An Assessment of Modelling Temporal Constraints in the e-Procurement Domain

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Abstract. Although temporal data are widely used with temporal SQL, the corresponding uptake of its abstraction to temporal conceptual data modelling (TCDM) remains underutilised, despite its potential to enhance data quality and integrity. This may be due to a disconnect between TCDM languages and business needs that would help shape the modelling. To shed light on the need for TCDM, we conducted an empirical assessment applying the most recently proposed TCDM language, TREND, to assess and model temporal information for the UML diagrams of the eProcurement Ontology (ePO), a large-scale conceptual model developed for European public procurement. Both the model-derived glossary and the modellers proved most insightful, with the most important constraints being the transitions of an entity's roles in the future and, implicitly, the past, and frozen attributes, and the request to model what triggers changes. Based on the insights and lessons learned, future directions for industrial use of TCDM are formulated.

Keywords: Temporal Conceptual Modelling · eProcurement Ontology

1 Introduction

Data quality and process traceability are important in information systems, particularly in domains dominated by business processes. Business Process Management (BPM) systems [14] depend on time-sensitive data to model, monitor, and improve processes, but often lack explicit temporal representation in their data models to ensure that the data adhere to the logical temporal flow. While temporal SQL is well-established [21], and temporal data modelling languages have been proposed (e.g., [1, 7, 9, 19, 20]), the conceptual design lacks corresponding modelling practices and demonstrated use in industry. Yet, the more precisely one can represent temporal aspects of data—such as when events occur or how people and organisations evolve across roles—the greater the potential to enforce temporal constraints and thereby enhancing integrity of the data as well as supporting better analytics of higher quality data. For instance, to ensure that each Contractor on a contract *must have been* a Winner for that contract

before, or that an organisation carrying out a contract *must already have been* awarded that contract, and in consulting, a project member might transition to a team lead *after a set period*. Given a business process, the relevant objects and tuples in the database are expected to migrate accordingly. Consequently, such temporal constraints need to be modelled. This can prevent fraud and enforce fairness, among others, because then, e.g., ⟨`org1,proj1,t1`⟩ cannot be added in a `Contractor` database table if there was not already ⟨`org1,proj1,t0`⟩ in the `Winner` table (with $t1 > t0$).

However, temporal conceptual data modelling (TCDM) has seen limited adoption in practice. To date, TCDM has largely remained an academic activity, with few modelling applications, notably the MADS use case in avalanche prevention [25] and the TRENDy web tool [23]. The gap between academic research and industry use raises questions about the adequacy of current temporal modelling languages, such as [1, 4, 15, 19, 20, 24], and it is unclear which temporal constraints are important, other than that evolution constraints on attributes were hardly used in user studies with students in domains of typical university exercises [2]. It is unknown how this compares with concrete cases in industry, let alone devising modelling methods beyond a 'go forth and model' used in [2].

To investigate TCDM language adequacy and importance of temporal constraints in industry systematically, we seek to answer the following key questions:

RQ1: Is Temporal Conceptual Data Modelling relevant in a concrete, large, industry/eGovernment case?
RQ2: Which constraints are relevant, if any, and how often are they used?
RQ3: Procedurally, what assisted in data analysis and the modelling of the temporal information?
RQ4: What are the lessons learnt in the process of figuring out where to look and how to do it, such as examining the requirements specification first, other documentation, interviews, or systematically assessing models snippets?

A thorough analysis of a TCDM Language (TCDML) in general with a deployed large model, including devising a lessons-learnt, is expected to serve both as a step toward industry use of TCDM and as indispensable input to modelling methods for temporal conceptual data modelling.

We conducted a detailed comprehensive case study on the eProcurement Ontology (ePO), which is a large, modular conceptual model. ePO is developed and maintained under the governance of the Publications Office of the European Union and is used as a reference conceptual model for implementing and harmonising public procurement data across EU Member States, in alignment with EU Directives and Regulations, and it functions as an essential component of the Public Procurement Data Space (PPDS) for the Single Market economy [6, 12]. The ePO model is developed as a set of UML Class Diagrams and is documented extensively. Despite the domain's procedural nature, ePO does not have temporal constraints beyond time/date data types. It has hints thereto, such as the non-enforceable epo:NeedsToBeATenderer association end on the Winner-side of the association with Tenderer. These omissions cause risks for data integrity and hamper detecting anomalous event data (e.g., a winner who never tendered).

We conducted a detailed, mostly qualitative, analysis on the applicability of temporal modelling for ePO, consisting of i) a harvesting stage from all ePO documentation for anything possibly temporal, ii) an analysis stage where each item was discussed with modellers on whether it was indeed temporal, and if so how (aided by the TRENDy tool [23]), and whether it was relevant for ePO, iii) a structured interview with domain expert business users, and iv) drawing lessons-learned involving also a re-assessment of our first feature list of temporal constraints for conceptual modelling.

