A TCO Analysis Tool based on Constraint Systems for City Logistics

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***Abstract*—This paper presents an approach to extend existing total-cost-of-ownership (TCO) models by a logic and numeric constraint system. Instead of an only vehicle-centered cost view, these constraints enable the modeling of various dependencies occurring in a complex application field like logistics. The resulting tool will ensure an economical disposition, fleet management and business decision-making.**

***Keywords*–TCO; Constraint Model; Electrification; Logistics.**

I. Introduction

There have been a lot of changes in the field of city logistics over the last years, like the electrification of vehicles (EV), new means of transport built for last-mile-deliveries or whole approaches like distribution points (hubs), car-sharing or multi-use concepts. But, despite extensive funding in research and development in this area, the transportation market is remaining reserved regarding changes. The cost analysis in [1] and [2] for example have shown, that electric vehicles only get profitable with a relatively high mileage compared to conventional vehicles. This fact is besides the hesitant development of a charging infrastructure and the limited range a primary explanation of the hesitant commitment to EVs in commercial applications. This paper introduces a conceptual method not only to support and ensure the profitability of fleet restructuring, but also to enable long-term economical monitoring, extrapolation of new scenarios and strategy development. This method is based on the idea of TCO models, as introduced in the related work section.

The rest of the paper is structured as follows. In section 2, we embed our approach in the context of current work and fundamentals. In the following main section, we will introduce the pivotal idea of the combined use of numerical and logical constraints for achieving a more comprehensive TCO analysis in logistics. We close this paper with a concept architecture for a TCO tool, as well as a summery of the problem area we will prospectively work in.

II. Related Work

A vehicle TCO model consists of all expenses which arise by the acquisition and operation of that vehicle. Thereby, it is possible to offset these costs against profits or to compare different vehicle alternatives or rather multiple deployment scenarios. Especially market changes in automotive industries over the last years and the upcoming engines based on renewable energies made a TCO approach very useful for economical decision-making. Most TCO models, like [1] or [2], are very vehicle-centered and only contain vehicle specific influencing factors like acquisition, insurance, workshop or fuel expenses. To fully implement such a TCO model into a commercial application, it is necessary to enrich the model with application specific factors. The method of this paper is based on a TCO model especially built for logistics by [3]. Besides vehicle costs, this model contains expense data of the operational context. This covers personnel costs of the driver, possible trailers or hubs and information about the cargo and customers. All TCO models have in common that the use is intended to calculate costs for a specific set of parameters. An optimization or variation is only possible by experimentally varying the parameters.

III. Constraint System

The evaluation of vehicles in logistics on an operational level does not only result from vehicle cost factors. Different means of transport may have varying requirements regarding driver qualification, cargo size and weight or temporal restrictions of customers. The choice of a vehicle is strongly entangled with a tour specification and available resources.

TCO models may be an appropriate basis for one-time decisions like the acquisition of a vehicle for a generic use case. The method of this paper though proposes a much more holistic approach by implementing the TCO model into an arithmetic constraint system and extending it by adding logic constraints. A constraint system features a set of constraints, which are processable by an automatic solver. This solver calculates a solution space for every variable in the constraint system. By doing so, the TCO model gets much more flexible. Trivially, the solver can compute TCOs, but also possible combinations of variable input factors like a specific vehicle for given TCO for example. By adding comprehensive restrictions and dependencies of a logistic domain, the system solves the satisfiability problem which is identical to a resource allocation task. A constraint based TCO model is therefore a much more valuable tool for disposition, fleet management and business strategy finding. This method differentiates two types of constraints:

A. Numerical Constraints

Constraints are typically over a specific domain, but can be mixed and calculated within a solver. The logistics TCO model by [3] is a set of arithmetic formulas in Matlab, which are transferred into a domain for real numbers. Depending on the particular application or nature of constraints, a finite, rational or linear domain would also be conceivable. We propose the use of CLP(Q, R)[4] library for SICStus Prolog, because this solver supports multiple types of domains. By this, the equation for overall-costs of a vehicle assigned to a tour for example

$$\mathbb{K} = (12 * K_{\text{salary}}) + (S_{\text{workdays}} * K_{\text{tour}}) + K_{\text{insurance}} + K_{\text{inspection}}$$

is transformed into an element of the constraint set in Prolog

```
clpr:{K #= (12 * Salary) + (Workdays * TourCosts) +
    Insurance + Inspection.}
```

 ISBN: 978-1-61208-643-9

where the `clpr` identifies the domain of the various variables.

