The Suitability of Artificial Neural Networks in Service Quality Control and Forecasting for Healthcare Contexts

Research-in-Progress

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ABSTRACT

Over the last decade there has been considerable research into the area of service quality. Service, however, as an intangible, perishable, and heterogenic transaction, is very difficult to quantify and measure, and little success has been reported on a systematic approach in modeling of quality of service transactions (with SERVQUAL and its derivatives as the notable exception). In this paper, we propose an Artificial Neural Network (ANN) to monitor quality of service transaction as a dynamic and real-time monitoring and forecasting system. ANNs are widely used in many engineering fields to model and simulate complex systems. The resulting near-perfect models are particularly suited for applications where real-world complexities make it difficult or even impossible to mathematically model the system. Given the complex nature of healthcare decisions, the following reports on a research in progress study that focuses on applying ANN to a specific healthcare context of the emergency room.

Keywords

Service, Service Quality, Artificial Neural Network, ANN, Healthcare, emergency room, emergency department

INTRODUCTION

The service sector in developed countries such as the United States and Australia currently accounts for some 80 per cent of all economic activity (DFAT 2008; Spohrer et al, 2007). The service economy encompasses not only private enterprise but also the diverse services provided by government, such as education and healthcare. Service systems can be described as dynamic configurations of resources (people, technologies, organizations and shared information) that can create and deliver value to customers, providers and other stakeholders (IfM and IBM, 2008: p.18).

Despite the sheer size of economic activities that are classified as services, service quality remains an abstract and elusive construct mainly because of three unique features: intangibility, heterogeneity, and inseparability of production and consumption of services(Parasuramaran A., Valarie A. Zeithaml et al. 1985). There is not even global consensus on what constitute quality in service transactions; there are indeed a number of definitions for quality. One of the most comprehensive definitions of quality is the "degree to which a set of inherent characteristics fulfils requirements"(ISO 2005). In this definition, requirements is defined as the "need or expectation that is stated, generally implied or obligatory"(ISO 2005). This definition of quality is different than that defined in manufacturing, for example, where definition of the requirements and hence the quality is set and measured objectively by such indicators as durability and number of defects (Crosby Philip B. 1979; Garvin David A. 1983).In the absence of objective measures, subjective methods such as SERVQUAL (Parasuramaran A., Valarie A. Zeithaml et al. 1988), SERVPERF(Cronin J. J. and Taylor S. A. 1992), Qualitometro (Franceschini F., Cignetti M. et al. 1988)have been developed and used extensively in service sector.

Computational techniques and simulation methodologies have played a significant role in modeling and optimization of production and process management over the past few decades. Lack of objective measures in services however, has hindered adoption of simulation, control, and computational techniques in this section of the economy. There is now a clear and growing understanding amongst service scientists that there is a need for a modeling or simulation tool for services.

Artificial neural networks (ANNs) are computational networks that attempt to crudely mimic the networks of neurons of biological system such as that of humans or animals (Daniel Graupe 2007). ANNs belong to a category of meta-heuristic modeling, control, and optimization algorithms, called Evolutionary Algorithms (EAs). EAs are inspired by nature through exhibiting complex collective behavior from a collection of seemingly simple agents. These include artificial neural networks, genetic algorithm, tabu search, ant colony optimization and simulated annealing. Most of these techniques have long been used in engineering and in industry; there are reports of the application of ANNs for example, in quality control (Abbasi Babak 2007). Their application in quality control however, has been mostly limited to manufacturing industry. We propose there is merit in considering EAs in service quality control and service quality forecasting.

In the following section we cover service quality as it has been studied in academia, followed by an introduction to ANNs. We conclude this paper by summarizing advantage and disadvantage of using ANNs in service quality control and service quality forecasting as well as a case study in healthcare industry.

SERVICE QUALITY

The concept of service quality as a whole construct is large and varied. The conceptual foundation for service quality was emerged from the works of a handful of researchers who examined the meaning of service quality (Sasser W. W., Olsen R. P. et al. 1978; Gronroos Christian 1982).