The results show that TCDM is indeed useful in a real-world, large-scale model, identifying practically relevant temporal constraints, notably: transition constraints in the future and frozen attributes. We also report on the processes and challenges, and observe that both the UML diagram-derived glossary and ePO modellers were the most fruitful sources to discover and assess temporal constraints.

The remainder of the paper is structured as follows. Section 2 presents the related work and introduces the ePO. Section 3 describes the methodology and Section 4 the results. We discuss in Section 5 and conclude in Section 6.

2 Related Work and Subject Domain

Temporal conceptual data modelling has been studied extensively over the past decades, initially for ER and later also UML class diagrams, with the first comprehensive review of models up to 1999 described in [11], which highlights different ways of handling time in data modelling. This spurred new research in the 2000s, resulting in ER extensions, notably TimeER [10], TimeERplus [9], ER_{VT} [1], ERD^T [7], annotated USM [20], and TREND [2, 19] that add a subset of a variety of temporal elements and constraints, including transition constraints (object migration), the telic/atelic distinction, repeatable temporal objects, and status entities (see the appendix for a list of temporal features and [2] for a recent review). Temporal features have been proposed also for Object-Role Modelling [8, 13, 18] and UML class diagrams and OCL [3, 27]. While these approaches perhaps assumed it made temporal modelling accessible for practitioners thanks to using widely adopted modelling languages, they were not evaluated except for TREND [2, 19], and they also lack reported evaluation in industry cases, except for the MADS approach [25] with a use case on avalanche prevention. Domain experts struggle with modelling temporal information of attributes and concepts such as 'maintenance' and 'repair' (e.g., [22, 16]).

It has not been investigated systematically which temporal features are needed from a business perspective, to the best of our knowledge. This makes it difficult to evaluate the merits of proposed TCDMLs for industry uptake, and even more challenging to devise suitable modelling methods for modelling temporal data. For instance, Khatri et al.'s [20] proposal focuses on telic/atelic constraints that few are familiar with: telic events have an inherent completion point, e.g., awarding a contract, whereas atelic situations describe ongoing states without a defined endpoint other than one determined outside the process, e.g., being a contractor.

Teasing out the distinctions may need answering competency questions, alike the "MpCQs" (interrogating about a metaproperty of an entity) intended for ontologies [17], to extract such information from domain experts. Likewise, TREND's transition constraints [2, 19] easily sprawl into many options of "extension" (the object *also* becomes an instance of another entity type; e.g., a student becomes a tutor as well) and "change" (the object becomes something else, *ceasing to be* the old thing, e.g., a lecturer is promoted to professor) that can be optional (EXT, *ext*, CHG, *chg*) or mandatory (MEXT, *mext*, etc.), in the past (lowercase) or in the future (uppercase), quantitative in the past or future (QEXT, *qext*, etc.) or at some point, permanent (PEXT etc.) or reversible, for entity types only or also for relationships (EXTR etc.) and for attributes (e.g., QCHGA for quantitative change in the past, FRZ for frozen). Experiments showed that both visual and natural language renderings were preferred over other notations [19], but this only amounts to input to a possible modelling method. MADS [25] adds cognitive load with *spatio*-temporal modelling. The most recent review on temporal conceptual modelling in [2] does not address these challenges.

Despite significant research, the adoption of TCDM in real-world applications remains limited, possibly due to complexity or lack of suitable tools. The most recent proposal is the temporal modelling language TREND [2, 19] that has a supporting tool TRENDy that relies on the visual notation and generates also the verbalisation of the temporal constraints [23], both of which evaluated with students, with promising results in academic toy domains. Usefulness in large-scale, real-world models with domain experts is yet to be demonstrated as well.

Considering e-procurement, the domain concerns the process through which a (public) buyer requests offers from economic operators, evaluates these offers, awards a contract, and then manages the resulting contractual relationship. Participants involved in procurement processes transition through various roles, including tenderer, winner, and contractor, and it is essential to model it precisely to ensure transparency, legality, and integrity in procurement workflows, and to verify compliance and maintaining historical accuracy. While processes can be modelled with BPM, the data stored about it needs to comply with them. This is currently not documented in the atemporal conceptual model of ePO (see footnote 2), and therewith cause possibly compromised data due to weakened enforcement of critical business rules. Specific temporal constraints include that a candidate can only transition to a tenderer upon tender submission and that a tenderer must exist prior to being designated as a winner. It looks promising to model this with the *transition constraints* available in TREND. For instance, $mchg_{\mathsf{epo:Tenderer},\mathsf{epo:Winner}}$, i.e., each object as instance of Winner must have been an instance of Tenderer before, but is not now[1], which is contingent upon an official award decision. Other transition constraints in TREND are described earlier in this section. Such constraints can then also become enforceable in the

