Eur. Transp. Res. Rev. (2017) 9: 23
DOI 10.1007/s12544-017-0241-0

ORIGINAL PAPER

A data-driven quantitative assessment model for taxi industry: the scope of business ecosystem's health

Yong Zhang[1] · **Miner Zhong**[1] · **Yunjian Jiang**[1]

Received: 1 December 2016 / Accepted: 12 April 2017 / Published online: 28 April 2017

Abstract
Introduction The taxi industry has boomed over the years, both in street-hail and dispatch market. However, few studies focus on comprehensive perspectives, which make decisions such as implementing regulative or incentive policies difficult. As an economic community working in the value-oriented process, the taxi industry requires a holistic performance evaluation to determine how to adapt strategies to survive and grow.
Methods This paper proposed the concept "Taxi Industry Health degree" based on the theory of Business Ecosystem and the evaluation of its health. A four-layer criteria set is developed from aspects of robustness, productivity and sustainability, and weights are determined through Analytic Hierarchy Process.
Results A synthetic evaluating model combining Fuzzy Comprehensive Evaluation and Artificial Neural Network is used to maintain the goal of multi-criteria decision-making. With the GPS and Taximeter dataset of taxicabs in the whole taxi industry in Wuxi, the model is applied to empirical studies.
Conclusions This paper provides sensibility analysis on not only the company's order volatility, revenue growth and utilization of resources, but also influence on citizen's welfare, energy consumption and environmental pollution, which enables practical regulations and policies within taxi industry.

✉ Yong Zhang
zhangyong@seu.edu.cn

Miner Zhong
evelovestokyo@163.com

Yunjian Jiang
jyj402@163.com

[1] School of Transportation, Southeast University, Nanjing, Jiangsu 210096, China

Keywords Taxi industry · Quantitative analysis · Business ecosystem · Health degree · Combine evaluation

1 Introduction

Taxi industry thrived in China after the reform in 1978, and it has developed for nearly 40 years. As shown in Fig. 1, the number of taxis in China has reached about one million for the last ten years, and statistics in Jiangsu province play an important role (*China Statistical yearbook 2005–2015*). Although the service quality was improved and most of the travel demand was met, there appear negative anticompetitive practices, which would consequently impede the development. Some taxi companies levy very high operation fees to obtain profit, which results in poor service and driver's pressure [1]. In recent years, some local governments has prohibited for-profit ridesharing from making profits, which provides similar service with traditional taxi [2]. Thus, performance evaluation is needed to demonstrate the existing demand trends, operation peak, stakeholders concerns, and potential needs [3].

Researchers identified four different segments: hailing, taxi rank, and pre-book segment [4]. Some adds the contract segment [5]. In most countries, taxi services are provided by companies and individual operators. Other stakeholders within the industry include taxi associations and regulatory authorities. Taxi fare are regulated in most European countries, and entry regulation were established in some countries such as Belgium, Italy, France, etc. [6]. In some other countries, deregulation policy showed great impact on taxi industry. The Netherlands saw sharp increase in taxi number too, but the service quality has declined [7]. In South Africa, the minibus taxi industry accounts for 67.9% of the public transport market. Although metered taxis exist, they do not provide a

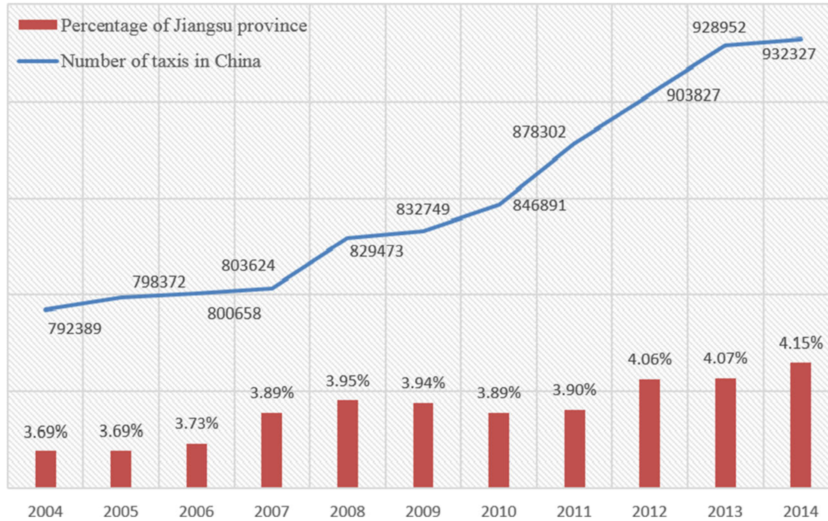


Fig. 1 Number of taxis in China and Jiangsu province (2004–2014)

big share [8]. Therefore, it is of great significance to have an efficient and comprehensive evaluation tool to gauge the impact of new policies.

For both well-established companies and new ventures in taxi industry, success requires strategic thinking to make use of resources and capabilities [9]. The term "Business Ecosystem" means a network of actors interact with each other with an essential technology for survival and success [10], the health of which are shown in its longevity and growing propensity [11]. The performance indicator of business ecosystems proposed by previous researchers are robustness, productivity and niche creation [12]. Understanding the existing taxi industry performance helps to create sound models and policies for improving the quality of overall business ecosystem. In this paper, a multi-dimensional evaluation framework is introduced based on theories of business ecosystem, sustainable development and industrial security.

Due to the disunity between subjective opinions and the objective criteria, assessment of the overall performance usually composes of four steps: proposing the criteria framework, determining the weights, analyzing the data and finally provide suggestions [13]. GPS equipped in taxi can collect and transmit the position and time related data to control centers in taxi companies, which helps record trajectories, occupancy and fares [14]. Therefore, the evaluation tool can obtain detailed and real-time information from the GPS dataset. The proposed evaluation tool is used when new policy is introduced in taxi industry. The objective is to anticipate and assess impacts in different perspectives, including efficiency of taxi trips, revenue of taxi drivers, and environmental influences. It is mainly designed for policy-makers in public authorities, who can use "health degree" as a usable indicator for the impact brought by different policies. Also, taxi-fleet operators can use this tool to anticipate their profitability under different kind of market, and therefore making decisions in taxi supply management.

In this paper, an evaluating framework of the taxi industry's overall performance is proposed from the perspective of business ecosystem, and quantitative analysis is carried out with large datasets of GPS and Taximeters. As shown in Fig. 2, based on features of taxi industry, we

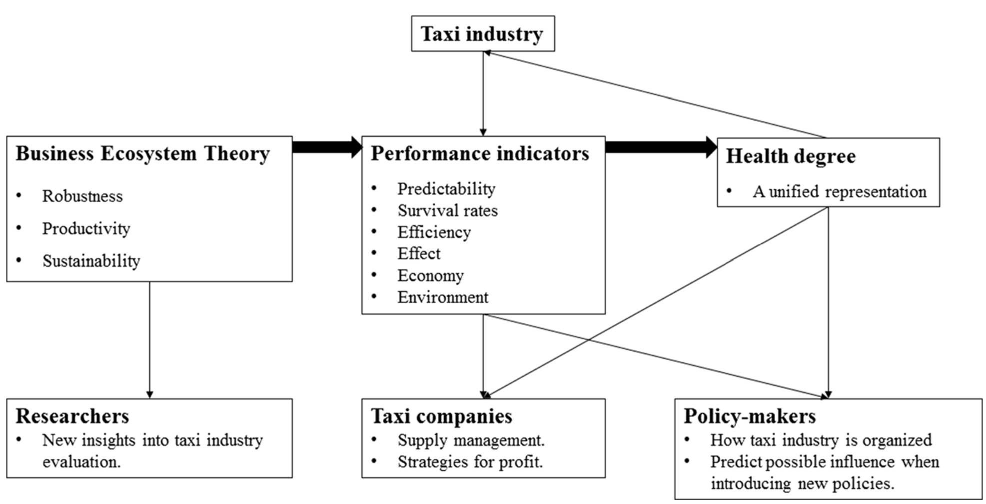


Fig. 2 Structure of the proposed taxi industry evaluation model

extend theories of taxi industry assessment and investigate the application of criteria based on business ecosystem. By providing "health degree" as a unified representation, our study contributes to the relatively underexplored for the purpose of making more efficient decisions. This study is structured as follows. Section 2 presents a review on related literature. Section 3 and 4 describes the criteria framework for assessment, and the research methodologies respectively. Results of empirical case study are presented in Section 5, sensitivity analysis and implications are also discussed in this section. Section 6 concludes the study.

