Demystifying Prescriptive Analytics Frameworks and Techniques

Selva Lakshmanan, Madasamy Sornam, Jimmie Flores

Abstract: Big data analytics refers often a very complex process to examine the large and varied data sets to provide the organization to take smarter decisions and better results. Big data analytics is a form of advanced analytics including predictive, prescriptive models and statistical algorithms. The prescriptive analytics is a later stage of the Big data analytics which is not just anticipating what the event will happen as in the predictive analytics but also suggests the decision options and consequences of the decision. The paper addresses the survey of prescriptive analytics and the importance of prescriptive analytics. The prescriptive analytics techniques and methods include machine learning, operation research/management science, optimization techniques, mathematical formulation, and simulation techniques and methods. The paper discusses the techniques and methods, frameworks, and domain applications of prescriptive analytics.

Keywords : Machine Learning, Meta Heuristics, Optimization, Predictive Analytics, *Prescriptive Analytics*

I. INTRODUCTION

The history of the prescriptive analytics starts with IBM who initially coined the term prescriptive analytics and it has been trademarked by Ayata, an Australian software company. The penetration of prescriptive analytics is growing consistently. As of 2018, the market share of prescriptive analytics is around \$2 Billion and it is projected to reach $12.35 Billion by 2026 with compound annual growth rate (CAGR) 26.6% [23].

The basic idea of data analytics refers to the process of extracting useful insights from raw data. There are a number of stages in the big data analytics but major stages are descriptive, diagnostic, predictive, and prescriptive analytics. The descriptive analytics and predictive analytics are well-established areas whereas prescriptive analytics is a quite new and emerging area.

Selva Lakshmanan*, Research Student, School of Business and Technology, Aspen University, United States. Email: selvag@hotmail.com

Dr. Madasamy Sornam, Ph.D., Professor, Department of Computer Science, University of Madras, India. Email: godsor28@unom.ac.in

Dr. Jimmie Flores Ph.D., D.M., Dean, School of Business and Technology, Aspen University, United States. Email: jimmie.ores@aspen.edu

Gartner's data analytics maturity model (DAMM) refers to the different stages of the company and its level of analytics need and how the company can grow and move up to the next level [40]. The value and difficultly increases at each level of the data analytics maturity model. There are five levels of analytics maturity include reactive reporting, advanced reporting, strategic analytics, predictive analytics, and prescriptive analytics. The predictive analytics refers to the insights into what is likely to happen whereas prescriptive analytics refers to the foresight of data that can shape actions and perceptions. Grossmann [16] proposed a framework named Analytic Process Maturity Model (APMM) to evaluate the analytic maturity of the organization and the framework is broadly based on Capability Maturity Model (CMM) (See fig 1).

Fig. 1.Capability Maturity Model

The main purpose of the prescriptive analytics is to identify the issue or an event even before it occurs using statistics and modeling. The prescriptive analytics determines the set of high-value alternative decisions/actions for a given complex set of constraints, objectives, and requirements by using a set of mathematical techniques to improve the business [16]. In big data analytics, the bonding between descriptive analytics and predictive analytics is strongly connected similarly to the bonding between predictive and prescriptive analytics.

According to Hertog & Postek [18], the definition of the prescriptive analytics is unclear and the deep connections between the predictive analytics and prescriptive analytics are neither understood nor exploited. The full potential of predictive analytics can be achieved with the conjunction of the prescriptive analytics with the challenge of a time interval between prediction and proactive decisions. The time gap between prediction and prescription always poses a challenge particularly in real-time and data-driven systems.

The success of prescriptive analytics is based on the reduction of this time interval [24].

For instance, in the Operations Research and Management Science (OR/MS) problems, you can combine the machine learning and OR/MS optimization techniques in developing the prescriptive framework model to prescribe the optimal decisions from the predictions [6]. From the researcher's perspective, most of the software uses the optimization techniques in terms of prescriptive analytics to obtain predictive models rather than implementing prescriptive analytics techniques.