[1] More precisely in TREND [2], and to provide a flavour of the formalism, *mchg* is defined as $o \in mchg_{C_1,C_2}^{\mathcal{I}(t)} \rightarrow (o \in \mathtt{C_1}^{\mathcal{I}(t)} \rightarrow \exists t' < t . o \in \text{CHG}_{C_1,C_2}^{\mathcal{I}(t')})$ with CHG defined as: $o \in \text{CHG}_{C_1,C_2}^{\mathcal{I}(t)} \rightarrow (o \in \mathtt{C_1}^{\mathcal{I}(t)} \wedge o \notin \mathtt{C_2}^{\mathcal{I}(t)} \wedge o \in \mathtt{C_2}^{\mathcal{I}(t+1)} \wedge o \notin \mathtt{C_1}^{\mathcal{I}(t+1)})$

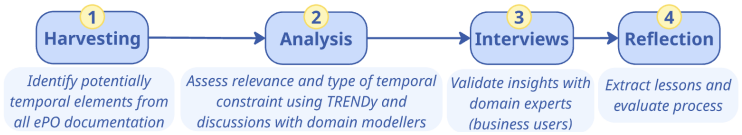

Fig. 1. Workflow for assessing the applicability of temporal conceptual data modelling for the selected case, being the ePO conceptual model.

database through triggers and built-in date comparisons [23], and therewith also queryable.

3 Methodology

In order to assist the assessment of TCDM needs and patterns in an industrial-scale domain and setting, the immediate goal is to identify temporal patterns, constraints, and transitions that are either implicit or absent in the current ePO Conceptual Model (CM), and assess if and if so how they can be represented. The assumption is that the TREND modelling language would suffice, possibly aided in the analysis by TRENDy or a similar tool (note: evaluation of any tool is beyond the scope of this paper). We carried out a multi-stage qualitative analysis consisting mainly of the following steps (see also Fig. 1):

1. *Harvesting* of potentially relevant time and temporal aspects, from all materials available from the ePO website (see footnote 2);
2. *Analysis* of the 'harvest' with ePO modellers, using note-taking software and online collaborative platforms (text editor, Confluence, GSuite, Slack);
3. *A Structured Interview* with procurement business experts, using collaborative note-taking software (Confluence) and an online meeting platform (MS Teams);
4. *Reflection* including further analysis and an extended literature search to extract insights and lessons learnt, and to devise future directions.

We began by harvesting potentially temporal content from a broad set of ePO v4.2.0 resources, including: i) the ePO ontology requirements specification documents (ORSDs) for the eAccess, eSubmission, and eInvoice modules, ii) the ePO combined glossary, iii) the ePO CM consisting of UML class diagrams—comprising 361 classes, 290 attributes and 255 associations—with their comprehensive annotations, and iv) related documentation, such as meeting minutes and GitHub issue discussions[2]. Since the investigation part of this work started, ePO had a major release, the latest version being v5.2.0. No major changes have been made related to the temporal use-cases presented in this paper, and therefore this investigation is valid for the newer versions as well. We note that the workflow of ePO modelling applies the LOT methodology [26], by first writing

[2] All documents are available from https://docs.ted.europa.eu/epo-home/index.html and the related GitHub repo at https://github.com/OP-TED/ePO.

the ORSD, then developing the module as a CM, and finally automatically generating the glossary from the richly annotated CM[3]. Therefore, one might expect to obtain most of the information from the glossary.

These materials were examined both manually and with keyword-assisted methods to flag references to time, dates, events, and changes in role or state. For example, the AgentInRole classes were first ordered in a spreadsheet according to the corresponding procurement phases. Then, the temporal relationships between these roles were added using the glossary and the CM.

All flagged content was examined to determine whether it carried temporal semantics. This collaborative assessment was supported by the TRENDy tool [23] that offers manual modelling and automated verbalisation of temporal constraints, albeit in extended ERD bubble notation where arrows denote transitions and a clock that the entity is a temporal entity. Using TRENDy, we tested how candidate constraints could be expressed and checked against the formal definitions in TREND such as temporal entity type, relationship, and attribute (including 'frozen'), and the transition constraints such as *change*, and *extension*. Whenever ambiguity arose, domain knowledge was sought from the ePO modellers, ensuring that the candidate constraints reflected meaningful scenarios within the public procurement domain and were not simply artefacts of language or design abstraction.

Once validated by the ePO modellers, temporal constraints were modelled using temporal constraints of TREND and annotations were added. For each case, we recorded what kind of temporal pattern was involved (e.g., role transition, deadline constraint, sequence of events), how it could be formally expressed, and how it mapped to existing or missing parts of the ePO model. This was complemented by an assessment of what was not modelled, and why, if known (e.g., due to tool limitations, unclear semantics, or low perceived relevance).