Service quality is usually expressed from customer point of view as a function of customer's expectations of the service compared to the perception of the actual service experience (Gronroos Christian 1984; Parasuramaran A., Valarie A. Zeithaml et al. 1985; Johnston R. and Heineke J. 1998). Imrie et al (Imrie B. C., Cadogan J. W. et al. 2002) showed that using service quality as a key point of market differentiation positively influenced customer retention and market growth. Interestingly, Parasuramaran et al (Parasuramaran A., Valarie A. Zeithaml et al. 1988) stated that in measuring perceived service quality, the level of comparison is what a customer *should* expect, whereas Mahdavinia (Mahdavinia H. 2007) prefers in measuring customer satisfaction, the appropriate comparison is what a customer *would* expect. In addition, service levels need to be set and strategies devised that first recognize the relative impact of individual factors on overall perceptions and secondly, link them to organization's quality strategy (Johnston R. and Heineke J. 1998).

Overall there have been five predominant service quality measurement tools reported in literature since 1991. These tools can be summarized in chronological order in table 1:

Tool	Description
SERVQUAL	SERVQUAL is used to measure consumer's and service providers' expectations and perceptions. This approach enables the exceptions and perceptions gaps to be assessed, while providing a measure of service quality gap and service delivery gap. According to Parasuraman et al model (Parasuramaran A., Valarie A. Zeithaml et al. 1988), the gap between consumer's expectations and perceptions are a function of several other gaps in the service delivery process (Mangold G. and Emin B. 1991). Some other models were proposed after the first introduction of SERVQUAL.
Qualitometro	Qualitometro (Franceschini F., Cignetti M. et al. 1988) is founded on the determinants of service quality. Customer expectations and perceptions are evaluated in two distinct moments. Quality evaluation is carried out by means of a comparison between quality and expectations and perception profile. Qualitometro employs the same semantic scale and dimensions as SERVQUAL (Mahdavinia H. 2007).
Two-way	Two-way used latent evaluations factors based on the theory that service quality is evaluated by answers given by customers about "objective" (quality attribute) and "subjective" (satisfaction level) (Schvaneveldt S. and Enkawa T. 1991; Mahdavinia H. 2007)
SERVPREF	Cronin et al (Cronin J. J. and Taylor S. A. 1992) proposed SERVPREF based on their survey on theory that service quality is evaluated by perception only. The key difference with SERVQUAL is that only perceptions is evaluated (Mahdavinia H. 2007).
Normed quality	Normed quality (Teas R. K. 1994) is uses the distinction between ideal expectation and feasible expectation to calculate service quality. It also employs the same semantic scale and dimensions as SERVQUAL. Normed is the second well-known model (after SERVREF) that is derived from SERVQUAL (Ghoseiri K. and Pishdad S. 2006)

Table 1 The Five Major Service Quality Measurement Tools

In addition to the well-known service quality models described above, there are other less-known models (Technical and functional quality model (Gronroos Christian 1984), GAP model (Parasuramaran A., Valarie A. Zeithaml et al. 1985), Attribute service quality model (Haywood-Farmer J. 1988), Synthesised model of service quality (Brogowicz A.A., Delene L.M. et al. 1990), Performance only model (Cronin J. J. and Taylor S. A. 1992), Ideal value model of service quality (Mattsson J. 1992), Evaluated performance and normed quality model (Teas R. K. 1993), IT alignment model (Berkley B.J. and Gupta A. 1994), Attribute and overall affect model (Dabholkar P.A. 1996), Model of perceived service quality and satisfaction (Spreng R.A. and Mackoy R.D. 1996), PCP attribute model (Philip G. and Hazlett S.A. 1997), Retail service quality and perceived value model (Sweeney J.C., Soutar G.N. et al. 1997), Service quality, customer value and customer satisfaction model (Oh H. 1999), Antecedents and mediator model (Dabholkar P.A., Shepherd C.D. et al. 2000), Internal service quality model (Frost F.A. and Kumar M. 2000), Internal service quality DEA model (Soteriou A.C. and Stavrinides Y. 2000), Internet banking model (Broderick A.J. and Vachirapornpuk S. 2002), IT-based model (Zhu F.X., Wymer W.J. et al. 2002), Model of e-service quality (Santos J. 2003)).

All the above service quality models share a common feature; they evaluate quality of services through the same approach; they apply questionnaire or other data gathering tools and evaluate the quality based on their respective subjective concepts.