2 Literature review

Previous studies that have tried to evaluate the taxi market are mostly aimed at providing policy advice. A field experiment in South Africa metered taxi industry concluded that cost efficiency are achieved by introducing informal bargain. In this experiment, comparison of excessive mileage and price are made between regulated and unregulated markets [15]. The case study in Ireland showed that deregulation has led to a three times larger taxi number and much shortened passenger waiting time [16]. Another case study of 43 cities in the US and Canada showed that the impact of entry regulation on service performance are different among cities characterized with dispatch, street-hail or taxi stand markets [17]. These studies provide interesting insight but empirical studies yield less generalized results, and therefore cannot serves as an efficient evaluation tool. In recent years, some researchers have applied the analysis of big data into the modeling of taxi performance. Data resources that are mostly from GPS [18], GIS [19], Taximeter and Float car data [20]. For example, GPS data collected in Berlin for one entire week provide clear demonstration of the variation in taxi demand [21]. Therefore, we designed this evaluation model based on data collected from GPS and taximeter.

Early studies on taxi market considered the spatial structure of the market where supply and demand interact. For cruising taxi system, the supply and demand functions are described with general data, including the number of taxis, taxi trips, prices and production costs [22]. Driver's revenue is one of the main indicator for supply–demand equilibrium, which can be used for forecasting impacts of regulation changes (e.g. fare increase and e-hail apps application in New York City [14]). Efficiency of taxi system are defined in terms of time or distance utilization. The former is the ration of occupied time to empty time, and the latter is the ratio of paid mileage to the unpaid miles driven [23]. Researchers linked competitiveness of taxi industry with profitability and survival [24]. For taxi companies, the social surplus, firm profit, and customer demand are influenced primarily by the demand-supply equilibrium in regulated, competitive, or monopoly markets [25].

More recent studies show that analysis of taxi industry should not be restricted to the market itself. The satisfaction level of customer differs not only in different kinds of markets, but susceptible to other service qualities [26]. Moreover, the competitive level of an industry is affected by the local development, productivity and demand level in local economic conditions [27]. By adding detailed context, the elasticity of taxi industry under certain political conditions can be scaled [28]. However, these studies did not address problems such as the outer impact of taxi industry such as revenue stability and environmental influences.

Evaluation of an industry from a macro perspective is conducive to making both short-term and long-term strategy plans. The extrinsic influential factors of the aviation industry concentrate on both economy and environmental issues [29]. Previous evaluation of the performance were done with Lerner index [30] or combining static and dynamic datasets [31]. For electric vehicle industry, indicators include performance in other areas such as social welfare and transportation efficiency [32]. In the field of business ecosystem, criteria set can be derived from areas of robustness, productivity and niche creation [11]. A "healthy" industry must reach a dynamic equilibrium among organization structure, productivity and robustness [33]. In sum, building an evaluation framework requires considerations of multiple aspects, and the concept of business ecosystem provides a guideline.

Researchers have developed business ecosystem theory and its practical application in some particular business context [12]. But, literature on methodologies for strategic analysis on business ecosystem is still in its infancy ([34] and [35]). As business ecosystems tend to be dynamic and context-specific, the use of data-based analysis is very important [36]. Usually, combined evaluation method can be more objective and suitable [37]. Therefore, synthetic evaluation models are developed to solve this kind of problems such as questionnaires, attitude scales and preference ranking method [38]. Multi-criteria decision-making (MCDM) is described as a methodological tool for modeling and solving complex problems [39]. Decision-makers from both public and private sectors participate in decision-making process [40]. MCDM is one of the helpful evaluation techniques in public transportation system, which can integrate the stakeholders' opinions in decision process [41].

In our paper, we first translate the "healthiness" of a taxi industry into multiple levels of criteria. Then we use the AHP method to obtain the weights of the criteria sets (the judgment matrix). And this matrix is input of an integrated hierarchical fuzzy MCDM method. And in order to automate the evaluation process, a neural network model is built to simulate the process of fuzzy comprehensive evaluation.

3 Taxi industry health degree and evaluation criteria

3.1 Taxi industry health degree

A taxi industry can be regarded as a sustainable business with typical roles include policymakers, regulators, companies, drivers and customers. Previous research on taxi industry focused on diverse perspectives. Although insightful, these studies are not able to effectively evaluate its overall performance, and thus obstructing exploration into how it is organized and how to adapt strategies to survive. For policy-makers, the ultimate objective is to provide help to the transport network. It depends on the municipal development strategy whether the growth in the taxi industry is a desirable outcome. The proposed model is an evaluation tool, which gives a neutral indicator, and the decisions of policy-makers are based on comparisons of these indicator.

Indeed, it is now well accepted that companies actually compete in ecosystems [42]. A Business ecosystem is an economic community involving many companies working together in the value-oriented collaborative process [43]. It underlines the value of the relationships among different roles that directly and indirectly contribute to what guarantees their existence and taking advantage from the balance of power [44]. This paper starts from an assumption that there are different taxi industries with differing processes. The taxi industry's capability to survive and grow depends on multi-facet performance indicators, which requires a clear definition of the ecosystem main goal [45]. Based on the business ecosystem's health theory, a healthy taxi industry is characterized as:

- Robustness: Companies within the industry are well-organized, operating in good condition. The amount of revenue can be estimated correctly, and almost every big oscillation can be predicted.
- Productivity: Companies within the industry are capable of maintaining a balance of demand and supply, and resources are utilized efficiently.
- Sustainability: Companies within the industry can reach a balanced budget at least, and the income of the drivers is guaranteed. Besides, both energy used and carbon should be kept to a reasonable level.

A unified representation of all the characteristics mentioned above-health degree-is defined as: 1) It is a non-dimensional numerical value between 0 and 100; 2) It is a comprehensive result of all statistical indicators; 3) It can be interpreted into hierarchical results, and denotes the degree of taxi industry's health. Numerical value of the health degree is shown in Table 1.

Table 1 Value of taxi industry health degree

Degree	Very healthy	Healthy	Nearly healthy	Unhealthy	Very unhealthy
Value	90–100	80–90	70–80	60–70	0–60

3.2 Evaluation indicator system for taxi industry health degree

The framework is based on the concept of evaluating performance according to some selected criteria, where such criteria are assessed by indicators. Performance indicators can provide essential information to enable guided decisions making regarding policy and regulation making [46]. Measuring business ecosystem health on the industry level requires more detailed data, and literature review can be useful in listing such criteria and indicators (See Table 2).

Decision-makers within the taxi industry consists of various participants, such as industry managers, company managers, taxi drivers and customers. Meanwhile, academics also play significant roles in decision-making. Thus, we surveyed all five kinds of decision-makers mentioned above on the selection of indicators, allocating each with distinctive weights (Table 3). The indicators with high scores are considered as potential ones for taxi industry health degree.