From the harvested and analysed material, we selected a representative subset of cases for formal modelling using TREND (see Section 4.3 for details). We prepared a structured interview with an agenda and interview questions based on the selected cases and generic questions, such as "Did you ever come across temporal data modelling?", "Do you currently analyse the procurement data?", and case-specific questions, such as "Would you want to analyse data across time instants? E.g.: How long did it take (on average) for a winner to have become a contractor on that contract? and: What is the percentage of candidates that eventually become contractors on a given lot/contract?" (see supplemental material for details). The authors also prepared a document with three prepared cases and emailed it to the participants the day before the online meeting, together with a brief overview of temporal modelling as optional reading material, being the `E11-thisTemporalER.pdf` from the publicly accessible supplementary material of [2] that was used in their final experiment with their students.

The interview was structured and conducted jointly with the three business experts to allow clarification and cross-validation of interpretations among them.

[3] It use the model2owl tool (https://github.com/OP-TED/model2owl) that transforms UML class diagrams into both technical and documentation artefacts.

The predefined set of questions and modelling scenarios was followed, and the moderator ensured that each participant provided an individual response before the open discussion. When disagreements occurred, they were recorded, though not necessarily resolved, during the interviews. This approach preserved the systematic nature of a structured interview and permitted covering ample scope in the limited interview time while benefiting from expert interaction and reducing the risk of individual misinterpretation of the modelling constructs. Given the collaborative nature towards consensus of the ePO development, no separation in answering questions for determining inter-rater agreement was carried out.

Participants BU1, BU2, and BU3 are ePO contributors, with BU1 being the lead business domain expert and BU2 and BU3 also contribute the software support for the business domain. The three experts were selected based on their professional expertise in public procurement and the high amount of involvement in the development and deployment of the ePO. All participants combined domain knowledge with hands-on experience in conceptual modelling, ensuring that the feedback reflected both modelling intent and practical data validation needs in procurement systems. BU1 was new to temporal modelling, and BU2 and BU3 had a basic understanding of it before the interview. All authors attended the meetings and took notes during the meeting in a shared document.

Finally, we reflected on the overall modelling process to extract lessons learned. This included identifying which modelling steps were most productive, what kinds of documentation yielded the most temporal insights, and how tool support (in this case TRENDy) affected the modelling effort. The insights were then used for further analysis and identification of gaps to determine future directions for languages and methods for temporal conceptual data modelling.

4 Results: potential use of temporal constraints

We present the results in the order as described in the procedure.

4.1 Harvesting Temporal Elements from ePO Documentation

The aggregate statistics of harvested potentially temporal elements and constraints are included in column 2 of Table 1. We flagged occurrences of, mainly:

- Role transitions; e.g., from Candidate to Tenderer (see also Fig. 2);
- Deadlines and date attributes; e.g., contract signing or submission dates.
- Associations to Duration and Period. Currently ePO models periods and durations as classes, so that they can be referred by any ePO class via an association (predicate);
- Dependencies between business events; e.g., that an award decision must follow (be after) the submission deadline;
- Context-specific role properties; e.g., a Payee being optionally different from a Seller, but they have to be different for a specific transaction, and that an organisation may be both a Candidate and a Winner but not at the same time for the same project.

Table 1. Aggregates of the number of harvested and analysed temporal entities and constraints, separated by document resource.

Source	Harvesting	Analysis	Comments
ORSD: eInvoicing	5	2	
ORSD: eAccess	23	16	
ORSD: eSubmissions	13	13	
CM Diagram 'documents'	13	9	date/time attributes
CM Diagram 'terms'	14	14	date/time attributes
CM Diagram 'information concepts'	5	5	date/time attributes
CM Diagram (rest/other)	6	6	date/time attributes
Glossary (manual): classes and associations	24	20	associations to epo:Period, epo:Duration
Glossary (manual): attributes	38	35	date/time attributes
Glossary (automated): classes and associations	7	5	
Glossary (automated): attributes	9	7	
ePO Roles (CM diagram and meeting minutes)	12	10	mostly optional EXT

The date/datetime data types found in the CM also appear in the glossary. The manual harvesting of classes and associations directly from the diagrams of the CM retrieved more than the automated assessment of the glossary, but the automated assessment did result in additional candidates and new options or requirements derived from the output, such as that epo:OfferSubmitted is before epo:AwardDecision, and instead of the proposed frozen epo:Contract:arrivalDate to add a more relevant frozen epo:Contract:ConclusionDate.

To explain the difference in harvesting results between the CM diagrams and the automated assessment of the glossary, a manual assessment of the glossary was performed as well, with results being closer to those of the CM diagrams.