Many quality characteristics can be measured and stated as a numerical value. For instance, service delivery may be timed and reported in seconds or minutes or hours. These types of quality characteristics are called "variable characteristics". Advantage of questionnaire-based approaches is in their ease of collecting and the use of variable characteristics. There are however, there are other types of measurements that can only assume nominal (reject, accept), ordinal (bad, good, excellent), or categorical (married, single, divorced) values. These are called "attribute characteristics". Collecting and processing of attribute characteristics are a much harder proposition as they inherit subjective principal and values. We propose the use of Artificial Neural Networks (ANNs) in order to overcome the complexity in processing these tacitly implied and subjective measurements. ANNs have been used in engineering and manufacturing, to the best of the author's knowledge they have not been applied in service quality control and forecasting.

Artifical Neural Network

Artificial Neural Networks (ANNs) mimic biological neural networks to model and solve a variety of problems arising in forecasting, function approximation, pattern classification, clustering, and categorization (Pao Y.H. 1989). There are different classes of network architectures including *single-layer feed-forward networks*, *multi-layer feed-forward networks*, and *recurrent networks(Simon Haykin 1999)*, but figure 1 shows a basic concept of a nonlinear ANN model.

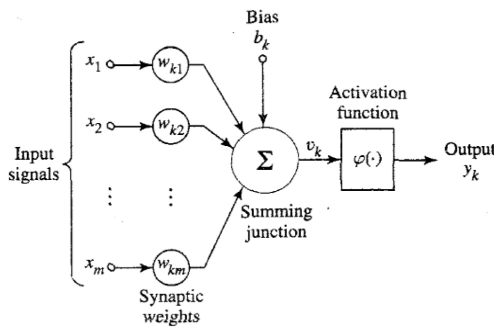

Figure 1 — nonlinear model of neuron

After constructing a neural network, it needs to be trained based on some available data (different inputs and their corresponding outputs) to be able to forecast the output for future inputs with an acceptable error level through an ongoing modification process. The property that is of primary significance for a neural network is the ability of the network to learn from its environment, and to improve its performance through learning. Learning is a process by which the free parameters of a neural network are adapted through a process of stimulation by the environment in which the network is embedded. The type of learning is determined by manner in which the parameter changes take place. There are different types of learning including *unsupervised learning* and *supervised learning*. In the supervised training process, the user plays an important role as the network learns. However, in an unsupervised process the user lets the network train itself (Simon Haykin 1999).

Merits and demerits

Generally, the use of neural networks offers useful properties and capabilities including but not limited to: (Simon Haykin 1999)

- *Nonlinearity*. It can be linear or nonlinear.
- *Input-Output Mapping*. The synaptic weights (free parameters) of the network modified to minimize the difference between the desired response and the actual response of the network produced by the input signal in accordance with an appropriate statistical criterion.
- *Adaptivity*. It has a built-in capability to adapt their synaptic weight to changes in the surrounding environment.
- *Uniformity of Analysis and Design.* Basically, neural network enjoy universality as information processors.

- *Neurobiological Analogy*. The design of a neural network is motivated by analogy with the brain, which is a living proof that fault tolerant parallel processing is not only physically possible but also fast and powerful.

Regardless of all aforementioned merits, neural network has the following drawbacks(Jerome Friedman, Trevor Hastie et al. 2001):

- Trial and error element to building good models (In training phase)
- It is hard to interpret what is happening in the model (Black Box) and people only see the inputs and outputs
- Model performance relates to starting input values and parameters.

Application of Artifical Neural Network to service quality

In spite of considerable number of available service quality methods, there are some shortcomings shared between them:

1. Firstly, all proposed methods for quality control in service industry are somehow subjective and they are mostly designed based on SERVQUAL. These models employ static methods for data analysis. A periodical analysis can be performed in a regular base (e.g. monthly, 6 monthly, yearly and etc) if trends are to be determined. These methods are retrospect and are not able to monitor service quality in real-time. Whereas, in dynamic methods, one can monitor quality of delivered service in real-time (as the service is being delivered). Based on the past history (training data set), and real-time data gathering, artificial neural networks have the ability to forecast the outcome (service quality). Exactly as humans deal with imprecise data, service quality forecasting can be performed even in the case of imprecise or imperfect real-time data.
2. Secondly, in subjective methods, the correlation between different factors is not reckoned and each characteristic (e.g. reliability, responsiveness and etc.) is monitored through one or more questions in the questionnaire. However, in reality characteristics and attributes of service transactions do correlate and can affect service quality indirectly. Considering these characteristics in isolation ignores such indirect consequences.
3. Thirdly, in applying subjective model based on questionnaire or other means of data gathering, some variable data are missed or converted to numeric attribute. For instance, qualitative values are usually given numeric rankings. Artificial neural networks can deal with qualitative values as they are, alleviating this limitation.

Based on the above, it seems the use of ANNs for service quality control and service quality forecasting is well justified. A model for applying ANNs in service quality control is proposed in Table 2.

Phase	Description
Problem definition	Case description, problem assumptions (service quality model …)
Designing	Type of model, type of connections, number of layers, number of neurons, activation function, cutting value
	Estimating parameters (Based on historical data)
	Generating training data based on estimated parameters
Training	Training of neural network
Verification	Testing trained network based on random generated or historical data
Programming	Coding and running the network based on related assumption (cutting value and ...)
Validation	Validation of network in real case study

Table 2 — A model for applying ANN in service quality

Application to Healthcare context

There are some different services that can be nominated in application case study e.g. education, public transportation, banking, healthcare, and so forth. In comparison with other types of servicing, healthcare providers face many challenges, while they are concurrently under public scrutiny as consumer demands escalate. Medical care quality control and improvement as confidence in the medical community providing safe and effective patient care. Note that poor quality in patient care processes can run the spectrum from minor dietary issues to patient morbidity and fatality. It seems that applying a biological-origin concept in health care industry would be interesting. (Ginny W. Frings and Laura Grant 2005). Health care is the most crucial service industry because of its nature of zero tolerance for mistakes and potential for reducing medical (Y.H. Kwak and Anbari 2006). Health care is the largest service industry accounting for 17 percent of the US GDP ahead of education at 10 percept (Richard C. Larson 2009). There are about 7,500 hospitals in the United States but about 4,000 institutions of higher education (Richard C. Larson 2010).

The Commonwealth Fund, in its annual survey, "Mirror, Mirror on the Wall", compares the performance of the health care systems in Australia, New Zealand, the United Kingdom, Germany, Canada and the U.S. The Organization for Economic Co-operation and Development (OECD) also collects comparative statistics, and has published brief country profiles (The Commonwealth Fund 2007; Organization for Economic Co-operation and Development 2008; Wikipedia 2010)

The Institute of Medicine's definition of quality has proved of enduring usefulness: "Quality is the extent to which health services for individuals and populations increase the likelihood of desired health outcomes and are consistent with current professional knowledge"(Mark R. Chassin 1998).

Some operational inefficiencies are associated with the direct medical service delivery process. Others are associated with the administrative, logistical, and operational side of the healthcare delivery system. Both areas can benefit from systematic process innovation activities (Henk de Koning, John P. S. Verver et al. 2006).

A lot of different attribute and variable quality characteristics can be considered in healthcare to monitor predict and improve. (Loey Sehwail and Camille De Yong 2003; Richard Stahl R, Schultz B et al. 2003) posit that the quality characteristics in health care can be classified into four categories:

- Service level (e.g. access to care, wait time, service time);
- Service cost (e.g. cost per unit of service, labor productivity);
- Customer satisfaction (e.g. patient or family, referring physician, employee);
- Clinical excellence (e.g. guidelines for medication or treatment, standard procedures for patient monitoring

From different angle, Elizabeth A. McGlynn et al. (Elizabeth A. McGlynn, Steven M. Asch et al. 2003) proposed different quality indicator in three types of care including preventive, acute and chronic and in four different functions including screening, diagnosis, treatment and follow up. In an analytical paper published by The Quality in Australian Health Care Study (QAHCS), Ross McL Wilson et al. analyzed the cause of adverse events resulting from health care in Australia from different categories like human error categories, delay categories, treatment categories, and investigation categories(Ross McL Wilson, Bernadette T Harrison et al. 1999).