B. Logical Constraints

A holistic approach to a cost model in logistics comprises much more dependencies though. Especially the relation between vehicle, tour and driver implies non-arithmetic constraints, like qualifications or legal restrictions. We are approaching these problems by modeling ontological constraints in a logic domain as usually done by default in Prolog. In [5], we published an ontology specialized for inner-city logistics including the relation between various driver license classes in the European Union. We hereby used this description to build a logical constraint knowledge base in Prolog. First, we defined taxonomy facts about driver licenses and their associations with drivers. As shown in Listing 1, we further formalized generic rules about how the property of a license is subsumed.

```
driverL(dlA).
driverL(dlB).
subL(dlA,dlB).

staff(bob).
hasLicense(bob,dlB).

hasLicense(X,SubL) :- staff(X), driverL(SubL),
        subL(SubL,DlX), hasLicense(X,DlX).
```

Listing 1. Basic rules for a driver license taxonomy in Prolog

This basic set of facts allows the solver to determine drivers with a specific or implied subsumed license. In combination with the arithmetic TCO model, the solver then only calculates costs for appropriate tour-vehicle-driver-allocations. The TCO gets calculated much more on purpose with a resource allocation as by-product.

IV. User and Data Interface

Because the handling of a descriptive constraint knowledge base is not feasible for average consumer, we significantly focus on the integration of a suitable graphical user interface (GUI). Figure 1 shows the overall architecture concept of our tool. The Prolog knowledge base initially consists of the terminological knowledge and basic constraints. A data importer collects data from the logistics software systems and translates these into either arithmetic or logical assertional knowledge constraints. On the user side, an interface interprets functions to Prolog querys and proccesses results into changes of the GUI.

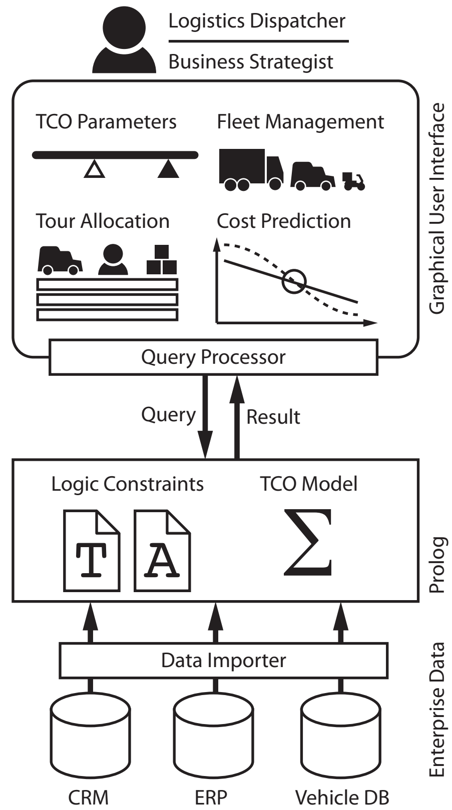

Figure 1. Conceptual Architecture of TCO-Tool

V. Conclusion and Future Work

In contrast to the existing vehicle-centered TCO models, our method furthermore represents a holistic economical view on the disposition process. Besides the calculation of vehicle, tour or personnel costs it ensures the profitability of resource allocation by implementing the constraint system as an optimizer. By using fuzzy ranges or plain variables as TCO parameters, the tool is able to find solution spaces which is useful for decision-making by logistics experts. The holistic and descriptive model covers also a daily dispatchers, as well as long-term use for business strategists.

To date, we implemented basic concepts and rules in addition to the existing TCO model from [3] to show the feasibility. We want to extend this basic knowledge base gradually by all relevant facts and dependencies of a logistics domain. Eventually, this tool will be tested and evaluated within a field test by various newspaper and media logistic companies.

Acknowledgment

The underlying research project of this paper, Smart Distribution Logistik is funded by the german Federal Ministry of Economics and Technology (Bundesministerium fr Wirtschaft und Technologie - BMWi) during the term May 2017 to March 2020.

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