From Prediction to Decision Making – Predictive Optimization Technology –

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Abstract

Energy demand forecasting for each city area, sales prediction for each product in a retail store, prediction of decline in customer satisfaction toward provided services, etc. The importance of accumulation and utilization of big data is now recognized widely. Progress in the machine learning technologies, such as in NEC's heterogeneous mixture learning technology is enabling highly precise data-driven predictions. This paper introduces decision making and actual application cases using artificial intelligence (AI) together with the associated challenges that go beyond prediction. The "Predictive Optimization" discussed here is the state-of-the-art technology that allows us to make decisions (what should we do) based on predictions (what will happen).

Keywords

Big data, data science, advanced analysis, predictive analysis, decision making, machine learning, heterogeneous mixture learning, artificial intelligence (AI), mathematical optimization

1. Introduction

Energy demand forecasting for each city area, sales prediction for each product in a retail store, prediction of decline in customer satisfaction toward provided services, etc. The importance of accumulation and utilization of big data is now recognized widely. Progress in the machine learning technologies, such as in NEC's heterogeneous mixture learning technology thereby enables highly precise data-driven predictions. NEC has developed a heterogeneous mixture learning technology[1)2)] and has applied various predictive analysis solutions that include: power demand forecasting[3)], water demand prediction, product sales prediction[4)] and inventory demand prediction[5)].

Machines have begun to use predictive analysis to generate large amounts of predicted information. Attempts to make planning and decisions (what should we do) on the basis of the predicted information as well as prediction (what will happen) are being started at the leading edge of advanced analysis. For example, decision making such as energy production planning to minimize energy wastage, price strategy to maximize store revenue, and promotion planning to maximize satisfaction of each customer have all previously been undertaken by human experts based on their experience. Although it has recently become possible to support customers via predictions based on large amounts of data, the predictions themselves are merely information and are not capable of providing direct support and automation for decision making.

In this paper, we will introduce NEC's "Predictive Optimization" technology, which enables prediction-based decision making using AI. This technology has the following three features:

1) Fusing prediction and optimization
2) Balancing safety (risk) and effectiveness
3) Overwhelming computation speed

In the following, we explain the background and salient points of each feature and go on to introduce case study of their application to the optimization of retail prices. In the demonstration experiment[*1], we optimized

[*1] Off-line validation/trial computations using past data.

the prices of 30 kinds of beverage based on the data of the past two years of a retail store and succeeded in deriving a strategy to bring about 16% higher sales (simulated value) than that achieved from ordinary optimization. Regarding the time taken for the computations, while ordinary optimization (mixed integer programming) is not capable of computations in a realistic period of time, our predictive optimization technology achieved a significant increase in speed by completing computations in less than a second. Thus demonstrating that predictive optimization can maximize the effect and value of decision making.

2. Predictive Optimization Technology

2.1 The Fusion of Prediction and Optimization

The predictive optimization technology brings commercial value by making use of the predictions of heterogeneous mixture learning technology and by adopting information that cannot be directly, thereby making possible advanced optimization that was previously unavailable (**Fig. 1**). Heterogeneous mixture learning technology is a technology for deriving highly accurate predictions with high explanatory capabilities. This is done by identifying the relationships that exist between the various parameters in the huge amounts of data. Our predictive optimization technology performs optimization by using the derived prediction as the input. Now let us see why prediction is necessary for advanced optimization.

This is because the traditional optimization that is based simply on the direct observation of data has a limit. For example, in commodity price decisions, lowering the price of product A may require consideration of the sales of a related product B, as well as an increase or decrease in the sales of product A. Such complicated relationships cannot be obtained directly from the data. It is the heterogeneous mixture learning technology that uncovers the predicted values as well as the relationships between the various factors involved in the optimization.

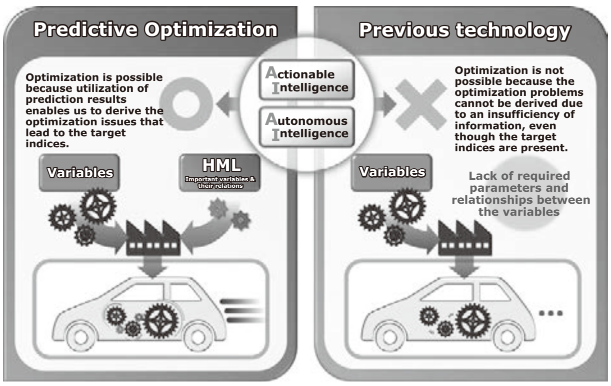

Fig. 1 Fusion of prediction and optimization.

