restructure regulations to make them outcome-based, i.e., goals are explicitly defined, the relative importance of regulations is clearly captured, and questions for inspectors are linked to corresponding regulations. This ensures that the regulations can result in a measurable outcome.

In step 2, the jUCMNav tool, with minimal pre-processing, imports the structured regulations including the questions and generates a goal model with KPIs. Note that relative importance and questions are not part of the regulatory text but are rather captured because they are part of the goal model and used by that model for analysis.

In step 3, we collect the answers to the questionnaires used by inspectors and feed them into the KPIs of the goal model with the help of GRL strategies. The goal modeling tool then converts the real-world values of the KPIs (i.e., the answers) into GRL satisfaction values and, in step 4, runs the evaluation of the goal model based on the defined GRL strategy. This step calculates a satisfaction value for each of the goals and KPIs in the goal model, yielding a detailed assessment of compliance.

Step 5 imports this data into the database system eventually accessed by the BI tool. Steps 3 to 5 have to be repeated for every set of real-world KPI values, i.e., each filled out questionnaire or inspection sheet. For example, if compliance is being monitored every quarter, then to generate a one-year dataset, we have to run evaluations for the four quarters based on the answers to the quarterly questionnaire.

In step 6, we are able to bring regulations under the analysis of traditional BI techniques by designing dashboards and reports that are regulations-aware. Traditionally, dashboards that reflect compliance only are developed. But using this methodology, a regulatory institution can also *reason about the regulations themselves* (step 7). Potentially, regulations can be improved to enhance compliance, or rewritten when needed. Areas where compliance is consistently high for example may warrant raising the bar.

While our previous work addresses individual building blocks of the proposed methodology (i.e., what the structure of the goal model should look like [18] and the general idea of integrating answers of questionnaires as KPIs in the goal model), it does not explain how to establish an end-to-end methodology and does not discuss an instantiation of said methodology that provides semi-automatic support for the performance modeling of regulations.

IV. MOTIVATING EXAMPLE

To demonstrate the methodology proposed in this paper, we use an example based on the Ontario Highway Traffic Act – Part X: Rules of the Road. An excerpt of the regulations from this act is shown in TABLE I. While the regulations are simplified for didactic purposes, they still allow the steps of the methodology introduced in Section III to be analyzed realistically.

The presented driving regulations consist of a mix of prescriptive and outcome-based regulations. For example, 134.(1) states why a police officer may have to direct traffic. This is outcome-based since the objective of the regulation is explicit, i.e., safety related issues such as preventing injury and permitting proper emergency actions.

On the other hand, the following regulations, i.e., 134.(2-4), mandate what a police officer or person is allowed and is not allowed to do. These regulations are concerned with actions, and not the outcome. For example, the intention of regulation 134.(4) is that emergencies where the safety of the general public is concerned may override highway closures. However, the prescriptive nature of the regulation explicitly addresses some situations but not all situations that could arise. For example, the regulation does not allow a civilian to use a closed highway for other emergencies.

Similarly, regulations 140.(1)(b) and 140.(4) are more outcome-based while the other regulations numbered 140 and 144 are certainly prescriptive. Again, ensuring safety is the overarching intention of the regulations. However, situations such as a pedestrian crossing a road when a solid "don't walk" signal is showing violates regulation 144.(27) even though it is safe to do so when there is no traffic and clear visibility.

Regulatory text is typically long and follows a loose structure. Written mostly by lawyers, such text is often complex and relationships among regulations are not always clear. In addition, the text requires subjective judgments and intentions are implicit, making it difficult to measure whether the desired outcome is achieved. Domain experts must contribute to the conversion of prescriptive regulations to outcome-based regulations.

