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An expert system for financial performance assessment of health care structures based on fuzzy sets and KPIs

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ABSTRACT

Interest in the field of performance assessment of health care structures has grown in recent decades. In fact, the possibility of determining overall performances of health care structures plays a key role in the optimization of resource allocation and investment planning, as it contributes to reducing the uncertainty of future performance. In this context, key performance indicator (KPI) tools have been developed to assess the performance of health care structures from process, organizational, cost, financial, and output points of view. In practice, they are periodically calculated, and the effect of several KPIs on the overall performance of health care structures is determined by management through human judgment or software that provides synthetic dashboards. Given their non-stationary nature, performance assessment and forecasting are generally tackled by employing adaptive models, but these approaches cannot reflect the holistic nature of performance itself, nor take into account the impact of KPIs on the overall performances. In order to overcome these shortcomings, this study presents an expert system whose engine relies on fuzzy sets, in which the input–output relations and correlations have been modeled through inference rules based on time-series trends. The focus is on the financial performance assessment of a health care structure, such as a hospital. The approach is of an interdisciplinary kind, as several indicators were taken as inputs that relate to output, process, and cost KPIs, and their impact on the output measure, which is of a financial kind (namely the total reimbursement). The output measure calculated by the expert system was then compared with that predicted using only adaptive forecasting models, and the error with respect to the actual value was determined. Results showed that measures determined by fuzzy inference, able to effectively model actual input–output relations, outperform those of adaptive models.

1. Introduction

Today, the possibility of assessing and forecasting health care performance is of fundamental importance in properly planning investments and allocating financial resources. In accomplishing these tasks, managers usually rely on Key Performance Indicators (KPIs) able to support them in the decision-making process, providing process, organizational, output, cost, and financial indicators. Managers analyze KPIs and seek to determine the overall effect of such variables on health care performance, usually relying on human judgment or software that provides synthetic dashboards. In order to forecast future health care performance, the non-stationary behavior of KPIs is usually modeled through adaptive forecasting models, but these are unable to capture the effect of several variables simultaneously. However, in order to make decisions, the effect of all the variables affecting the overall performance has to be taken into consideration. Thus, traditional approaches, aimed at providing KPI dashboards are not sufficient; in fact, they do not allow us to infer the performance in relation to multiple factors interacting simultaneously, as they do not account for the holistic behavior of health care performances, assessment of which has to be characterized by multidisciplinary approaches. In other words, traditional tools do not allow us to synthesize the overall impact of several input variables on the global performance. For this reason, it is necessary to model the simultaneous role of different KPIs in determining the final score. In this regard, there is little in the literature, with only a few cases of frameworks aimed at determining the global health care performance based on a set of input factors. This paper presents an expert system for the assessment of financial performance of health care structures that takes into consideration the simultaneous impact of the process, cost, and output KPIs, relying on a fuzzy-based inference engine,

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whose knowledge base is represented by a data warehousing tool developed within the Smart Health 2.0 project (PON04a2_C).

2. Review of the literature and goal of the study

2.1. KPIs and health care performance assessment

Health care performance assessment has attracted the interest of researchers in recent decades, as the possibility of monitoring performances through a set of KPIs is seen as a suitable tool for investigating the actual state of health care structures from organizational, processing, and clinical standpoints.

Based on classification reported by Kalinichenko et al., [20], health care KPIs can be divided into the structure, process, outcome, and output measures. "Structure" involves organizational characteristics of the caregivers, including human, physical, and financial resources. In particular, financial resources can refer to reimbursements recognized by the regional/national government, and to parameters used to determine the entity of reimbursements, such as diagnosis-related group (DRG) weights. "Process" indicates those activities involving health care practitioners and patients, such as length of stay in hospitals, procedures, and other treatment practices, and use of prescribed medicines. "Outcome" refers to the impact of these activities on a patient's current and future health status. Finally, "Output" indicates the quantity of health services provided, without taking into account effects of these activities on patients' health, e.g., the number of visits or patient volume.

It is worth mentioning that based on the use one can make of KPIs, they can be divided into internal, namely that used to monitor and improve the outcomes of care processes, and external, used by governments, patient organizations, and payers to assess the quality of a health care provider, and to compare it with the performance of other health caregivers [4].