Previously, optimization has been based simply on information that may be clearly observed from the data. Fusing the heterogeneous mixture learning technology makes it possible to utilize the highly accurate predicted values and the estimated relationships as the inputs for optimization. When "following-day-demand" can be predicted and the relationships between product demands can be made clear, it will also be possible to place orders for minimum stock-outs for multiple products. The predictive optimization technology will enable even invisible information sources to be uncovered and provide more profound optimization that will extend far into the future.

2.2 Balance of High Safety and Its Effects

The predicted values and estimated relationships generated by machine learning are "uncertain information" that contain both predictions and estimation errors[*2]. Decisions made based on predictions are always accompanied by risks, in as much that it is impossible to make 100% correct predictions. To make active use of prediction-based decision making in a business environment, it is essential to derive highly effective and high safety (low-risk) planning and decisions by correctly evaluating the risks and effects of the uncertainty that accompanies prediction (prediction errors).

It is a difficult task for humans to identify and to judge quantitatively how prediction errors are produced and which are the cases that might increase profit or loss. The predictive optimization technology learns the trends of errors produced in prediction results and reflects the results automatically to optimization. By this process, it can deal with problems that are hard to deal with by conventional optimization procedures. Such as by the deviation of errors from the normal distribution and increased uncertainty due to the accumulation of errors produced by a large number of predictions by means of unique optimization techniques. Thereby, preventing the significant losses that would be incurred by prediction errors and the derived planned values with which both the safety and effectiveness coexist (**Fig. 2**).

[*2] Errors caused by probable fluctuations of the parameters estimated by machine learning.

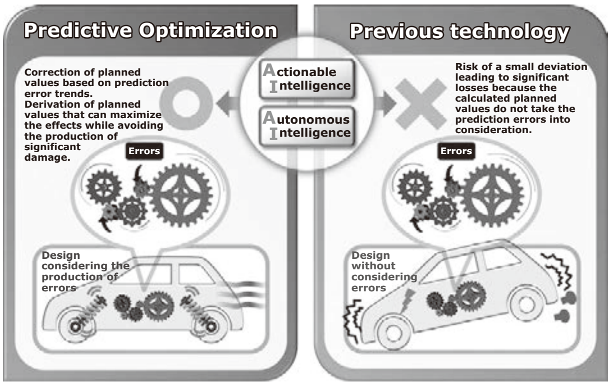

Fig. 2 Optimization considering prediction uncertainties.

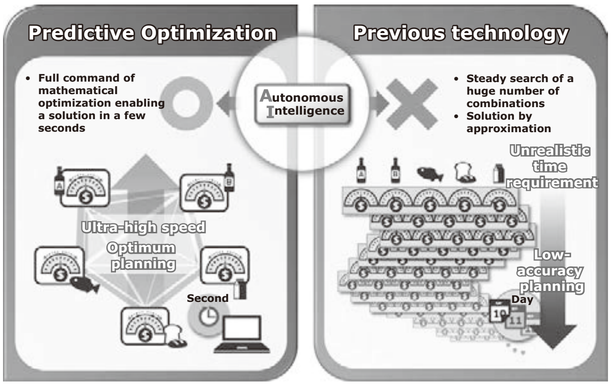

Fig. 3 High-speed algorithm based on graph theory.

2.3 Impressive Computation Speed

Many of the actual decision-making problems can be formulated as "combinatorial optimization". As the variables increase, the combinations to be searched increase exponentially and require a very long time for calculating a solution. Meanwhile, the predictive optimization technology enables a significant speed increase by using a revolutionary and unique algorithm that models the relationships between variables (such as those between the sale and price of articles) as a mathematical "graph" (**Fig. 3**)[6]. By using the predictive optimization technology even a problem that would require an unrealistic computation time if searched via ordinary mixed integer programming[*3] may be solved and can provide an optimum strategy in less than a second. Furthermore, we have also confirmed that the strategy derived via this technology can provide much improved effects compared to those of the mixed integer programming. Combining the significant speed increase and the high interpretability of heterogeneous mixture learning technology enables strategy optimization while testing the various extraneous factors and conditions associated with optimization.