II. ANALYSIS

There are several papers on the descriptive and predictive analytics and the objective of the paper is to investigate the prescriptive analytics and providing the frameworks and techniques/methods of the prescriptive analytics. The next section covers the domains of prescriptive analytics.

A. Frameworks

The predictive and prescriptive analytics requires modeling the problem based on the experts' domain knowledge. There is another alternative to model the problem using a data-driven approach. The predictive and prescriptive analytics are key activities of utilizing the data-driven business model (DDBMs). There are a number of frameworks and methodologies used in data analytics. The Cross-Industry standard process for data mining (CRISP-DM) was the rst model to model data mining and business data analytic process. Still, 15% of the organizations use the CRISP-DM methodology in their predictive model [7].

The proactive decision-making framework Open Data Architecture - Condition Based Maintenance (ODA-CBM) is used in the predictive analytics for naval eet maintenance [36]. The layered architecture in the big data analytics consists of the data layer, batch analytics layers, data storage layers, big data processing/analytics layer, and visualization layer [12]. The analytics layer consists of descriptive, predictive, and prescriptive analytics and also refers to the real-time stream analytics. In healthcare, the data layer consists of data such as electronic health records (EHRs), Social media, Sensors, and lab tests. In the decision management system and real-time analytics, Colonel John Boyd has developed the model Observe-Orient-Decide-act (OODA) loop.

The prescriptive information fusion (PIF) framework is introduced by Shroff et al to integrate predictive modeling, optimization, and simulation. The prediction model uses observations from the field or practice and the optimization model will prescribe the actions[31]. The PIF framework is close to the concept of reinforcement learning. The reinforcement learning is highly desirable for the automatic prescriptive analytics due it is unsupervised there is no need to produce labeled data to produce a model. The prescriptive analytics can refine the prescriptions based on analyzing the new circumstances and the closed feedback loop so that it can improve the prediction accuracy and best decision scenarios.

The 5W1H framework approaches the context of prescriptive analytics with six basic questions such as what, when, where, who, why, and how [14]. The descriptive

analytics methods can answer what, when, and where and predictive analytics methods can answer how and why. The prescriptive analytics methods can answer when, where, and what section. Bergman et al. described the framework JANOS seamlessly integrates two streams of analytics (predictive and prescriptive) using standard optimization modeling elements such as constraints and variables [4]. The purpose of JANOS is to integrate machine learning models with a discrete optimization model. Appelbaum et. al proposed the Managerial Accounting Data Analytics (MADA) framework based on the balanced scorecard methodology [2].

B. Techniques/Methods

The prescriptive analytics is the domain which intersects the data-centric (data science) and problem-centric (operation research) paradigms and resolves the problems using the scientific study, mathematical modeling, and statistical techniques. The predictive analytics relies more on the techniques include linear regression, predictive modeling, forecasting, and prescriptive analytics extends its techniques such as graph analyses, simulation, constraints programming, optimization, and recommendation engines, etc. The main categories of the prescriptive analytics are machine learning techniques, operation research/management science, optimization, meta-heuristics, simulation, what-if analyses, decision support, data mining, and knowledge data discovery (KDD) techniques.

The decision theory lays the theoretical foundations of prescriptive analytics. The decision theory allows you to derive the best course of action based on the objectives and knowledge of the problem [34]. Machine learning, natural language processing (NLP), Operations Research (OR), and applied statistics are major mathematical-based disciplines of prescriptive analytics. Lepenioti et. al. discussed the categories of prescriptive analytics including probabilistic models, machine learning, data mining, mathematical programming, evolutionary computations, simulations, and logic-based models [25]. The roles of machine learning techniques are highly established in predictive analytics compare with prescriptive analytics.