A case study in Healthcare

In order to check the application of ANN in service quality control and forecasting in healthcare industry. A case study is under progress in emergency department of one of the biggest hospitals in Melbourne, Australia. This emergency department primarily serves an adult population and has a yearly attendance of over 28000 patients with 10000 admissions to hospital. We have chosen such an approach since as noted by Yin (1994, 2003) an exemplar case study is a very appropriate methodology when conducting such exploratory and theory building research. In addition we subscribe to rigorous qualitative techniques as outlined by Kvale(2008), Boyatzis(1998) and Yin(2009) regarding conducting of rigorous qualitative research and construction of appropriate themes for thematic analysis.

In this study, the output of the network is considered "waiting time to see a doctor" with the purpose of finding the most critical input factors on waiting time to decrease that and consequently improve customer (patient) satisfaction as well as forecasting the patient's waiting time in future based on the ANN model. The primary model parameters are shown in table 3.

Discussion and Concluding Remarks

Service quality and methodologies of measuring it were discussed and then from the case vignette contextualized for a healthcare context. In this way we demonstrated the potential benefits of applying ANN into healthcare to facilitate the achievement of superior healthcare delivery. The gaps in the currently available methodologies were highlighted. Based o the lessons learnt in manufacturing in dealing with analogous problems, the use of Evolutionary Algorithms (EA) in service quality control and forecasting are proposed, and a simple model for applying artificial neural networks (a sub-class of EA) is presented.

For completeness, it is noted that the application of artificial neural networks in service quality control and forecasting have the following characteristics:

1. No restriction on the type of inputs and outputs (qualitative values, quantitative attributes, or any combination thereof)
2. No assumption is made on the statistical distribution of variables and their interdependence
3. No limitation on the number of inputs and outputs (although it is noted that as the number of inputs and outputs increase, the network might become prohibitively complex).
4. No requirements on access to large data sets. EV can be trained and used with much smaller data sets than statistical methods afford.
5. Computationally very efficient, which can translate into much faster data analysis; affording near real-time data analysis in the case of artificial neural networks.

We believe artificial neural networks are a prime candidate in service quality control and service quality forecasting. Research is already underway in designing and applying an artificial neural network as a dynamic model for monitoring and forecasting of service quality in the healthcare industry. It is a research in progress and at present which is in modeling phase. The model parameters have already been determined and the data gathering is in place simultaneously. In next step, the designed model is trained, verified and validated using the historical and fresh data.

Model parameters	**Measure**	**Description**	**Type of Measure (attribute/variables)**	**Importance Weight (1-5)**	**Operational Range**
Output	Y	Waiting Time	variable		0-480 minutes
Input Signals	X1	Age	variable	3	0-110
	X2	Gender	attribute	1	M/F
	X3	Time of Arrival	variable	4	0:00-24:00
	X4	Day of Arrival	attribute	4	Mon>Sun
	X5	Mode of Arrival	attribute	3	Ambulance vs walk-in
	X6	Acuity	attribute	4	1,2,3,4,5
	X7	Presenting Complaint	attribute	2	Gastrointestinal/Respiratory/Cardiovascular/Neurological/Eyes/Ears/Injury-minor/Injury-Major/psychiatric/genitourinary/skin/general/musculoskeletal
	X8	ED Occupancy	variable	4	0-100%
	X9	Hospital Occupancy	variable	4	0-100%
	X10	%ED occupancy patients waiting for beds	variable	4	0-100%
	X11	Arrivals per Hour	variable	4	0-20
	X12	Discharges Per Hour	variable	3	0-20
	X13	Medical Staffing (hourly)	variable	5	2 to 15
	X14	Medical Staffing including Med Students (hourly)	variable	5	2 to 20
	X15	Nursing Staffing (hourly)	variable	4	3 to 25
	X16	Clerical Staffing (hourly)	variable	4	1 to 10
	X17	Orderly Staffing (hourly)	variable	3	1 to 6
	X18	Seniority (%specialist)	variable	3	0-100%
	X19	Medical Seniority (%specialist)	variable	3	0-100%
	X20	Nursing Seniority (%Div)	variable	3	0-100%
	X21	% staff on last hour of shift	variable	4	0-100%
	X22	Doctor "output" per hour	variable	4	2 to 45

Table 3: ANN model parameters

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