4.2 Analysis of the harvested content by modellers

All annotated elements were discussed collaboratively in 5 meetings, to try to map them to potential temporal constraints. The analysis revealed that temporal constraints were indeed implied in textual descriptions or process definitions, as can be seen in column 3 of Table 1. The ORSDs had comparatively large numbers of 'false positives', because not all content of the ORSD was subsequently in scope and multiple instances are modelled with a single modelling solution. Among others, use case "4. Invoice payment" is not modelled in the invoicing module and the class epo:ESPDRequest has an attribute issued, respectively. While the issue date implies a temporal constraint on when submissions are valid, this is not formally encoded in the model as a temporal rule.

epo:Buyer	Procurement roles in ePO		
phase	**Offering party**	**Auxiliary party**	**Acquiring party**
pre-award	epo:OfferingParty		epo:Buyer
eAccess, eSubmission, Evaluation, Awarding, (Tendering Process)	epo:Candidate , epo:Tenderer, epo:Winner, epo:ReliedUponEntity, epo:Subcontractor	epo-sub:LegalRepresentative	epo:Buyer, epo:ProcurementServiceProvider
Contract	epo:Contractor		epo:Buyer
Catalogue	epo:CatalogueProvider, epo-ord:Seller, epo-cat:Manufacturer (Supplier)		epo:CatalogueReceiver, epo:Buyer
Ordering	epo-ord:Seller,		epo-ord:Originator, epo:Buyer, epo-ord:Consignee

Fig. 2. Selection of the harvesting stage for roles, taken from the meeting minutes and ePO CM diagram.

Using the TRENDy tool, we modelled the main cases using TREND constraints, such as those shown in Fig. 3 and Fig. 4. A principal difference of Fig. 3 with the ePO model is that the Tenderer, Winner, and Contractor roles were analysed *together* with the Lot and Contract, therewith obtaining a better overview of their interactions. This is not present in ePO other than the assertions that epo:Contractor epo:needsToBeAWinner epo:Winner and epo:Winner epo:needsToBeATenderer epo:Tenderer. A temporal constraint can propagate automatically to the data layer, whereas a 'needs to be' is not.

The two diagram snippets in Fig. 4 combine explorations from two meetings: the "EXT" states that a PlannedProcurementPart may also become a Procedure, "*ext* 6" is a quantitative extension in the past (a Procedure may have been a PlannedProcurementPart before for the duration of six months), and the "*chg*" asserts that each Procedure was a PlannedProcurementPart but is not now. The Procedure in Fig. 4 exhibited two different modelling challenges encountered. First, the identity of PlannedProcurementPart and 'how disjoint it is' from Procedure (and similarly for ContractAmendment: is it a part of a procedure, a procedure, or evolves into a procedure?). This was left unclear in the atemporal model, but since they are definitely temporally related, it brought up the question how, and therewith also what they really are. Second, Procedure appears twice in ePO, but in different modules, once for planning notices and once for competition notices (with the latter occurring after the former), which were drawn in one model snippet in TRENDy. The competition notice's Procedure is the one from the planning notice, but with a few more attributes, hence, the intuition for *ext*. Logically, one would not extend to itself, but to another entity type that is compatible (i.e., not resulting in an unsatisfiable entity type or relationship). The TREND logic does not forbid this assertion, due to the semantics of subsumption, and this may be better handled by a warning in a tool.

This initial modelling with TRENDy was superseded in part by short-hand notation once the transition constraints were fully understood and confidence in their use gained. For the harvested and ordered roles (recall Fig. 2), only the applicable temporal constraints were added in the spreadsheet to save time, as shown in Fig. 5.

The use of TREND enabled us to clearly model not just the presence of a role or event, but also how one moves in or out of a role. For example, the transition

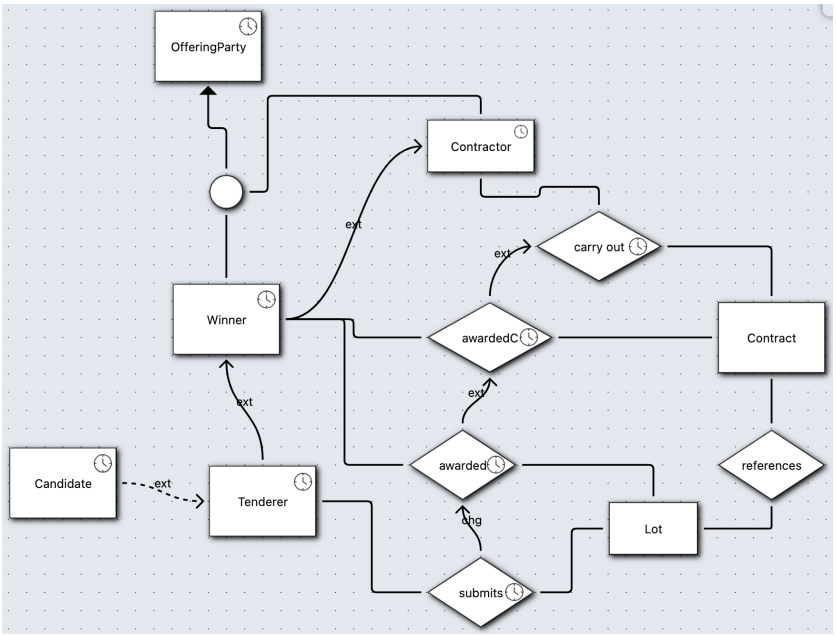

Fig. 3. Roles transition model snippet; ext: extended in the past; chg: changed in the past; solid-lined open arrow: mandatory; dashed-lined open arrow: optional.