TABLE I. EXCERPT FROM ONTARIO HIGHWAY TRAFFIC ACT

ID	Regulatory Text
134.(1)	A police officer may direct traffic according to her discretion, and every person shall obey her directions, when she considers it reasonably necessary,
134.(1)(a)	to prevent injury or damage to persons or property; or
134.(1)(b)	to permit proper action in an emergency.
134.(2)	For the purposes of subsection (1), a police officer may close a highway to vehicles by placing traffic control devices.
134.(3)	Where traffic control devices have been placed under subsection (2), no person shall operate a vehicle on the closed highway in intentional disobedience of the traffic control devices.
134.(4)	Subsection (3) does not apply to the driver of a road service vehicle, an ambulance, a fire department vehicle, a public utility emergency vehicle or a police department vehicle.
140.(1)	The driver of a vehicle shall yield the right of way to a pedestrian by slowing down or stopping if necessary, when the pedestrian crossing a roadway within a pedestrian crossover,
140.(1)(a)	is upon the half of the roadway upon which the vehicle is travelling; or
140.(1)(b)	is upon half of the roadway and is approaching the other half of the roadway on which the vehicle is approaching so closely to the pedestrian crossover as to endanger her.
140.(4)	No pedestrian shall leave the place of safety at a pedestrian crossover and move into the path of a vehicle that is so close that it is impracticable for the driver of the vehicle to yield the right of way.
144.(5)	A driver who is directed by a traffic control signal erected at an intersection to stop his or her vehicle shall stop,
144.(5)(a)	at the sign or roadway marking indicating where the stop is to be made; or
144.(5)(b)	if there is no sign or marking, immediately before entering the nearest crosswalk.
144.(7)	When under this section a driver is permitted to proceed, the driver shall yield the right of way to pedestrians lawfully within a crosswalk.
144.(22)	Where portions of a roadway are marked for pedestrian use, no pedestrian shall cross the roadway except within a portion so marked.
144.(27)	No pedestrian approaching pedestrian control signals and facing a solid or flashing "don't walk" indication shall enter the roadway.

Step 1 in the presented methodology addresses such issues. Regulation 134.(4) hence may be rephrased to "Subsection (3) does not apply to a driver of a vehicle requiring use of the closed highway in an emergency situation.", while regulations 144.(22) and 144.(27) may be replaced by "No pedestrian shall cross or attempt to cross a roadway in an unsafe manner.". These changes are made based on case-by-case decisions and rely heavily on domain experts.

Furthermore, Step 1 involves rating the regulations according to their *relative* importance and ensuring that the outcome can be measured by providing metrics that should be captured. Prioritization is a prerequisite to having meaningful compliance values as not all regulations are of equal importance and not all captured metrics measure compliance equally. Consider the example from the introduction. A red light violation should be given higher importance compared to parking violation. This relative importance is captured in the goal model as relative weights.

In our work, we had to rely on domain experts (lawyers and operations experts in the domain) to assign relative weights to regulations and metrics. In the case of the example introduced in this section, all regulations are important in terms of ensuring the safety of the general public, but one could argue that regulations about pedestrian crossings are slightly more important than regulations about highway closures. Hence, the relative importance value for the former regulations is 11 while the one for the latter regulations is 10 (i.e., slightly less, by ~9%). Typical means for determining relative importance are Analytic Hierarchy Process (AHP), the Delphi method, or simply group consensus, allowing multiple experts to agree with the results. Furthermore, the relative weights derived by theses methods may be revisited after having been validated by performing a number of assessments of regulated parties. Given the results of these assessments, the chosen relative weights may be refined to better reflect the real-world measurements.

Metrics (called KPIs in the goal modeling context) that help capture whether a driver or pedestrian complies with the intention of the regulations are shown in TABLE II. KPIs help clarify and concretize the intentions in complex and domain-specific prescriptive regulations, where the objective or outcome behind the regulations may not always be clear.

Such KPIs can help us objectively measure how safe the use of a closed highway and the crossing of an intersection are. Typically, questions are derived from the KPIs listed in the table that are used by inspectors to assess compliance with regulations for a specific regulated party (e.g., "What is the number of accidents on closed highways?" could be asked to a municipality). Note that it is also possible to define weights for each KPI, hence differentiating between the relative importance of KPIs. The presented example, however, assumes equal importance for all KPIs, for simplicity.