3.2.1 Robustness (A)

- Predictability (A_1)

A_{11}:Order Volatility (OV): Order means taxi trip, including occupied and empty trips. TO_t denotes the amount of taxi trips in t_{th} period; s is the number of period; ATO is the mean of total amount of taxi trips of s periods.

$$OV = \sum_t (TO_t - ATO)^2 / (s-1) \quad (1)$$

A_{12}:Revenue Growth (RG), TR_t denotes the sum of revenue during t_{th} period.

$$RG = (TR_{t+1} - TR_t)/TR_t \times 100 \quad (2)$$

- Survival rates (A_2)

A_{11}:Order Amount (OA): The amount of valid taxi trips are calculated by using the amount of total taxi trips recorded by GPS minus the repetitive and wrong records. The repetitive records means more than one taxi trips running at the same time recorded by one GPS device. The wrong records are recorded taxi trips

Table 2 Literature review of taxi industry evaluation indicators

Criteria	Reference
(1)Number, (2)Fare, (3)Disposable income, (4)Availability, (5)Occupied journey time, (6)Daily passenger demand, (7)Passenger and taxi waiting time, (8)Utilization	H. Yang et al. (2000) [3]
(1)Passenger waiting time, (2)Taxi revenue, (3)Costs of operations	S. Li (2006) [47]
(1)Driver income, (2)Company's total revenue, (3)Taxi waiting time, (4)Driving speed, (5)Accident rate	He (2009) [48]
(1)Number, (2)Mileage utilization, (3)Service availability, (4)Service availability for disabled people	Chen (2009) [1]
(1)Revenue per mile, (2)Passenger satisfaction degree, (3)Mileage and time utilization, (4)Passenger number	Hassan et al. (2013) [46]
(1)Number, (2)Mileage utilization, (3)Total travel mileage, (4)Companies' total revenue, (5)Fuel consumption	Bai et al. (2014) [20]
(1)Accessibility, (2)Regularity, (3)Reliability, (4)Convenience, (5)Effectiveness	Miteva, Pencheva, & Grozev (2015) [49]
(1)On time, (2)Safety, (3)Crowd level, (4)Noise level, (5)Travel time, (6)Cleanliness	Shaaban & Kim (2016) [50]

which are not consistent with real trips. *TR* denotes total data record; RR_n is the n_{th} repetitive record; WR_m is the m_{th} wrong record.

$$OA = TR - \sum_n RR_n - \sum_m WR_m \tag{3}$$

A_{21}:Practitioner (*P*), *P* is the total amount of employees in the taxi industry, including drivers and administrative workers. It can be obtained from Statistical Reports.
A_{22}: Operating Vehicles (*V*), *V* is the amount of vehicles that both GPS and Taximeters are of working status.

3.2.2 Productivity (B)

- Efficiency (B_1)

B_{11}:Mileage utilization (*MU*): M_i denotes the mileage of valid taxi trip *i*; *TM* denotes the overall mileage of the same period.

$$MU = \sum M_i / TM \tag{4}$$

B_{12}:Time utilization (*TU*): AT_i denotes the off-taxi time of valid taxi trip *i*; BT_i denotes the on-taxi time of valid taxi trip *i*; *TT* denotes the overall time of the same period.

$$TU = \sum_i (AT_i - BT_i) / TT \tag{5}$$

- Effect (B_2)

B_{21}:Average operating time (*AT*): OT_k denotes the operating time that k_{th} taxicab spent during t_{th} period; *N* is the amount of operating vehicles.

$$AT = \left(\sum_k^N \sum_t^S OT_{k,t}\right) / (N \times s) \tag{6}$$

B_{22}:Average mileage (*AM*): OM_k denotes the mileage that k_{th} taxicab covered during t_{th} period.

$$AM = \left(\sum_k^N \sum_t^S OM_{k,t}\right) / (N \times s) \tag{7}$$

B_{13}:Average speed (*AS*): M_i is the mileage of valid taxi trip *i*; AT_i is the off-taxi time; BT_i is the on-taxi time.

$$AS = \sum_i M_i / \sum_i (AT_i - BT_i) \tag{8}$$

3.2.3 Sustainability (C)

- Economy (C_1)

C_{11}:Total revenue (*TR*): *RPO* denotes the revenue of i_{th} valid taxi trip; *TO* is the amount of total trips.

$$TR = \sum_i^{TO} RPO_i \tag{9}$$

Table 3 Weights of different decision-makers

	Industry manager	Company manager	Taxicab driver	Passenger	Academician
Robustness	5	4	3	2	5
Productivity	5	5	5	4	5
Sustainability	5	3	2	4	5

C_{12}:Average daily income (*ADI*): TR_i represents the total income of period *i*; AN_i is the average operating vehicles at the same period.

$$ADI = TR_i/AN_i \tag{10}$$

C_{13}:Income difference (*ID*): *Ii* is the income of taxi *i*; *ADI* is the average daily income, and *N* is the amount of vehicles.

$$ID = \sum_i (I_i - ADI)^2/(N-1) \tag{11}$$

- Environment (C_2)

C_{21}: Energy intensity (*EI*): VN_{ij} is the amount of vehicles; ATD_{ij} is the average mileage; FE_{ij} is the intensity of fuels (e.g. 0.725 kg/l for 93 gasoline); *i* is the kind of fuels; *j* is the vehicle's age.

$$EI = \left(\sum_{i,j} VN_{i,j} \times ATD_{i,j} \times FE_{i,j}\right)/(IPC \times N) \tag{12}$$

C_{22}: Carbon intensity (*CI)*: EC_i is the amount of fuel *i* consumption; EF_i is the CO_2 Emission Factor of fuel *i*. According to *IPCC national greenhouse gas inventory Guide 2016*, the CO_2 Emission Factor of gasoline is 3.06556 kgCO2/kg.

$$CI = \sum_i (EC_i \times EF_i)/(IPC \times N) \tag{13}$$

4 Synthetic evaluation process of taxi industry health degree

At the beginning, a four-layer criteria set is determined from the scope of healthy business ecosystem, and AHP technique is applied to obtain the weight sets for weight calculation. Then the fuzzy comprehensive evaluation technique provides output value applied for the neural network model. Lastly, sensitivity analysis of each input parameter in the established neural network is made. The synthetic evaluation process is shown in Fig. 3.

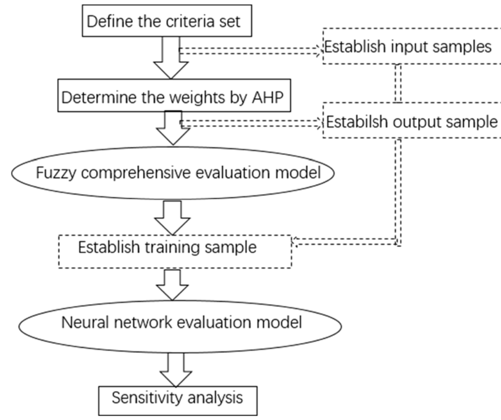


Fig. 3 Synthetic evaluation process of taxi industry health degree

4.1 Define the criteria set

As is mentioned above, the goal is the health degree of taxi industry, with the macro-criteria of robustness, productivity and sustainability. Each macro-criterion consists of 2–3 mid-criteria, which are explained by some more specific micro-criteria. The criteria set is shown in Fig. 4.

4.2 Define the weights by AHP

For multi-criteria decision making process, the Analytic Hierarchy Process (AHP) is based on pair-wise comparisons of criteria to establish the weights [51]. It's the only known MCDM model that can provide a method of the consistency in the decision maker's decisions [52]. The three steps are as follows.

Step 1: Articulate preferences with matrix A in which element a_{ij} (i, j = 1, 2, …, n) is the quotient of weights of the criteria. The value of a_{ij} is determined according to the scales of pair-wise comparison (as shown in Table 4).

$$A = \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix} \tag{14}$$

$$a_{ji} = \frac{1}{a_{ij}}, a_{ij} \neq 0 \tag{15}$$

Step 2: Consistency check. This process involves four steps.