3. Demonstration Experiment of Retail Price Optimization

One of the most significant factors influencing the sale of a product at a retail store is the price. Decisions regarding list prices, including daily discounts and campaign prices are of critical strategic importance that can improve the competitiveness of a store. However, as may be seen with cross price elasticity (the fact that the discount of product A affects the sale of product B) and cannibalization (contradictory relationships between the sales of products A and B), the price and sales are in a complicated relationship in which N-to-N products are intertwined and price settings that rely on human factors such as intuition have their limits. With the demonstration experiment introduced here, we have derived a price strategy that can maximize the total sales of products by simultaneously optimizing the prices of 30 beverages in a retail store.

We first analyzed the sales information[*4] of the 30 products over about two years with the heterogeneous mixture learning technology in order to define the relationships between sales and prices as well as those for external factors such as the weather. The learned relationships are inputs to the predictive optimization technology in order to derive a price strategy that can maximize the weekly sale.

Conventional optimization that does not consider the uncertainty of prediction can formulate this issue as a mixed integer programming problem. In general, however, a mixed integer programming problem requires computation time of an exponential order. According to the experiment, it took more than five hours to obtain the prices of 30 articles even when a commercial high-performance solver[*5] was employed. On the other hand, the predictive optimization technology was able to solve the problem in less than a second thanks to the unique optimization algorithm described in section 2-3 above. This makes possible interactive strategy planning based on simulations by varying the conditions.

When the strategy of calculating with ordinary optimization that does not consider the uncertainty of

[*3] In the example of price optimization described in chapter 3, a computation time of more than five hours was required to calculate the optimum val ues of the prices of 30 articles.
[*4] Experiment data provided by KSP-SP Co., Ltd. (http://www.ksp-sp.com).
[*5] For the purpose of comparison, a GUROBI Optimizer 6.0.4 was used in the present demonstration experiment.

prediction as described in 2-2 (1) and the strategy calculated with the predictive optimization technology that considers the uncertainty (2) are compared; strategy (2) was able to improve the sale by about 16% while strategy (1) had a sale reduction of about 20%*6. This result suggests that strategy (1) attempted to optimize by accepting prediction results that may contain errors and consequently, increased the risk of deteriorating the sale, while strategy (2) could avoid risk by considering the uncertainty of prediction errors and consequently succeeded in deriving a strategy that has a high probability of improving the sale.

4. Expanding Scope of Application

The predictive optimization technology is a universal technology that implements decision making, planning and decisions (what should we do) based on prediction (what will happen) by means of artificial intelligence (AI). For example, cases of water supply operation management, purification, storage and distribution are planned based on the experience of administrators according to the predicted water demand value. This method has nevertheless been accompanied with issues, such as the large amount of water wasting due to excessive treatment, high electrical energy costs due to inefficient pump operations and frequent changes of plan caused by demand underestimations.

According to our trial calculations assuming application in the technology fields introduced herein, it would be possible to reduce the energy cost by up to 20% and decrease the planned changes due to demand underestimation by 90%. Furthermore, the scope of application of predictive optimization technology extends over a wide range of fields. These include the continuing retention of high customer satisfaction by means of campaigns based on satisfaction predictions, and the safety and security improvement of social infrastructures due to maintenance based on equipment/infrastructure degradation predictions.

5. Conclusion

In the above, we introduced the technical features of the predictive optimization technology together with the results of its demonstration experiment. These features implement decision making (planning and judgment) based on predictions using artificial intelligence (AI). As the big data analysis and AI technology are increasing in importance, attempts to make business decisions under the support of AI are expected to increase even further in the future. The authors of the present paper aim to enable decision making in the field of large-scale social systems, which are difficult to achieve by humans alone. In order that we may contribute to the realization of a better society, this will be done by means of the heterogeneous mixture learning and predictive optimization technologies.

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*6 Though a detailed explanation of the statistical confidence interval is omitted here, it can be said that roughly the 90% confidence interval means that a certain event (no more than X% of sale increase) is rejected with a 90% probability.

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