The meta-heuristic has made significant contributions to prescriptive analytics techniques by providing a modern and cutting-edge techniques to handle the real-world complex. The unification of synergies of two fields analytics and meta-heuristics is known as meta-analytics [15]. The simulated annealing, the probabilistic technique in the meta-heuristics is used in the data-driven e-warehousing predictive and prescriptive analytics [38]. There are few prescriptive analytics methods proposed in the bootstrap robust optimization techniques such as Nadaraya-Watson and nearest-neighboring learning [6]. Edali and Yucel proposed the agent-based model that uses the support vector regression (SVR) conjunction with decision-trees to incorporate a tree-based method that extracts the embedded knowledge in the metamodel [11]. Siksnys proposed conceptual model PrescriptiveCPS, the multiagent and multi-role model which continuously taking and realizing decisions in near real-time in the prescriptive analytics tools in the cyber-physical system [32].

Hartmann has extended the CPS system to provide a multi-dimensional graph data model and what-if analyses in prescriptive analytics [17].

In the feature selection process, the genetic algorithms are one of the most advanced algorithms. The genetic algorithm is based on heuristic optimization technique and it can handle the unknown and random by stochastic method function. The fuzzy logic is used in the predictive models in the brace treatment prescriptive analytics [10]. Ito and Fujimaki proposed NP-hard binary quadratic programming (BQP) to formulate the price optimization problem [37]. Hertog and Postek argued that all kinds of predictive models lead to the general mixed-integer nonlinear optimization (MINO) problems and which cannot be assumed to convex. The robust optimization and stochastic optimization techniques can be used in the predictive models [18]. Ceselli et al. proposed the prescriptive analytics approach to integrating the advanced temporal clustering and mathematical formulation to address the mobile edge computing (MEC) orchestration problem [9]. The techniques/methods of prescriptive analytics can be categorized into machine learning, operation research/management science, data mining/knowledge data discovery (KDD), optimization, and meta-heuristics.

III. DOMAINS

To model the prescriptive and predictive analytics system, the extensive domain knowledge and experts' involvement are required. The effectiveness of the system is based on the approach to the complexity of domain and definition of actions and actionable rules. The paper lists the domains and applications of prescriptive analytics in the domain. The domains include Industry 4.0/Logistics, Healthcare, Oil and Gas, and Finance.

A. Industry 4.0/Logistics

Industry 4.0 covers all major areas including logistics, supply chain, retail, sales, inventory management, advertisement, physical systems, networks, fleet management, etc. The prescriptive analytics can be used to identify the possibilities of online recommendations by considering the real-time sensor data particularly in the area of decision-making for condition-based maintenance. In the supply chain, the predictive analytics focuses more on the demand forecasting, capacity planning, production planning, network design, and inventory management. Prescriptive analytics uses mathematical optimization models to derive decision recommendations based on descriptive and predictive analytics.

The SCM decisions can be at strategic, tactical, or at the operational level of the supply [33]. The prescriptive analytics can prescribe warehousing operations such as order picking and order consolidation [38]. Prescriptive analytics solutions are applied in the challenges of digital advertisement ecosystems such as misalignment of incentives, problems at the interaction between supply-side network and advertisers, and the problems at the interaction between ad-exchange and its participants [35].

The arrival time prediction and cost index optimization prescriptive techniques are used in the short-haul flights and airline operations [1]. Also, the prescriptive analytics have used in the long-range aircraft conflict detection and resolution (CDR) problem with the stochastic hidden Markov model [3].

B. Healthcare

The healthcare analytics enables Healthcare organizations (HCOs) to make better decisions and take appropriate actions. US healthcare is adopting electronic health records (EHR) and electronic medical records (EMR) rapidly to capture the volume of clinical information electronically. It has led to exploring non-stationarity on big data analytics and predictive modeling [21].

The popular predictive modeling in healthcare is predicting early hospital readmission. The predictive/prescriptive techniques use the diagnosis-related group techniques (logistics regression, logistics regression with multi-step heuristics, random forest, and support vector machines) and scalable methods such as Stochastic Gradient Descent, and Deep Learning methods [13].