TABLE II. KEY PERFORMANCE INDICATORS (KPIS)

ID	KPIs related to closed highway – 134.(3), 134.(4)
K1	Number of accidents on closed highway
K2	Number of accidents on closed highway where highway was used without emergency cause
K3	Number of complaints about dangerous driving on closed highway
K4	Number of vehicles stopped by police on closed highway
K5	Number of vehicles stopped by police on closed highway where highway was used without emergency cause
ID	**KPIs related to pedestrian crossings – 140.(1), 144.(22), 144.(27)**
K6	Number of accidents involving pedestrians on roadway
K7	Number of accidents involving pedestrians on roadway where pedestrian crossed or attempted to cross roadway in an unsafe manner
K8	Number of complaints about dangerous driving endangering pedestrians on roadway
K9	Number of pedestrians stopped by police for unsafe crossing of roadway or an unsafe attempt to cross roadway

For complex domains, a regulation may refer to other regulations or to appendices where specifics are elaborated. Such references must be handled as part of Step 1 to maintain a cohesive regulation structure.

V. BRINGING STRUCTURE TO REGULATIONS

As part of Step 1, the largely unstructured regulatory text must first be transformed into a more structured representation of the regulations to allow for their modeling and analysis with the help of goal models. The creation of such a structured representation may make use of information about regulations that is already stored in a basic database.

The main goal of the presented regulations is ensuring the safety of traffic participants. The result of the transformation should be a representation of the regulatory text that (i) explicitly defines the impact of each regulation on the main goal, (ii) provides structural information about the regulatory text, (iii) consists of items that contain only single regulations, and (iv) does not refer to external documents or other sections of the same document.

A structured representation of the regulations is illustrated in TABLE III. The table shows the unique identifier (ID) of regulations, the regulatory text, the relative weight (RW) that specifies the impact of a regulation on its corresponding goal, and composition information (CI). General tree-like composition information is also given by the ID scheme used for regulations. Furthermore, related KPIs are shown for each regulation and the text for the KPIs is included in the structured regulation as shown in TABLE II. Note that only the first three words are shown for regulations that have not changed in Step 1. In addition to the presented table columns, a translation may be specified for bilingual models (e.g., English and French for Canadian laws) and a URL may be specified that links precisely to the source.

The CI column is required for the construction of the goal model. AND, OR, and XOR compositions are supported, meaning that the parent regulation as identified by the ID scheme is impacted by all, by one or more, or by exactly one of its sub-regulations. Regulations at the top, or root level, do not have compositions.

TABLE III. SAMPLE OF STRUCTURED REGULATION

ID	Regulatory Text	RW	CI	KPI
Part X		5		
134		10		
134.(1)	A police officer…	1		
134.(1)(a)	to prevent injury…		OR	
134.(1)(b)	to permit proper…		OR	
134.(2)	For the purposes…	1		
134.(3)	Where traffic control…	1		K1 K3 K4
134.(4)	Subsection (3) does not apply to a driver of a vehicle requiring use of the closed highway in an emergency..	1		K2 K5
140		11		
140.(1)	The driver of…	1		K6 K8
140.(1)(a)	is upon the…		OR	
140.(1)(b)	is upon half…		OR	
140.(4)	No pedestrian shall…	1		
144		11		
144.(5)	A driver who…	1		
144.(5)(a)	at the sign…		OR	
144.(5)(b)	if there is…		OR	
144.(7)	When under this…	1		
144.(22)	No pedestrian shall cross or attempt to cross a roadway in an unsafe manner.	1		K7 K9