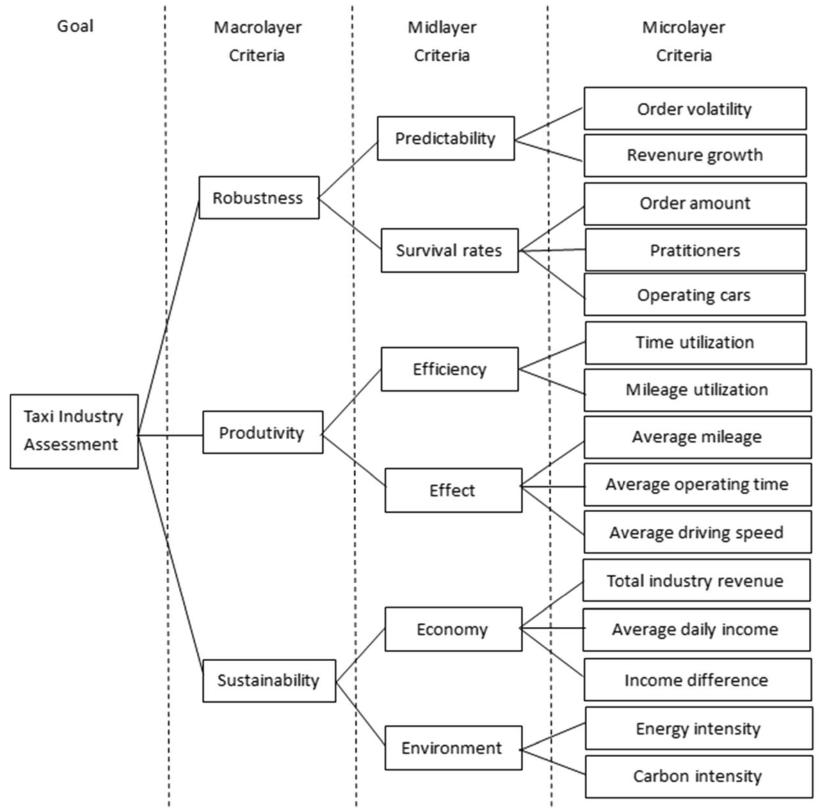
1) Get the largest eigenvalue.

$$(A - \lambda_{max} I)^* q = 0 \tag{16}$$

2) Calculate the consistency index *CI*.

$$CI = (\lambda_{max} - n)/(n-1) \tag{17}$$

Fig. 4 Criteria set of taxi industry's evaluation



3) Calculate *CR*, where *RI* is the random index, which depends on *n*.

$$CR = CI/RI \tag{18}$$

4) Compare CR to the accepted upper limit value of 0.1. If CR exceeds 0.1, the procedure has to be repeated to improve consistency.

Step 3: Derive criteria weights as follows:

$$W_i = \left\{W_{i1}, W_{i2}, \dots, W_{iq_i}\right\}, \left(\sum_{i=1}^{q_i} W_{ij} = 1\right) \tag{19}$$

Table 4 Scales of pair-wise comparison in AHP

Definition	a_{ij}	Definition	a_{ij}
Equally important between i and j	1	i is moderately more important than j	3
i is strongly more important than j	5	i is very strongly more important than j	7
i is extremely more important than j	9		

4.3 Fuzzy comprehensive evaluation model

Multi-criteria decision can be made by integrating AHP with other evaluation techniques [53]. And fuzzy comprehensive evaluation is widely used. The six-step process is as follows.

Step 1: Simplify the description of health degree as $E = \{e_1, e_2 \dots e_m\}$.
Step 2: Suppose the maximum and minimum value of criterion c is v_c^{max} and v_c^{min} respectively, x_c is the benefit-type criterion outcome. Then define the membership function $u_{ck}(x_c)$ as follows.

If k = 1:

$$u_{ck}(x_c) = \begin{cases} 1, & x_c \geq v_c^{max} \\ \dfrac{x_c - \left(v_c^{max} - d\right)}{d}, & \left(v_c^{max} - d\right) < x_c < v_c^{max} \\ 0, & x_c \leq \left(v_c^{max} - d\right) \end{cases} \tag{20}$$

If k = 2, 3, 4:

$$u_{ck}(x_c) = \begin{cases} 0, & \left[v_c^{max} - (k-2) \times d\right] \leq x_c \leq \left(v_c^{max} - k \times d\right) \\ \dfrac{\left[v_c^{max} - (k-2) \times d\right] - x_c}{d}, & \left(v_c^{max} - k \times d\right) < x_c < \left[v_c^{max} - (k-2) \times d\right] \\ \dfrac{x_c - \left(v_c^{max} - k \times d\right)}{d}, & \left(v_c^{max} - k \times d\right) < x_c \leq \left[v_c^{max} - (k-1) \times d\right] \end{cases} \tag{21}$$

If k = 5:

$$u_{ck}(x_c) = \begin{cases} 1, & x_c \le v_c^{min} \\ \frac{\left(v_c^{min} + d\right) - x_c}{d}, & v_c^{min} < x_c < \left(v_c^{min} + d\right) \\ 0, & x_c \ge \left(v_c^{min} + d\right) \end{cases} \quad (22)$$

Where $d = \frac{v_c^{max} - v_c^{min}}{m-1}$.

Step 3: Evaluate the micro-level criteria C_{ij}. The weight set is $W_i = \{W_{i1}, W_{i2} \dots W_{iq_i}\}$, and the evaluation vector is $B_{ij} = \{u_{ij1}, u_{ij2} \dots u_{ijm}\}$.
Step 4: Evaluate the mid-level criteria C_i. Obtain the membership matrix $U_i = (u_{ijk})_{q_i \times m}$, and the evaluation vector is $B_i = \{b_{i1}, b_{i2}, \dots, b_{im}\}$.

$$b_{ik} = \sum_{j=1}^{q_i} W_{ij} \times u_{ijk} \quad (23)$$

Step 5: Employ similar procedures to evaluate the macro-level criteria C with $W = \{W_1, W_2 \dots W_q\}$, and $B = \{b_1, b_2 \dots b_m\}$.
Step 6: Calculate the final result P, where k_m is the value of each health degree (equals to $20^* m$).

$$P = \sum_{m=1} b_m^2 k_m / \sum_{m=1} b_m^2 \quad (24)$$

4.4 Neural network evaluation model

Artificial neural network is capable of relating the input and output parameters, learning from examples through iteration [54]. The main edge is its nonlinearity and adaptability, providing accurate prediction with uncertain data [55].

In this model, a three-layer BP neural network is constructed to simulate the ambiguous process of decision making (See Fig. 5). Input information is disseminated and weighted, and the response is compared with the target value. Adjustments are taken and the accuracy is improved through back propagation [56].

Step 1: The input vector $C = \{c_{ij}\}$ is normalized into $P = \{p_{ij}\}$, with fifteen nodes in input layer (micro-layer criteria) and one node in output layer (the goal).

$$p_{ij} = \left(c_i - c_i^{min}\right) / \left(c_i^{max} - c_i^{min}\right) \quad (25)$$

Step 2: The number of nodes in hidden layer is defined through trails and error, where the initial number is l_h, and

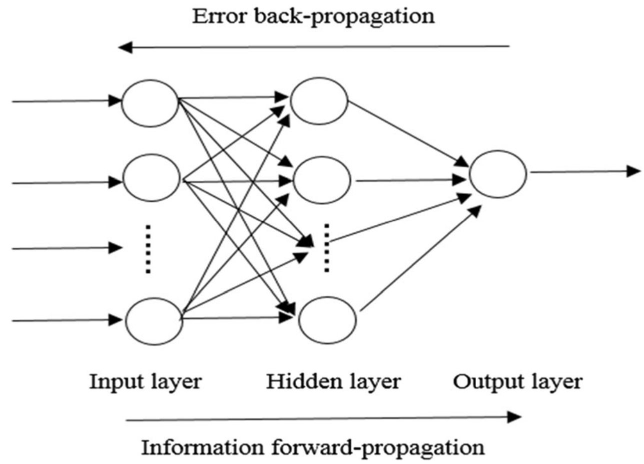


Fig. 5 Structure of a three-layer BP neural network

l_i, l_o is the number of notes in input and output layer, a is a random number from 1 to 10.

$$l_h = \sqrt{(l_i + l_o)} + a \quad (26)$$

Step 3: Determined transfer functions, and train the model with appropriate learning rate.
Step 4: Apply test data to evaluate the performance of the designed network. Usually, the mean square error (*MSE*) was used [57], where y_{ij} is the network output for example i at processing element j, and d_{ij} is the desired output.

$$MSE = \frac{\sum_{j=0}^{P} \sum_{i=0}^{n} \left(d_{ij} - y_{ij}\right)^2}{n \times p} \quad (27)$$

5 Case study

5.1 Empirical data

In China, regulators of taxi industry are the central and local governments. The local government release municipal taxi licenses by auction, which cannot be traded by individuals on the market. These licenses allows taxis to operate in dispatch, street-hailing and phone-hailing markets. The quantity of license is controlled and dependent on the policy made by central government. Taxi companies are license owners, but most taxis are leased to their employees—taxi drivers–who are responsible for fuel costs and car maintenance. Similar to the case in New York [7]. Two or more drivers take shifts in driving one taxi, which leads to the taxi running in the street for about 18 h a day.