The use cases of the predictive analytics have been limited in the healthcare and the future tends to move towards the prescriptive analytics.

The prescriptive analytics in healthcare supports the decision support but it doesn't tend to replace any human intervention or decision-making i.e., rather it suggests the recommendations for doctors and administrators to use healthcare analytics to support successful outcomes. Prescriptive analytics will play a significant role in the personalized medicine field. Zhuo devised a new prescriptive analytics method using the machine learning techniques such as k-nearest neighbor (KNN) regression, LASSO, and random forest models are used to predict the potential HbA1c and causal inferences to make personalized recommendations in the personalized diabetic management system [39].

Prescriptive analytics can be applied in healthcare applications such as clinical data analysis, financial data analytics, and administrative data analytics. Mohanraj et. al. listed the used cases of healthcare prescriptive analytics such as patient safety, cardiac research clinical outcomes, reducing hospital readmissions, wellness, and disease management, and monitoring baby's heart rate [27]. Also, the data-driven prescriptive models have opened a number of opportunities for improving healthcare for different tasks include early risk prediction of mortality, prediction of hospital admissions, epidemics, clinic capacities, drug dosage optimization, and medical image diagnostic decision support system [28].

C. Oil and Gas

In terms of the currency value, the Oil and Gas industry is the biggest sector in the world. Prescriptive analytics significantly reduces the risk of oil exploration by providing key insights, potential drilling situations, and opportunity areas. Prescriptive analytics can model the constraints and limitations related to fracking exploration [22]. Sappelli et al. listed three important applications of prescriptive analytics viz., predictive maintenance, Exploration of the drill, lift and frack, and automatic drilling support [30].

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D. Finance

The high sophistication of financial sectors has increased the complexity of the financial problems and it requires engineering-based analytic tools for planning, reporting, decision making, and supervisory control. The used cases of prescriptive analytics are portfolio management, banking, credit analysis, banking, and insurance. The financial analytics include risk analytics, fraud analytics, operational analytics, security analytics, HR analytics, and CRM analytics. The large volume of data is generated by digital banking and the predictive and prescriptive analytics can generate meaningful predictions and insights into the digital data [29]. The audit profession has good potential to undertake predictive and prescriptive-oriented analytics in the big data environment [2].

IV. SURVEY

The following table I provides the detailed survey of the articles related to prescriptive analytics with its addressed problem, merits, and used techniques and methods.

Table- I: Survey of Articles

Article	Problem-Addressed	Merits	Methods/Techniques
[1]	Flight arrival time prediction and cost index optimization models for short haul flights	Well defined predictive models and how prescriptive analytics used in the cost index optimization model.	Gradient Boosting Machine, Linear regression, the Optimization model
[4]	Framework of integrating prescriptive and predictive analytics	Detailed algorithmic details on the optimization over neural network and linear regression and analysis of real- world problem of University admission.	Linear regression, logistics regression, neural network, and optimization methods
[5]	Conditional Stochastic Optimization problem for a given imperfect observation and the unknown joint probability distribution factor of the problem	Mathematical constructs of the methods used converting data to predictive prescription and theorems related to data to predictive prescription with uncertainty. Real-world problems such as retailer inventory problem and censor data analysis	Local regression (LOESS), Classification and regression tree (CART), Random Forest (RF), k-NN, kernel methods, and Ensemble methods
[6]	Framework to prescribe an optimal decision based on the uncertain parameters	Mathematical/Operation research formulation of different formulations of the prescriptive analytics	Robust optimization, Statistical bootstrap, Nadraya-Watson Learning, Nearest Neighbors Learning
[8]	Decision making on Condition based maintenance and its framework, the modeling the connection between information space and decision spaces (reactive decision and proactive decision)	Well defined framework with detailed flow of the framework model for condition-based maintenance	Dynamic Bayesian Networks, Hidden Semi-Markov Models, Logistics regression, Baun-Welch algorithm
[13]	Describing and comparing the risk models predicting 30-day readmissions.	Well defined comparison between approaches used in the 30-day readmission issues with detailed results.	Neural networks, logistics regression, penalized logistics regression, random forest, support vector machine
[14]	The prescriptive analytics framework on CKAN cloud.	Covers Healthcare IoT related Big data issues for the prescriptive analytics with overall architecture based on CKAN cloud	5W1H (What, When, Where, Who, Why, and How) method
[17]	Model-driven live analytics, a multi-dimensional graph data model of cyber physical system	Prescriptive analytics on the data on the motion (real-time or near real-time) with temporal concept.	Graph database, Hadoop, Temporal graph, meta-meta model, Gaussian mixture methods
[18]	The gap between the predictive and prescriptive analytics and optimization method	Comparison between the proposed approach with the classical model building with real-time examples and drawbacks	MINO, Robust optimization, Stochastic programming, Model predictive control, and Black-box optimization