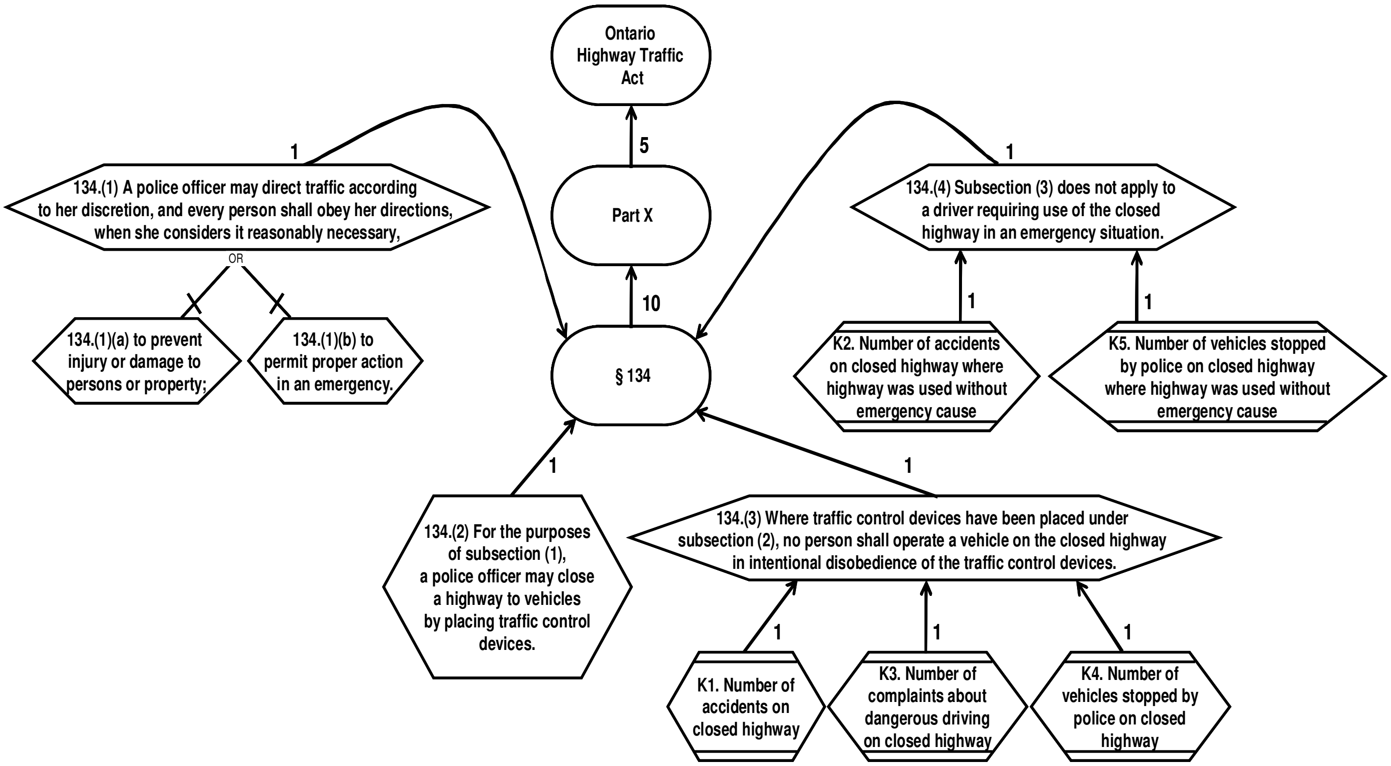

Fig. 2. Generated Regulations Goal Model (§ 134)