Table 5 Typical value of criteria in Wuxi taxi industry

Criteria	Mean	Max	Min	Std.
Order Volatility (%)	4.62	12.45	0.76	3.39
Revenue Growth (%)	4.65	12.06	−0.14	5.93
Order Amount	145,519	170,433	130,489	9120
Practitioner	4874	5106	4385	1,76
Operating Vehicles	3825	3930	3514	1,12
Mileage utilization (%)	65.00	71.30	59.11	2.44
Time utilization (%)	31.31	37.72	3.30	4.61
Average operating time (h)	23.72	23.83	23.81	0.23
Average mileage (km)	401.77	428.28	393.16	14.78
Average speed (km/h)	33.70	37.98	31.03	1.11
Total revenue (yuan)	3,075,752	3,650,759	2,774,778	201,512
Average daily income (yuan)	804.29	931.55	730.05	50.32
Income difference (yuan)	237.44	285.81	217.07	16.26
Energy intensity (kg/yuan)	171.98	190.46	149.54	8.66
Carbon intensity (kgCO_2/yuan)	522.82	579.02	454.59	26.34

Wuxi is a regional business hub in Jiangsu province with nearly 637 million inhabitants in the area of 4787.61 km2. It is about 130 km from Shanghai, which is the Chinese economic center. Wuxi is a textile manufacturing center. Also, chemical industry and electric motor manufacturing in the suburban industrial park has contributed much to its economic growth (the GDP is $ 19,000 per inhabitant in 2016). Urban areas in Wuxi has complex subway and bus network. And there are three train stations (one located in the city center and the other two in southern and northern area respectively) and one airport located 14 km from the city center. Therefore, Wuxi shows many similarities with cities in Europe and the US.

The data was collected from database of historical trajectories recorded by GPS and Taximeter, provided by all taxi companies in Wuxi. We take a sample of 61 days from May and June 2015. The total number of taxi trips recorded by all the GPS devices is 9,698,004. However, in the original GPS dataset, there were certain amount of repetitive or wrong records. So we got 8,876,660 taxi trips after eliminating the repetitive and wrong records. Some of the numerical results in the case study are dependent on the Wuxi context. But it should be noted that the model can also be adapted to other cities, because evaluations are made by discussing the changes of the "health degree".

As showed in Table 5, there are nearly 4874 taxi drivers and administrators. The average number of taxi trips is 145,519 per day. For each recorded taxi, the average number of trips covered per day is 38. Nearly 65% of the mileage is covered for profitable trips. However, the recorded taxis stayed vacant for nearly 70% of working hours. For the taxi company, the total revenue is ¥307 million per day. However, daily income of taxi drivers differs greatly (the average income difference is ¥237).

As the May 4th is Monday, it can be concluded from the graph that the health degree follows a weekly pattern. Take May 4th to May 11th as example, the health degree during weekday is relatively low and constant. However, it grows rapidly in from Friday until reaching the highest score in Sunday. It drops to the lower range when a new week starts. It should be noted that this weekly pattern is unique to the city. Evaluation should be made by comparing the health degree to its corresponding historical value (e.g. the value at the same day in the last week). For example, in the week from May 12th to May 19th, the health degree in Tuesday doesn't follow the pattern and the weekend-to-weekday drop comes early in Saturday. Therefore more attention should be paid to specific value of performance indicator in Tuesday and Saturday.

Table 6 Criteria weights derived from AHP

Criteria (robustness)	Weight	Criteria (productivity)	Weight	Criteria (sustainability)	Weight
Order volatility	0.16	Mileage utilization	0.02	Total revenue	0.03
Revenue Growth	0.04	Time utilization	0.14	Average daily income	0.12
Order amount	0.11	Average time	0.06	Income difference	0.07
Practitioner	0.04	Average mileage	0.08	Energy intensity	0.03
Operating vehicles	0.02	Average speed	0.06	Carbon intensity	0.02

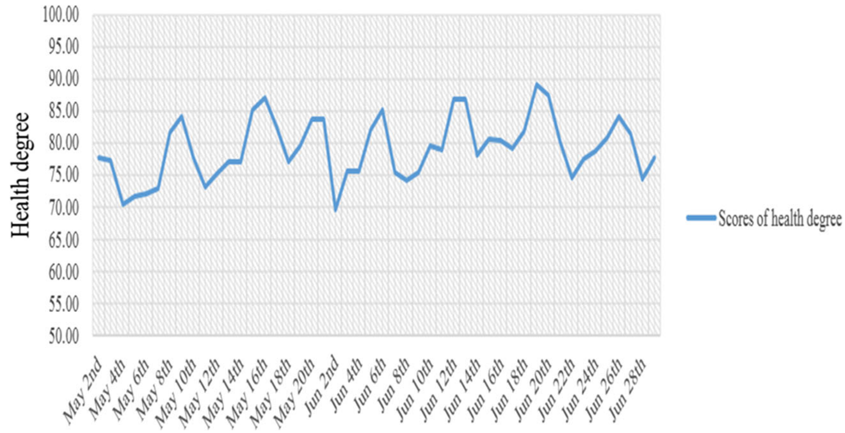


Fig. 6 Results of fuzzy comprehensive evaluation

5.2 Synthetic evaluation models

5.2.1 Fuzzy comprehensive evaluation model

The weights of all criteria obtained through the application of AHP to the preference matrix is summarized in Table 6 below. Then a fuzzy evaluation set with five categories, is used to evaluate daily performance of taxi industry in Wuxi.

Empirical data of Wuxi is applied to the fuzzy comprehensive evaluation model, and the results are shown in Fig. 6. As shown, during May and Jun 2015, taxi industry in Wuxi is basically healthy, with the health degree scoring over 70 for most days. Specifically, the health degree fluctuates between 70 and 89, with the mean of 79, and standard deviation of 4.

For further analysis, take each of the three macro-level criteria, robustness, productivity and sustainability as the goal of FCE, daily performance of taxi industry is shown more specifically. As showed in Fig. 7, scores of the three criteria fluctuate at different range, though reach high/low level almost synchronously (As in May 8th, Jun 2nd and Jun 26th). However, exceptions like Jun 8th and Jun 24th still exist.

5.2.2 Neural network evaluation model

The two-month input data is divided into training and testing set, with data from May 2nd to Jun 17th as training set and data from Jun 18th to Jun 29th as testing set. *Neurosolution Software Version 6* is used for model training. The process of trails and error shows that the best performance is obtained in a three-layer neural network with 10 hidden nodes, and both *logsig* and *tansig* transfer functions. The model is trained with the learning rate values of 0.5. As the relationship between the input and output data is directly linked to the criteria sets in the fuzzy comprehensive evaluation process, the training target (mse = 10^{-4}) is reached within 100 epochs.

The well-trained neural network applied to evaluate data samples. The result is compared with the result of fuzzy comprehensive evaluation, which is the direct result of decision-making (as shown in Fig. 8).