from Tenderer to Winner is modelled as a *chg* constraint, triggered by the announcement of an award decision. The trigger itself, however, could not be modelled with TREND or TRENDy. This issue surfaced also when assessing the ePO glossary, where some of the attributes extracted automatically were flagged as the triggers, including epo:hasAwardDecisionDate that raises a state change "from candidate to winner" (from tenderer, rather) and epo:hasEntryIntoForceDate, since it "Marks a transition to the enforcement state of the contract".

4.3 Modelling Temporal Constraints with the business experts

This section reports the findings from the interviews with the business experts. Examples selected for the business experts were about role transitions (Candidate → Tenderer → Winner → Contractor) that definitely requires temporal constraints, document transitions (Contract → Amended Contract) that likely do not but caused a discussion among the authors (see previous section), and procedures (PlannedProcurementpart → Procedure) for which the authors were unsure which temporal constraints would apply. The interview was scheduled by the experts initially for 30 minutes and effectively took roughly 1h10m, covering the interview set-up and consent, a brief overview of TCDM, and the first use case on roles. A second meeting was scheduled for the week thereafter to clarify temporal constraints with sample instances and to cover cases 2 and 3 (also about 1h).

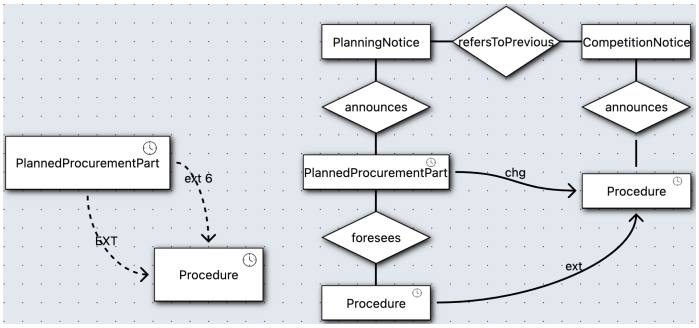

Fig. 4. Model snippet with explorations of optional transition constraints; see text for explanation.

Role A	Role B	Temporal relation	justification (Glossary)
epo-ord:Seller	epo:Contractor	No, they are the same	**epo-ord:Seller**: "The Seller is bound by a Contract"
epo-cat: Manufacturer	epo-ful:Despatcher	**Optional EXT**(Manufacturer may also become a Despatcher	**"epo-ful:Despatcher** : The Role is carried out by the Supplier or on behalf of the Supplier. This Role is often referred to as the Despatch Party, Consignor or Deliverer"
epo-ord:Seller	epo:CatalogueProvider	**Optional EXT** (Seller may also become CatalogueProvider)	**epo:CatalogueProvider** : The Catalogue Provider Role is usually played by the Agent that acts as a Seller, or by another Agent that acts on behalf of the Seller.
epo-ord:Seller	epo-inv:Payee	**Optional EXT** (Seller may also become Payee)	**epo-inv:Payee**: The role of Payee may be fulfilled by another party than the Seller,
epo:Candidate	epo:Tenderer	**Optional ext**	implied
epo:Tenderer	epo:Winner	**Mandatory ext**	epo:needsToBeATenderer predicate
epo:Winner	epo:Contractor	**Optional EXT** (Winner may also become the Contractor) **OR** **Mandatory ext** (A Contractor was already a Winner before)	epo:needsToBeAWinner predicate

Fig. 5. Selection of the outcome of the assessment of the roles collected from the harvesting stage (see also Fig. 2).

BU1, being accustomed to atemporal UML, struggled with understanding the TREND notation, but quickly picked up on the verbalisation of the temporal constraints. Regarding Fig. 3, BU1 asserted a $chg_{\mathsf{Tenderer,Winner}}$ when linked to a specific contract, and that $\text{EXT}_{\mathsf{OfferingParty,Candidate}}$ and $\text{EXT}_{\mathsf{OfferingParty,Tenderer}}$ must hold as well. Whether all candidates and tenderers were already offering parties, i.e., a mandatory *ext* (*mext*), was not discussed. For case 2 on amended contracts, it was confirmed no temporal constraints were needed. Regarding case 3 on epo:PlannedProcurementPart, the 'proposed' EXT shown (see Fig. 4) was evaluated as incorrect: a procedure was perhaps a epo:PlannedProcurementPart before, but not both at the same time, i.e.: optional change.