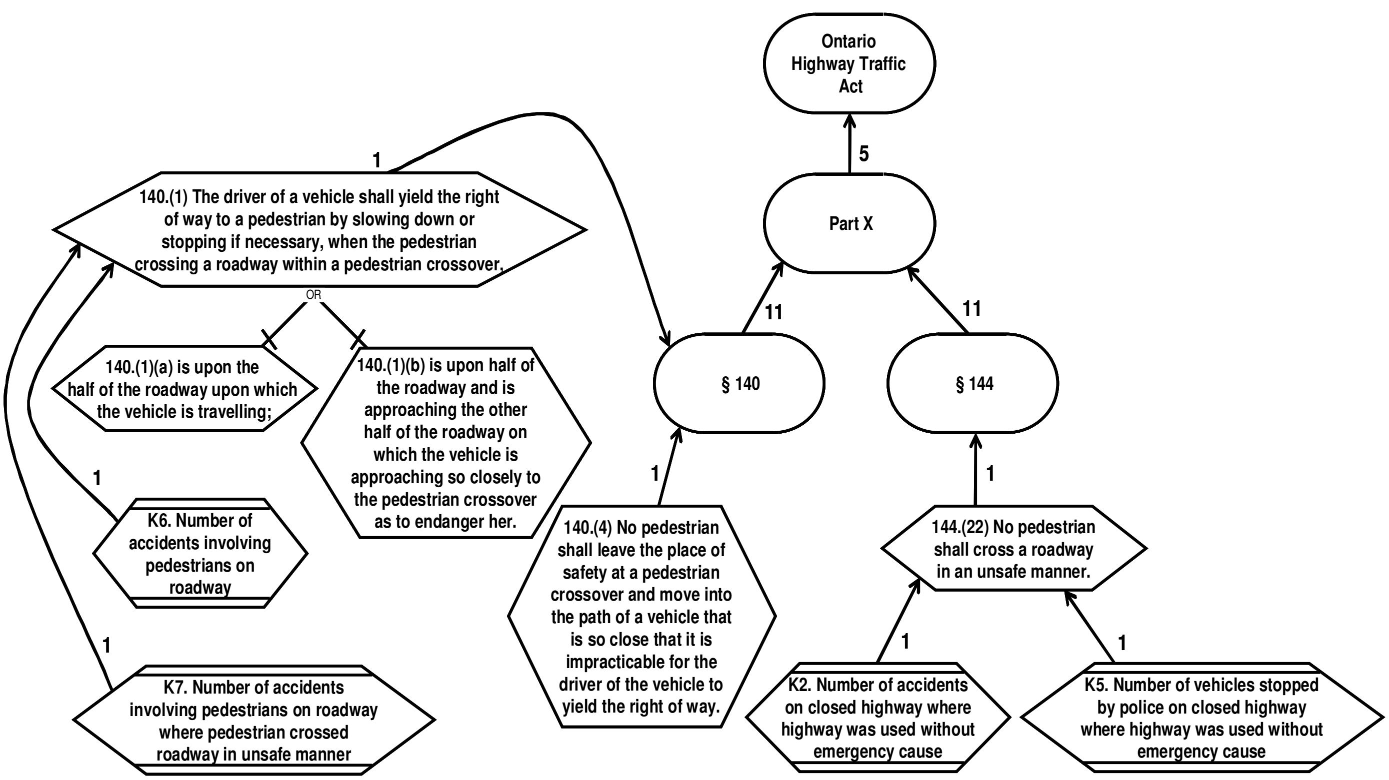

Fig. 3. Generated Regulations Goal Model (§ 140 and § 144)

VI. Goal Model Generation

We have implemented an import feature in the jUCMNav goal modeling tool which we use for Step 2. Given an augmented, structured representation of the regulations (e.g., TABLE III stored as a Comma-Separated Value file), the tool generates the equivalent goal model using the GRL notation. The resulting goal model is a visual representation of the regulations. However, the goal model requires some refactoring, because the hierarchy of the regulations may include intermediate levels with no semantic value. These intermediate levels are required for the readability of the regulatory text. For example, the document may be structured under chapters and sections. As we do not differentiate between a chapter and a section for our analysis, such hierarchy must be removed from the generated goal model. Similarly, if a particular regulation is broken down into sub-regulations that are too granular for our analysis, such sub-regulations should be removed from the hierarchy or combined under one regulation. These refactoring steps, which can be done in the input table or at the GRL level, are required in order to provide smooth reporting along the regulation dimension as will be discussed in more detail in Section VIII. The resulting goal model of the presented regulations is shown in Fig. 2 and Fig. 3.

Each regulation may be associated with multiple KPIs (i.e., questions) that measure levels of non-compliance. While the KPIs in the driving regulation example result in questions yielding integer numbers as answers, other types of KPIs and associated questions exist. Some questions may have simple binary answers (e.g., Yes, No), others may require a qualitative scale for answers (e.g., a five-point scale from “non-compliant” to “exceeds”). The URN standard allows for the specification of various types of conversion functions from real-world values to GRL satisfaction values. The jUCMNav goal modeling tool provides the ability to convert a real-world KPI value to a GRL satisfaction value between 0 and 100 based on the conversion function. Sample KPI conversions are shown in TABLE IV.