5.3 Sensitivity analysis

After evaluating results with both fuzzy comprehensive evaluation model and neural network model, sensitivity analysis is performed to illustrate how the model output varies in

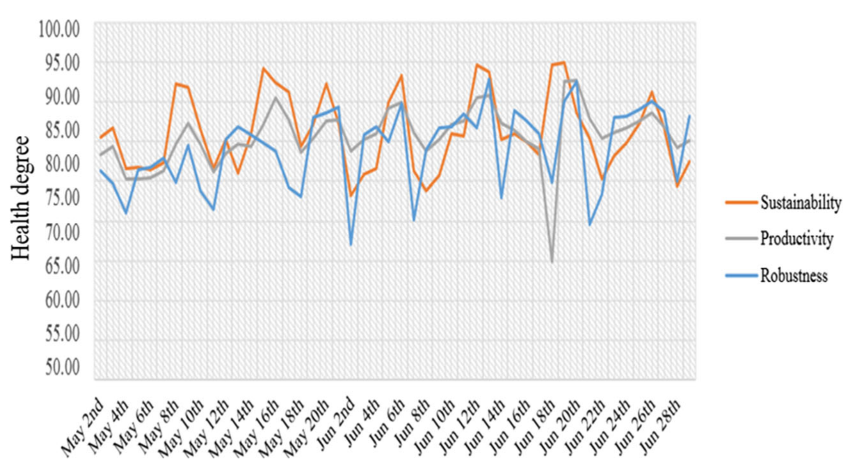


Fig. 7 Scores of robustness, productivity and sustainability of Wuxi's taxi industry

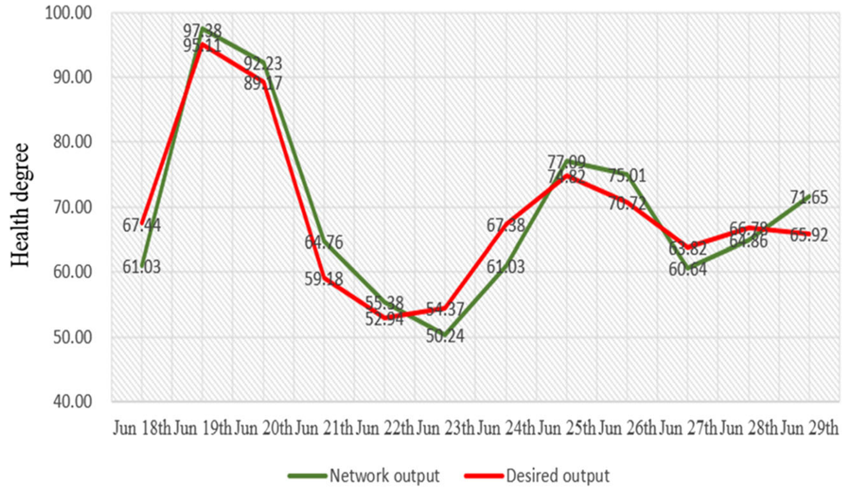
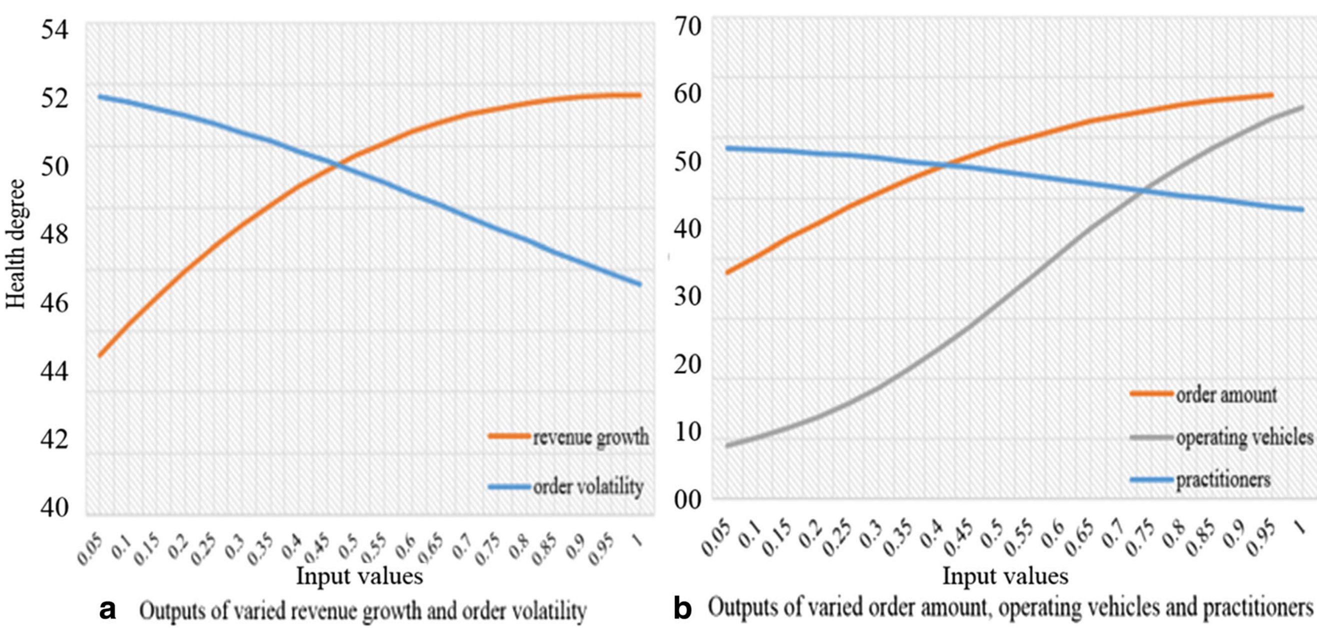


Fig. 8 Comparing the results of neural network models and the desired output

response to variation of the input. During this process, the network learning is disabled so that the weights are no affected [57]. The target input is varied between its maximum and minimum value while all other inputs are fixed, and the outputs of varied target input is computed. Plots showing the network output over varied inputs (both values are normalized) are shown in Figs. 9, 10 and 11.

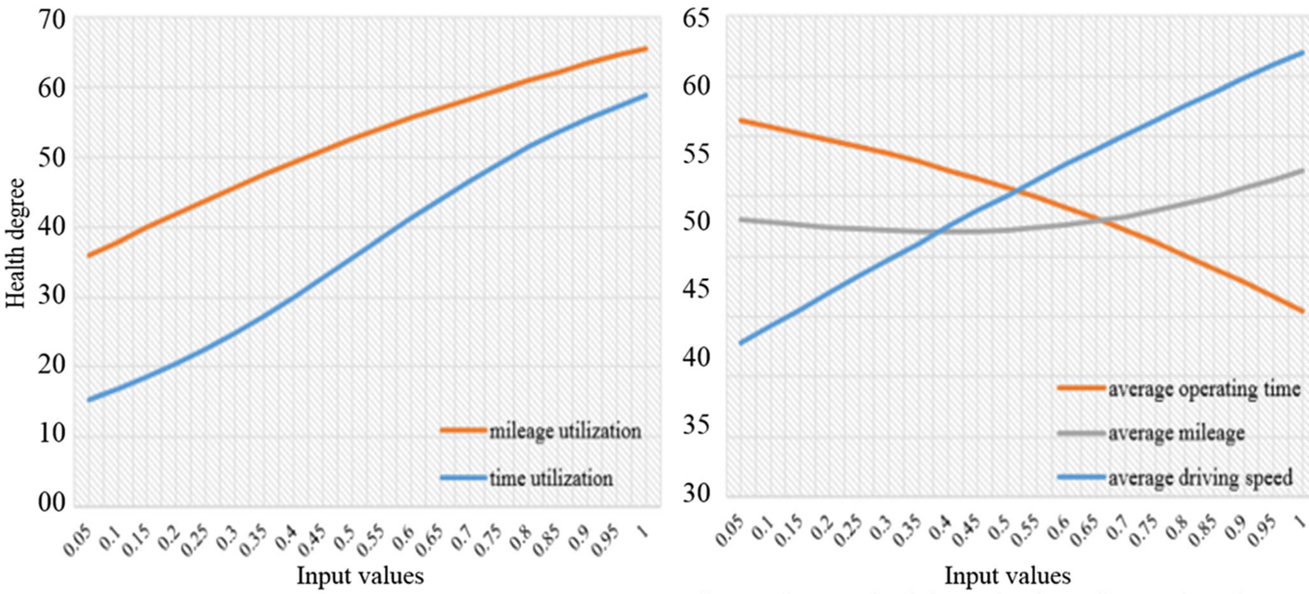
In Fig. 9, Chart a) shows that the healthy degree of taxi industry is in proportion to its revenue growth to some extent. However, high taxi trips volatility exerts adverse influence to its performance. That is, there is a trade-off between revenue growth and trips volatility, and cross point of the two curves denotes second-best scenario. Chart b) shows that as the amount of taxi trips increases, the taxi industry becomes healthier, which is accord with the common sense. However, when it comes to resources within the industry, such as vehicles and drivers, the health degree varied. For one thing, more operating vehicles means more taxi supply in the taxi market, which is a solution to the imbalance of supply and demand currently in Wuxi. For another thing, more employees mean more expenditure, which is harmful to the healthy taxi industry, but in a much more obscure and slower rate. Decision makers should pay more attention to the mount of operating vehicles while keeping a rational amount of practitioners.

