



# Decision Guidance Analytics Language: Syntax, Formal Semantics, and Application to Service Networks

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## ABSTRACT

This paper proposes a unified syntax and formal semantics for DGAL(X)—a Decision Guidance Analytics Language—for easy iterative development of decision guidance systems, where X is an external functional language, e.g., a noSQL query language such as JSONiq. It demonstrates the composability of analytic models using a case study of modeling and operational optimization of hierarchical service networks, described as recursive analytic models. Analytic models formally describe feasibility constraints and metrics of interest as deterministic/stochastic functions of fixed and control parameters. DGAL(X) provides a library of operators, including compute, predict, calibrate, and optimize. The uniqueness of DGAL(X) lies in the modularity and composability of simulation-like analytic models without manually crafting mathematical programming (MP), constraint programming (CP), and machine learning (ML) models. This results in the quality of optimization and machine learning results as well as the computational efficiency of the best underlying MP, CP, and ML algorithms, which outperform black-box-based simulations.

## KEYWORDS

Decision Support, Decision Guidance, Decision Optimization, Machine Learning, Data Management, Decision Analytics

## 1. INTRODUCTION

Decision Support Systems (DSS) are widely used to support organizational and personal decision-making in diverse areas such as engineering, finance, business, economics and public policy. They are becoming increasingly critical with the information overload from the Internet. While the scope of DSS is broad, as outlined in Brodsky and Wang (2008), Brodsky and Luo (2015), we view Decision Guidance Systems (DGS) as a subclass of DSS based on formal mathematical models that are designed to provide actionable recommendations to human decision-makers, with the goal of achieving the best possible course of action. To this end, DGS may need to:

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- Continuously collect large amounts of data from multiple sources;
- Elicit knowledge about model structure from domain experts;
- Train deterministic and stochastic models using historical and continuously collected data;
- Elicit metrics of interest, performance indicators and decision objectives from decision-makers;
- Perform analyses including descriptive analytics (what happened?), diagnostic analytics (why did this happen?), what-if predictive analytics (what will happen?), and prescriptive analytics (how can we make it happen optimally?);
- Present and explain actionable recommendations to decision-makers; and
- Solicit decision-makers' feedback for iterative improvement.

Typically, Decision Guidance (DG) applications are one-off and hard-wired to specific problems; require significant interdisciplinary expertise to build; are highly complex and costly; and are not extensible, modifiable, or reusable. We believe that these deficiencies originate mainly from the diversity of the required computational tools and algorithms, each designed for a different task, such as data manipulation, predictive what-if analysis, decision optimization, statistical learning and data mining. The computational tools require the use of diverse mathematical abstractions and languages to construct input models. For example, for modeling mathematical and constraint programming problems, equational languages such as OPL, AMPL and GAMS are used.

This introduces two major issues. First, the same underlying reality must often be modeled multiple times using different mathematical abstractions for different tasks and tools, instead of being modeled only once, uniformly. Second, the modeling expertise required by these abstractions and languages is typically not within the realm of DG users – neither domain-specific users (e.g., business professionals) nor DB application and software developers (who may be used to SQL-like languages and OO programming languages such as Java). This, in turn, leads to long-duration, expensive and non-reusable development of DG applications, which must involve a team with diverse interdisciplinary expertise. We further discuss related work and its limitations in Section 2.

To address these limitations, we proposed the concept of Decision Guidance Analytics Language (DGAL) in Brodsky and Luo (2015) to serve as a language for a Decision Guidance Management System (DGMS), introduced in Brodsky and Wang (2008). Furthermore, we reported in Nachawati et al. (2017) on the first DGMS prototype, called Unity, which implemented DGAL and the underlying software framework. The goal of DGAL and DGMS is to serve as productivity tools for fast development and management of Decision Guidance Systems, around a reusable model knowledge base. This is akin to Structured Query Language (SQL) and Database Management Systems (DBMS) serving as productivity tools for fast development and management of database applications. However, the initial DGAL concept we introduced in Brodsky and Luo (2015) was limited to a single language - JSONiq; lacked mathematical formalization of its semantics; and did not provide a case study on a real-world modeling and optimization solution to demonstrate DGAL capabilities.

Lifting these limitations is exactly the focus of this paper, which is a major extension of the DGAL concept we proposed in Brodsky and Luo (2015) to a complete language specification, its formal semantics, and a case study of service network modeling and optimization to demonstrate the capabilities of the DGAL framework. More specifically, we provide a complete unified syntax of DGAL( $X$ ) and its formal semantics, where  $X$  is an external functional language, such as a noSQL database query language JSONiq or the programming language Python. DGAL( $X$ ) is designed around the concept of *analytic models*, encoded in language  $X$ . Analytic models formally describe feasibility constraints and metrics of interest of a (real-world) process as a (deterministic or stochastic) function of fixed and control parameters. Analytic models can describe both “atomic” processes, e.g., for components of supply chain, physical devices or manufacturing equipment, and “composite”, recursively described processes, e.g., service networks involving supply chains, manufacturing processes, and electric power grids.

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