TABLE IV. Sample of Structured Regulation

Question Type	Answers (Real-World KPI value)	Converted GRL Satisfaction Value
Binary	Yes (1)	100
	No (0)	0
Five-point scale	Exceeds (4)	100+
	Compliant (3)	100
	Opportunity to Improve (2)	66
	Attention required (1)	33
	Non-compliant (0)	0
Numbers	Integer	converted with linear interpolation [11] based on specified worst, threshold, and target values

As an example of the last conversion in the table, consider the KPI “Number of accidents on closed highway”. In this case, the target value could be 0 (corresponds to GRL satisfaction value 100), the threshold value could be 2 (corresponds to GRL satisfaction value 50), and the worst value could be 50 (corresponds to GRL satisfaction value 0). A real-world value of 1 would hence result in the GRL satisfaction value 75 (1 is half way from 0 to 2 and 75 is also half way from 100 to 50), while a real-world value of 20 would result in the GRL satisfaction value 29 (20 is at the ~42% mark from 2 to 50 and 29 is at the same mark from 50 to 0).

KPIs are mostly added as leaf nodes in the goal model as they typically correspond to regulations at the finest level of granularity. However, it is also possible to specify KPIs for regulations at higher levels of granularity.

VII. Regulations Evaluation Strategy

With the regulation goal model including KPIs created, we are ready to feed the results of an assessment (i.e., a set of answers to the questions associated with KPIs) into a GRL strategy in Step 3, and then run the strategy in Step 4. The objective of this step is to calculate a GRL satisfaction value for each goal model element, i.e., for each regulation at each level. The outcome is a complete list of regulations and their corresponding satisfaction values for a particular assessment. The satisfaction values represent the level of compliance of regulations as captured by the assessment. Different assessments result in different strategies and hence different sets of compliance values for regulations.

Before the evaluation of the GRL strategy, the relative weights in the goal model are translated to regular GRL weights ranging from 0 to 100, inclusive, so that existing GRL evaluation mechanisms supported by the jUCMNav tool can be used for the goal model evaluation. In the context of compliance evaluation where the performance model is a well-organized tree structure, contributions of child elements to a parent element need to sum up to 100 [18]. This means that only if all child elements are satisfied, the parent element is also satisfied and compliance occurs. Hence, the relative weights of all child elements of a parent are prorated so that the sum of the weights of the child elements equals 100 while keeping the ratio expressed by the relative weights (e.g., the relative weights of three child elements 1, 2, and 1 translate to regular GRL weights 25, 50, and 25).

TABLE V. Sample Compliance Data

Year: 2012; **Location:** Ottawa	
ID	**Compliance**
Ontario Traffic Highway Act	96
Part I	98
…	…
Part X	99
…	…
134.	90
…	…
134.(3)	83
K1	100
K3	50
K4	100
134.(4)	85
K2	80
K5	90
…	…
Part XI	95
…	…

Finally in Step 5, the calculated satisfaction values are exported by jUCMNav to the database that is being used by the BI tool to provide reports to the regulatory institution as explained in Section VIII. An example export of compliance data fed to the BI tool is illustrated in TABLE V.

VIII. Dimensional Model for Regulations

In order to better understand performance and compliance, stakeholders of regulatory institutions need to be able to analyze and aggregate available data. This data is usually captured within operational databases. Conventionally, regulatory organizations collect large amounts of *facts*, which are the data about the compliance of each regulation. These facts, such as inspections data, are collected by the stakeholders at the operational level, for instance inspectors. However, in order to reason about performance and overall compliance, decision makers in regulatory organizations can benefit from BI solutions that aggregate and analyze those facts. BI tools are key enablers for visualizing the compliance to regulation and overall performance of institution over *dimensions*. Dimensions are the key contexts of a domain, against which the facts can be analyzed.

The key new dimension that this methodology for regulatory intelligence provides is the regulation dimension. This dimension represents the tree structure of the regulations, and it enables BI tools to provide *drill-down/up* functionality along the regulation dimension and explore compliances along a number of facts. This enables stakeholders to answer questions about compliance such as: (i) what are the overall compliance levels for a single regulation or multiple regulations? (ii) What areas of regulations seem to experience less compliance, and which areas tend to be more compliant? (iii) Are there specific groups or subgroups of regulated parties that comply/do not comply with specific parts of the regulations? Such questions can be examined in combination with traditional dimensions, such as time, location, etc.