On the question 'Do you check for such constraints in the data now?' BU1 answered they do not, though on 'Is this useful to record?', BU1's answer was "I would want to check back if a Contractor was a Tenderer in this procedure". BU2 and BU3 focused their questions on the precise relation of TCDM to BPM and event models on what triggers the changes, and brought up PPDS business rules checking "to infer things and validate", where the rules "are represented in text and SHACL, nothing visual". All three participants indicated interest in

the potential of TCDM, but also wanted clearer, concrete, information on its usefulness.

5 Discussion

Our investigation set out to determine whether TCDM is relevant in a real, large-scale project, and if so, what constraints are useful and how they can be identified and modelled. We first consider insights and lessons learnt, to then proceed to answering the research questions, and to the remaining challenges.

Insights, observations, and lessons learnt Our temporal modelling assessment provided insights into both the domain and the modelling process in five main aspects.

Documentation as a key source: The ePO glossary proved to be the richest source of temporal semantics. Conversely, the UML diagram often omitted these details from view and despite the modelling team's practice of annotating classes, reinforcing the importance of including narrative and process descriptions during modelling, i.e., annotating beyond definitorial content.

Prevalence of role transitions, attributes for causes of transitions: Most temporal constraints involved role-based transitions, confirming the process-driven nature of the e-procurement domain. These constraints were common and critical for ensuring procedural compliance. Attributes with dates were useful indicators for prospective 'triggers' that cause object and relation migration.

TCDML features: Persistence in transitions and frozen attributes, while clearly visible in the TRENDy interface, were initially largely ignored by the modellers and business experts alike; it is not clear why. TREND and other TCDMLs focus on *what* transitions from source to target, but not what *causes* it to transition, which was perceived useful to represent in the model so that it can propagate to a trigger in the implementation. This thus may be a potentially useful extension to a TCDML. It also merits investigation to consider creating predefined special dates with a particular semantics, such as deadline and milestone, to further facilitate this.

Effectiveness of TRENDy in collaborative modelling: While not under evaluation, the tool's verbalisation feature aided communication among team members and facilitated discussion with non-technical stakeholders. This was especially valuable when validating interpretations with domain experts and the initial stages for modellers to become acquainted with temporal modelling. The diagrammatic representation was used only for the temporal aspects, not for recreating the whole model snippet. For instance, subtyping, cardinality constraints and attributes were omitted from the drawing and perceived not needed in determining the temporal features. It also helped demonstrating potential use to the business experts thanks to its SQL schema generation feature.

Challenge of ambiguity: Some temporal aspects were only vaguely implied in the text, requiring interpretation and validation, including attempts at recalling conversations and referrals to the online ePO meeting minutes of which it was

hoped that decisions were documented. This experience highlights the need for structured temporal annotation guidelines in future model documentation.

Overall, our application of TREND to ePO revealed that temporal conceptual data modelling is both feasible and beneficial in a complex, real-world project. The identified constraints, though previously implicit, were important to elucidate for ensuring data integrity and supporting process-driven use cases in public procurement, and clarified also the semantics of several atemporal entities.

Answering the motivational research questions Returning to the motivational questions (Section 1), we conclude that temporal conceptual data modelling indeed is relevant in our concrete, large, eGovernment case with ePO (RQ1), partially for the temporal elements and constraints (e.g., the roles) and partially for interrogating atemporal elements better (e.g., the amended contracts). Many constraints were deemed optional transitions and extensions (RQ2), although that was largely due to modelling single classes and binary associations rather than in context; e.g., for a specific lot and contract, it is a change from tenderer to winner, not an extension just because the same organisation can still be a tenderer for another lot. The 'optionally some time in the future' constraints are uninteresting for database integrity checking, however, because they are trivially satisfied. Therefore, it may be useful in the modelling process to create the converse constraint and corresponding verbalisation so as to facilitate asking the modeller translating the future constraint into a past constraint, not unlike the NORMA tool's [5] 'verbalization in the negative' but then reworked for temporal constraints with past/future.

Procedurally, what assisted in data analysis and the modelling of the temporal information the most (RQ3), was TRENDy initially, for sketching ideas quickly and seeing the verbalisation of the constraints. Subsequently, it was faster to type it than to draw it. Better tooling is desirable, including a requirements analysis for most important tool features.

The lessons learnt in terms of the process of determining where to look for temporal constraints and how to do it (RQ4), we deemed that all existing ePO materials facilitated the initial narrowing down for selecting cases to analyse and discuss (cf. scanning over the UML diagram of ePO or systematically assessing the whole model), although the ORSDs less so. The ORSD nevertheless was of use to realise how much was set aside and how much the requirements evolved once the ePO modelling had begun.