[19]	Selection of expansion location for retailers selling add-on products based on the demand of other product.	Predictive and prescriptive analytics of demands of two spatially auto-correlated products between the locations.	Linear regression, support vector regression (linear kernel and radial-kernel)
[20]	The optimal price strategy using the prescriptive price optimization approach	Mathematical formulations for all MIP, BQP, and SDP methods.	Mixed Integer programming, Binary Quadratic Programming, Semi-definite programming, Optimization
[25]	Literature review of prescriptive analytics and prominent methods of implementation	The hierarchical structure of the prescriptive analytics methods with survey	Probabilistic models, machine learning, data mining, statistical analysis, mathematical programming, evolutionary computation, simulation methods, and logic-based methods
[26]	Designing the empirical decision-support system for real-world problem with a combinatorial optimization model	Empirical methods by embedding the different techniques in another technique.	Optimization models, ANN, Mixed Non-Linear Programming, Constraint programming, decision tree
[27]	Literature review and survey of prescriptive analytics in the healthcare s	Well defined the healthcare scenarios where prescriptive analytics can be used	The architectural framework for healthcare analytics
[31]	The unified Bayesian framework for prescriptive analytics information fusion.	Adaptive prescriptive analytics with closed feedback loop and comparison the framework with reinforcement learning concept	Machine learning, simulation, optimization, Bayesian mode
[32]	The complexity of cyber physical system (CBS) and prescriptive analytics tools with mult-agent software	Prescriptive analytics formulation on the cyber-physical systems with multiple techniques	Aggregation technique, What-if analysis, and visualization model analysis
[34]	Conceptualization of coherent view of prescriptive analytics system and its elements	Answering the research question about the constitute elements of IT-based predictive analytics.	Optimization, Heuristics, Simulation, Expert Systems
[37]	Prescriptive analytics for markdown-pricing optimization and price determination for e-commerce retailer	Algorithms for the markdown pricing based on the scenarios	Expectation maximation method, Randomized decomposition framework

V. CONCLUSION

The prescriptive analytics concentrates on how to take advantage of future opportunity to mitigate a future risk and implication of each decision option. The prescriptive analytics possess the uncertainty and complexity. The lack of prescriptive analytics in the practice and a number of researches are required to integrate the predictive models, optimization methods, domain expertise knowledge and decision-making processes.

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AUTHORS PROFILE

Selva Lakshmanan, has received his master degree in computer applications and has over 25 years of IT and ERP experience in business process architecture, application development, support, and optimization with various large public and private sector companies.

Dr. Madasamy Sornam has received her master degrees in Mathematics and Computer Applications and Ph.D. from University of Madras. Her specialties include artificial intelligence, machine learning, image processing, data mining, pattern recognition, and applications.

Dr. Jimmie Flores has earned two doctorates and seven masters. Dr Flores has held management & leadership positions in major companies and Dr. Flores is members of PMI (Project Management Institute), the Scrum Alliance, and the Society for Human Resource Management (SHRM).