Fig. 4 illustrates a dashboard that enables drilling down (and up) along the regulation dimension of the Ontario Highway Traffic Act for all municipalities in Ontario over the last five years, i.e., stakeholders can explore the time line as well as various locations in Ontario from cities to the whole province, and navigate to lower (and higher) levels or sections of the regulations. Color feedback is also provided (the greener, the better).

For each regulation, we have information on its level (distance from the root node = level 0), its parent, and its compliance value. Regulation levels are required by the BI tool to generate dynamic and interactive dashboards that allow stakeholders to view compliance of regulations at any level of detail. The level of each regulation is determined automatically as part of step 2 when the augmented, structured representation of the regulations is imported into the goal model.

For example, at the root level, a stakeholder may be interested to view compliance data for the last five years for a particular regulatory text (in this case the traffic act). If an area is showing particularly low compliance, for example, the stakeholder can drill-down that path to explore more detailed compliance data. In Fig. 4, the year 2012 was chosen first. Then, Level 1 corresponds to the various parts of the traffic act, while level 2 corresponds to the various regulations within a specific part, i.e. Part X of the traffic act.

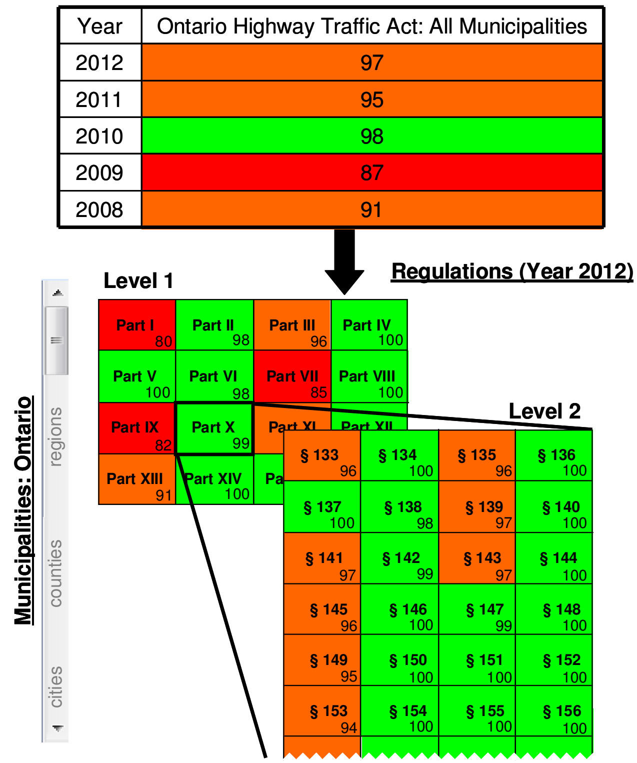

Fig. 4. Dashboard of Ontario Highway Traffic Act with Drill-Down/Up Capability

The presented methodology provides compliance data for all regulations at all levels of the hierarchy, and not only at the leaf nodes. Users can therefore combine the regulation dimension with other existing dimensions of their data. For other dimensions, additional data must however be made available, such as time stamps of assessments, location, etc. For example, the slider on the left of Fig. 4 allows the compliance data to be viewed for the whole province or at the regional, county, and city level.

Considering the whole Regulatory Intelligence methodology, the most time-consuming steps are not those related to technology, i.e., the transformation into performance models, the evaluation of the performance model, and the creation of BI dashboards, but rather the conversion of prescriptive regulations into outcome-based regulations, reaching agreement on relative weights, and the establishment of a measurement regime capable of capturing real-world measurements of regulated parties.

IX. Related Work

Goal-oriented modeling languages have been used in the past to model regulations and compliance according to a recent survey [9]. However, combining this with BI technologies in support of regulatory intelligence is new.

Tawhid *et al.* [20] present the work that a federal regulator has done to convert their prescriptive regulation to outcome-based regulations. Similar work is proposed in healthcare by Yin [24], where the focus has traditionally been on procedures and steps, rather than on effectiveness and outcome. Braun *et al.* [5] identify a number of strategies for instituting outcome-oriented regulations. The strategies range from converting prescriptive text to outcome-based models, to starting with outcome-based models as the single source of regulations. Behnam *et al.* [4] highlight the trend towards the outcome-based regulatory paradigm and the importance of goal models and measurable goals in such a paradigm. The authors provide a pattern-based approach that assists regulators with a set of systematic steps for eliciting the requirements, capturing reusable knowledge, and creating outcome-based goal models.