In Fig. 10, Chart c) shows that the health degree is greatly influenced by both mileage and time utilization. The results are polarized, with the health degree lower than 40 (the normalized value is 0.4 as shown) when time and mileage are not fully utilized. For decision-makers, utilization of mileage and time should be taken into account carefully. Chart d) shows distinctive trends of outputs to varied average operating time,



a Outputs of varied revenue growth and order volatility **b** Outputs of varied order amount, operating vehicles and practitioners

Fig. 9 Outputs of varied input of robustness



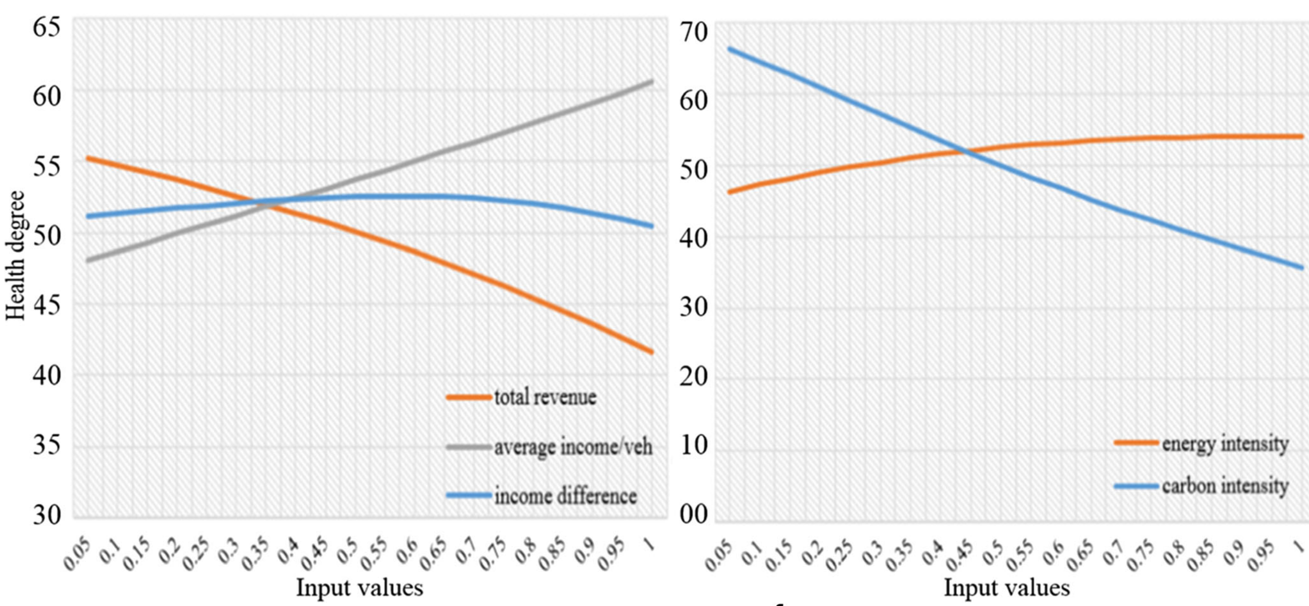
c Outputs of varied mileage and time utilizations

d Outputs of varied operating time, mileage and speed

Fig. 10 Outputs of varied input of productivity

mileage and driving speed. Firstly, the health degree of taxi industry is in nearly direct ratio to the average driving speed. Secondly, shorter average operating time within reason contributes to a healthier taxi market. Thirdly, the health degree decrease slowly at the beginning and increase later with the increasing mileage. In other words, a medium mileage is not beneficial to the whole taxi industry.

In Fig. 11, Chart e) shows that as the average income per vehicle increase, the taxi industry become healthier. Besides, high income difference affects the taxi industry in a harmful way. Nevertheless, the total revenue is in a different situation. This can be explained by the fact that the criterion of total revenue is defined by merely the pecuniary revenue of every taxi trip, and higher monetary revenue usually corresponds to excessive driving time and mileage as well as great externalities such as congestion and environmental pollution, which exerts more direct harmful effect to the whole industry. Therefore, total revenue should not be used as single determinant in decision making. Moreover, in Chart f), input like energy and carbon intensity are not as influential as the former inputs. However, variance of both input do show typical trends. Healthy taxi industry comes with great energy



e Outputs of varied total revenue, average income and difference

f Outputs of varied energy and carbon intensity

Fig. 11 Outputs of varied input of sustainability intensity and low carbon intensity, respectively. Considering the combined influence of energy and carbon intensity, the optimum scenario is achieved somewhere around the cross point of the two curves.

6 Conclusions

In this paper, an assessment framework of the taxi industry's overall performance is proposed from the perspective of business ecosystem, and quantitative analysis is carried out with large datasets of GPS and Taximeters. Weights of criteria is determined through analytic hierarchy process, and both conventional and automatic evaluating models are proposed by applying fuzzy comprehensive evaluation and neural network, respectively. Finally, results are drawn from temporal comparisons of the health indicator, and also implications of the sensitivity analysis. Specifically, for Wuxi, five main conclusions are made:

- There is a trade-off between revenue growth and trips volatility.
- Influence of mileage and time utilization are polarized.
- Total revenue should not be used as single determinant in decision making, since high income difference affects the taxi industry in a harmful way.
- Decision makers should pay more attention to the mount of operating vehicles while keeping a small amount of drivers and administrators.
- The optimum scenario is achieved somewhere around the cross point of the two curves of energy intensity and carbon intensity.

Taxi industry evaluation is a complex task because it involves administrators, employees, and academic such as transportation planners, who are faced with a lack of information when making evaluations. The unified representation-health degree-is helpful to the intuitive understanding and judgment, especially for non-economists since comprehension of the number does not require a strong economic background. Therefore, the proposed "health degree" help to eliminate the vagueness by providing a comprehensive evaluation of the taxi industry. This paper focus on developing a more structured and efficient evaluation tool. Its applicability is shown in the Wuxi case. Policy-makers in public authorities can use "health degree" as a usable indicator for the impact brought by different policies. Taxi-fleet operators can use this tool to anticipate their profitability under different kind of market, and therefore making decisions in taxi supply management. Considering the higher market penetration of GPS and Taximeter devices in taxicabs, and increasing availability of both data, the proposed models can be applied elsewhere.

Nevertheless, since not all city allows free access of GPS or Taximeter database, performance evaluation of taxi industry in some places are difficult to carry out. In this case, the criteria framework should be modified, catering to the accessible data. Besides, the importance of criteria may be hard to obtain in highly-diversified taxi markets, where both dispatch and street hail markets prevail. In this situation, goals and principles vary among different participants and decision-makers, suggesting the need to seek better alternative criteria and more efficient assessment method.

Acknowledgements This work was supported financially by Science and Technology Department of Jiangsu Province, China [2015070-25].