There are several studies in the literature that deal with the topic of KPIs for health care structure assessment. In particular, the attention of researchers has been focused on identifying the most suitable panel of KPIs in relation to the characteristic of the specific health care structure. As an example, Berg et al., [4] described the development and implementation of the first national, public, and obligatory set of hospital performance indicators in Holland. They focused on effectiveness and safety KPIs, and developed a set of indicators with the aim of monitoring the quality of the care delivered by providers, enhancing the transparency of the hospital sector, and prompting individual hospitals to improve their scores. Burge et al., [8] developed a set of quality indicators (QIs) for primary care practice, for the primary prevention and chronic disease management of ischemic heart disease, hypertension, hyperlipidemia, and heart failure using a four-stage modified Delphi approach. Bradley et al., [6] determined a set of 33 indicators to assess the quality of a childhood cancer system. Finally, Boulkedid et al., [7] proposed a panel of indicators for maternity units, while Cruppè et al. (2015) investigated the feasibility of 48 quality indicators in ambulatory care in Germany through a cross-sectional observational study. However, the authors mentioned limited their contribution to the determination of set of KPIs for health care, and did not consider the simultaneous impact of different KPIs on the overall health care structure performance.

KPIs can commonly be characterized by a non-stationary behavior in time, as they are affected by several exogenous variables that cannot be controlled by health care managers. For example, the diffusion of specific bacteria can promote some diseases that involve a greater number of patients to be hospitalized, with a consequent increase in health care costs. Moreover, hot summers can increase the need for care of respiratory problems and heart attacks, while cold winters can increase the need for pulmonary care. Financial and legislative decisions, such as decisions about the amount of reimbursements for health care services provided, also affect health care performances.

The possibility of forecasting future behavior of health care performance is a topic frequently addressed in the literature, as reported for example in Jones and Spiegelhalter [19]. Approaches usually used are based on forecasting tools that rely on regressive models (see, for example, [16]) that are simple to apply but, undoubtedly, not very flexible. In fact, given that health care policies and governance are affected by several external conditions (exogenous variables), e.g., legislative decisions, seasonality affecting some kind of diseases, the performance assessment is in turn a holistic issue. Thus, holistic methodologies, such as adaptive forecasting models should be preferred for modeling such complex systems. Adaptive forecasting usually allows us to model the health care structure behavior through a series of additive components (level, trend, seasonality) that characterize the structures themselves.

In this setting, the possibility of employing adaptive models and generalized exponential smoothing methods, which are holistic approaches, can be of great help in modeling and forecasting such phenomena. The classical Bayesian linear regression models are unable to reproduce some of the features frequently observed in non-stationary processes, while, on the contrary, in such cases time-series methods are extremely effective. Linear regression models allow us to model only phenomena in which the future behavior depends on that of previous periods. In particular, by definition, they are used when a phenomenon has a linear behavior in time (see, for example, [13]). In this context, non-stationary phenomena, such as those considered in this work, cannot be interpreted by models that are not flexible and able to capture the variation of data within short time periods. Conversely, adaptive forecasting methods can easily model phenomena that usually characterize non-stationary processes where the trend of data changes in the short term, and can be found, for example, in Simple Exponential Smoothing (SES), and Holt's and Winter's models [11]. Such models allow us to interpret level, trend, and seasonality of data by taking into account short-term variations, modeled through the use of constants, able to represent the impact that past data can have on future trends. In order to highlight these differences, in this study a fuzzy-based expert system is presented, and adaptive models are employed to test the effectiveness of results given by the designed fuzzy system, comparing data forecasted through adaptive models with those that arise from the fuzzy system itself.

2.2. KPI-based frameworks for performance assessment

Drivers for assessing health care performances through suitable frameworks arise from the need of measuring and raising the productivity of health care systems themselves [21]. For this reason, setting up a panel of KPIs for health care performance assessment can be a useful approach to improving knowledge with respect to specific aspects of health care performances, but is unsuitable when global and cross-dimensional knowledge is required. As observed by Toplicianu et al., [38], "*the atypical nature of health care services market and the specificity of the activity in hospitals, determines that performance analysis is a complex, multifactorial process.*" In this respect, methodologies in the literature neglect the importance of a comprehensive assessment that allows us to know how several different input variables simultaneously impact global performance. In order to satisfy this requirement, frameworks that allow us to determine overall performance should be applied. In other words, a holistic approach is needed to model the dependence of global health care performance on multiple factors that simultaneously interact. Examples of such approaches can be found