In a related domain, several approaches combine compliance modeling and performance modeling for the purpose of documenting safety cases, providing arguments based on collected evidence that a system's safety objectives are being met. The Goal Structuring Notation (GSN) [14] community standard helps construct safety goal models and link informal evidence. The notation however lacks formal representation to enable automated analysis as is available for URN.

Other goal notations such as *i** [23] and KAOS [21] are also used for safety compliance. For example, Sabetzabeh *et al.* [16] propose Modus, an add-on to a commercial UML tool. Modus models KAOS goals, obstacles, and probabilistic evidence which can then be analyzed through Monte Carlo simulations based on experts' opinions. The focus here is more on the agreement on evidence and the presence or absence of documents than on observable and quantifiable outcome-based measures. Rifaut [15] proposes a method for modeling regulations and the arguments for claiming compliance. The author uses GRL in a generic measurement model based on ISO/IEC 15504 [12]. Silveira *et al*. [19] focus on measuring compliance at the level of processes with the help of key indicators but do not extend their measurements to the level of organizations. Finally, Cyra and Górski [7] propose a way of combining a decision scale with a *confidence* scale. GRL could be extended with this concept to ensure that uncertainty in the data collected through questionnaires and fed into the performance model is taken into consideration during compliance analysis.

Regulatory intelligence technologies, on the other hand, are mainly about supporting regulated parties (especially in the pharmaceutical world) in their compliance obligations [8], rather than helping regulators measure the performance of regulated parties while enabling the adaptation and evolution of their regulations (i.e., their requirements).

X. Conclusion and Future Work

The regulation-based dimensional modeling methodology for regulatory intelligence discussed in this paper enables regulators to reason about regulations as well as compliance with regulations. While Business Intelligence (BI) tools have long provided the ability to reason along the dimensions of time, location, or organizational structures, the regulation dimension has been neglected until now and, hence, regulation-based reasoning is the main contribution of this work.

A key value of the presented methodology is its close alignment with existing technologies, such as business analysis through BI tools and goal modeling.

The methodology has been applied to the security and safety compliance domain as well as the financial domain. However, due to confidentiality issues, we cannot disclose the name of the regulatory entities involved or the specifics of their regulations and compliance procedures. We also wish to keep the focus of the paper on the methodology, rather than on the domain. However, having applied the methodology in two domains enables us to have a better understanding of the aspects that are domain specific and those that are core to the methodology. For example, some domains have periodic inspections, while others may have an irregular inspection schedule (which in itself is a means to ensure compliance). Our methodology, therefore, does not assume regular inspections schedules.

Even without considering important social, organizational, and cultural factors, the effort required for providing the technical infrastructure and required input data to support regulatory reasoning is substantive. Particularly time consuming are (i) the restructuring of prescriptive regulations into outcome-based regulations, (ii) reaching agreement on relative weights, (iii) establishing a measurement regime and consequently collecting inspection information and, to a lesser degree, importing such information into a performance model, and (iv) the integration with existing database systems and business analysis tools. However, we argue that the ability to reason about regulations is ultimately more valuable than the effort involved. We anticipate this work to motivate the restructuring of further prescriptive regulations into *measurable* outcome-based regulations.

Regulations are typically drawn from overarching laws and policies that determine core responsibilities and rights. Whenever laws or policies change, regulations must be reviewed to make sure they do not conflict with the new laws or policies. The presented methodology has not yet fully addressed the evolution of regulations over time, from a reporting perspective. This is partly a technical problem but partly also a policy problem as regulators need to decide on how to measure updated regulations with respect to the earlier versions of the regulations. In future work, we expect to address these issues, allowing a regulation to be designated as (i) a refinement of an existing regulation or group of regulations or (ii) a completely new regulation, and using this information for continued reasoning across several versions of regulatory text.

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