Challenges Working with domain experts confirmed the need for clear and verifiable representations of business rules and improved mutual understanding. However, some complexity remained. For instance, constraints about causes of change (e.g., award decisions as triggers) cannot be modelled in TREND nor in other proposed TCDMLs (recall Section 2), suggesting an area for language and tool extensions. The TRENDy web app appeared to be not stable for concurrent user support, took some time to get used to, and while the arrows for transition constraints make sense in the context of EER's bubble notation, they may lead

to confusion as appearing alike directed associations if the notation were to be copied over as-is to a UML modelling tool.

Not all data required temporal modelling—e.g., atemporal information where past data is out of scope, such as addresses—but TCDM makes that choice explicit, guiding modellers in designing fit-for-purpose systems. Integrating temporal constraints into data models will strengthen the bridge between BPM and data storage, especially in BPM-aligned domains such as procurement.

Finally, there are some threats to validity of the results. The number of modellers and domain experts in this study is relatively small. While this enabled obtaining detailed insights, it may not scale well, in that a detailed analysis of another large-scale model in a different domain with different modellers may observe more, less, or other insights.

Overall, this assessment of potential for TCDM contributes initial valuable insight into the feasibility and benefits of TCDM in real-world settings, to support a broader uptake of temporal modelling practices in industry.

6 Conclusions and Future Directions

The, to the best of our knowledge, first industry assessment of Temporal Conceptual Data Modelling (TCDM) in a real-world large and complex project, tested with the e-Procurement Ontology (ePO) (de facto a conceptual data model), showed that many relevant temporal constraints that are implicit in the atemporal ePO UML class diagram can be made explicit using the relevant temporal constraints, particularly those involving role transitions. The results demonstrate that TCDM is both applicable and beneficial in this large-scale, real-world project, for both temporal and atemporal modelling.

Methodologically, all documentation, and especially the model and textual analysis of the annotations in the derived glossary, was useful in pinpointing potential temporal constraints. While TREND and TRENDy supported the analysis and modelling phase and communication among modellers and with domain experts, our study also surfaced challenges, notably the desire to have a means to express triggers for change (e.g., award decisions) and how a TCDM links to a BPM. Based on the challenges observed in our assessment, future directions to devise robust methods for TCDM and increase its uptake in industrial (including eGovernment), settings should focus on:

- Investigating enhancing the modelling language with the capability to express the reason, or trigger, for change;
- Extending tool capabilities to better guide the modellers and domain experts, especially to support alternate and converse statements of temporal constraints in the case of the 'some time in the future' transitions, such as the mandatory and optional EXT and CHG constraints in TREND;
- Devising methodological support for TCDM for the scenario of enhancement of existing atemporal conceptual data models, such as manual and automated analyses of a model's glossary and pinpointing through time/date attributes and classes.

- Generating concrete case studies with actual instance data that show how and where TCDM has been shown to be useful, and useful in what way;
- Obtaining more industry feedback for TCDM also in other subject domains, together with training materials that can enable obtaining more feedback from modellers and domain experts.

Supplementary materials The supplementary materials are available at https://github.com/meaningfy-ws/supplementary-materials.

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Appendix: Inventory of temporal constraints

- **Stamping (as snapshot or temporal)**: on entity type, relationship, attribute/value type, attribute/value type (value changes)
- **Rigidity on entity**: on entity type, relationship, attribute/value type
- **Type of entity type**: Once-only vs. repeatable temporal object type
- **Evolution constraints over lifecycle**: entity type (status constraints), relationship (status constraints) attribute/value type (dynamic integrity constraints),
- **Transition constraints on entities**: extension past extension future, extension sometime, change past, change future, change sometime, persistence of transition; can be declared between entity types, between relationships, between attributes
- **Embedded in relationships**: generation relationship Production (objects in A are generated by objects in B, with different IDs, both active), generation relationship for Transformation (like Production, but B ceases to exist. using lifecycle), synchronization relationship (to enforce Allen temporal relations), across-time relationship (between active and disabled entities), Historical marks (stamping of relationships between objects not existing at the same time), Lifespan participation constraints (distinguish between relates now and relates to x over their existence), attribute update pattern (for transaction time), attribute observation pattern (for transaction time)
- **Time granularities**: arbitrary, day/week/month/year etc.
- **Time datatype types**: instant, interval, duration
- **Time type in system**: valid time, transaction time, bi-temporal (VT and TT), user-defined (with a domain meaning, e.g., milestone, birthday)
- **Time commitment ontologically**: 3D+temporal extension, 4D/perdurantism; discrete time, dense time; telic/atelic distinction, rigidity
- **Status entities (scheduled, suspended etc.)**: for entity types, for relationships, for attributes
- **Model or language features as a whole**: snapshot reducibility (whether snapshots of the temporal model are also a conventional CDM), upward compatibility (whether it preserves the atemporal semantics of conventional CDM when it's embedded into the TCDM), mandatory vs optional temporalisation (when converting, whether that modifies all entities to temporal and no way back), Graphical notation

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