References

1. Chen Y (2009) Analysis on current problems of taxi industry Stablizing and developing. Urban Stud 16(2):116-122
2. Wang Y (2009) The problems and consideration on the taxi industry under governmental regulation. Journal of Chongqing Technology & Business University 26(5):45–49
3. Yang H, Lau YW, Wong SC, Lo HK (2000) A macroscopic taxi model for passenger demand, taxi utilization and level of services. Transportation 27(3):317–340
4. Schaller B (2007) Entry controls in taxi regulation: implications of US and Canadian experience for taxi regulation and deregulation. Transp Policy 14(6):490–506
5. Aarhaug J, Skollerud K (2014) Taxi: different solutions in different segments. Transportation Research Procedia 14(1):276–283
6. Salanova JM, Estrada M, Aifadopoulou G, Mitsakis E (2011) A review of the modeling of taxi services. Procedia Soc Behav Sci 20(6):150–161
7. Darbéra R (2010) Taxicab regulation and urban residents' use and perception of taxi services: a survey in eight cities. In: Nautika i vodeni sport, 6. Zagrebački sajam sporta, pp 2508–2512
8. Akpa NAEE, Booysen MJ, Sinclair M (2015) Efficacy of novel interventions on speed compliance in the minibus taxi industry. Civil Engineering/siviele Ingenieurswese pp 33-36
9. Zahra SA, Nambisan S (2012) Entrepreneurship and strategic thinking in business ecosystems. Bus Horiz 55(3):219–229
10. Moore JF (1993) Predators and prey: a new ecology of competition. Harvard Business Review 71(3):75
11. Hartigh ED, Tol M, Visscher W (2006) The health measurement of a business ecosystem
12. Iansiti M, Richards GL (2006) Information technology ecosystem: structure, health, and performance. The Antitrust Bulletin 51(1):77–110
13. Aydin N, Celik E, Gumus AT (2015) A hierarchical customer satisfaction framework for evaluating rail transit systems of Istanbul. Transp Res A Policy Pract 77:61–81
14. Kamga C, Yazici MA, Singhal A (2015) Analysis of taxi demand and supply in New York City: implications of recent taxi regulations. Transp Plan Technol 38(6):601–625

15. Bengtsson N (2015) Efficient informal trade: theory and experimental evidence from the cape town taxi market. J Dev Econ 115: 85–98
16. Barrett SD (2003) Regulatory capture, property rights and taxi deregulation: a Case study. Econ Aff 23(4):34–40
17. Schaller B (2007) Entry controls in taxi regulation: lessons from North American Experience. In: Transportation Research Board 86th Annual Meeting, vol. 07–0265
18. Kim H, Yang I, Choi K (2011) An agent-based simulation model for analyzing the impact of asymmetric passenger demand on taxi service. KSCE J Civ Eng 15(1):187–195
19. Zhang DZ, Sun J, Peng ZR (2013) Urban taxi goodness index and system implementation of GIS. J Transp Syst Eng Inf Technol 13(1):87–96
20. Bai Z, Wang J, Xiao-Wei HU (2014) Operational efficiency evaluation of urban taxi system. J Transp Syst Eng Inf Technol 14(3): 227–233
21. Bischoff J, Maciejewski M, Sohr A (2015) Analysis of Berlin's taxi services by exploring GPS traces. In: International Conference on MODELS and Technologies for Intelligent Transportation Systems, pp 209–215
22. EFL J, Ch JDC, Julio BM (2006) A diagrammatic analysis of the market for cruising taxis. Transportation Research Part E Logistics & Transportation Review 42(6):498–526
23. Arnott R (1996) Taxi travel should be subsidized. J Urban Econ 40(3):316–333
24. García-Almeida DJ, Klassen N (2017) The influence of knowledge-based factors on taxi competitiveness at island destinations: an analysis on tips. Tour Manag 59:110–122
25. Yang H, Wong SC, Wong KI (2002) Demand–supply equilibrium of taxi services in a network under competition and regulation. Transportation Research Part B Methodological 36(9):799–819
26. Pautler PA, Frankena MW (1984) An Economic Analysis of Taxicab Regulation. Bureau of Economics Staff Report
27. Cui Q, Kuang HB, Wu CY, Li Y (2013) Dynamic formation mechanism of airport competitiveness: the case of China. Transportation Research Part A Policy & Practice 47(1):10–18
28. Rose JM, Hensher DA (2014) Demand for taxi services: new elasticity evidence. Transportation 41(4):717–743
29. Vespermann J, Wald A (2011) Much Ado about Nothing? – An analysis of economic impacts and ecologic effects of the EU-emission trading scheme in the aviation industry. Transp Res A Policy Pract 45(10):1066–1076
30. Zhang Q, Yang H, Wang Q, Zhang A (2014) Market power and its determinants in the Chinese airline industry. Transportation Research Part A Policy & Practice 64(2):1–13
31. Li KX, Yin J, Fan L (2014) Ship safety index. Transportation Research Part A Policy & Practice 66(1):75–87
32. Zubaryeva A, Thiel C, Zaccarelli N, Barbone E, Mercier A (2012) Spatial multi-criteria assessment of potential lead markets for electrified vehicles in Europe. Transportation Research Part A Policy & Practice 46(9):1477–1489
33. Fang XU (2008) Research on ecological evluating index system of industry security. Ecological Economy, pp 55-58
34. Battistella C, Colucci K, Toni AFD, Nonino F (2012) Methodology of business ecosystems network analysis: a case study in Telecom Italia future Centre. Tech Forcasting Soc Chang80(6):1194–1210
35. Galateanu E, Avasilcai S (2016) Framing the competitive behaviors of niche players: the electric vehicle business ecosystem perspective ☆. Procedia - Social and Behavioral Sciences 221:342–351
36. Adner R (2012) THE WIDE LENS: a new strategy for innovation. Prometheus Critical Studies in Innovation 31(2):164–166
37. Zhang C, Juan Z, Luo Q, Xiao G (2016) Performance evaluation of public transit systems using a combined evaluation method. Transp Policy 45:156–167
38. Xenias D, Whitmarsh L (2013) Dimensions and determinants of expert and public attitudes to sustainable transport policies and technologies. Transportation Research Part A Policy & Practice 48(2):75–85
39. Kahraman C (2008) Fuzzy multi-criteria decision making: theory and applications with recent developments. Springer Science & Business Media.
40. Pérez JC, Carrillo MH, Montoya-Torres JR (2014) Multi-criteria approaches for urban passenger transport systems: a literature review. Ann Oper Res 226(1):69–87
41. Lascano EC, Bertolotti A, Gómez CB, Ossés J, Negroni JA, Cuniberti L, Yannarelli GG, Molinari LE, Laguens R, Favaloro R (2015) Reviewing the use of multi-criteria decision analysis for the evaluation of transport projects: time for a multi-actor approach. Transp Policy 37(1–2):177–186
42. Basole RC, Russell MG, Huhtam KJ, Rubens N, Still K, Park H (2015) Understanding business ecosystem dynamics: a data-driven approach. Acm Transactions on Management Information Systems 6(2):1–32
43. Chou TC, Huang MY (2012) Understanding the roles of business ecosystems in large public IT infrastructure project development: the case of M-Taipei. Int J Inf Manag 32(1):88–92
44. Adner R, Kapoor R (2010) Value creation in innovation ecosystems: how the structure of technological interdependence affects firm performance in new technology generations. Strateg Manag J 31(3):306–333
45. Kalyanaram G, Aung ZZ (2015) Value-added ecosystem and customer experience enhancement framework. Kindai Management Review 3:49–62
46. Hassan MN, Hawas YE, Ahmed K (2013) A multi-dimensional framework for evaluating the transit service performance. Transportation Research Part A Policy & Practice 50(2):47–61
47. Li S (2006) Multi-attribute taxi logistics optimization. Massachusetts Inst Technol
48. He XF (2009) Research on the evaluation index system of urban taxi operation. Technol Econ Areas Commun pp 28–31
49. Miteva D, Pencheva V, Grozev D (2015) The role of key indicators for an assessment the quality of transport service in taxi transportations. in: The 3rd Global Virtual Conference, pp 168–171
50. Khaled Shaaban, Inhi Kim, (2016) Assessment of the taxi service in Doha. Transp Res A Policy Pract 88:223-235
51. Saaty TL, Vargas LG (2012) Models, methods, concepts & applications of the analytic hierarchy process. Springer Science & Business Media
52. Ling W, Jian C, Wu J (2007) Selection of optimum maintenance strategies based on a fuzzy analytic hierarchy process. Int J Prod Econ 107(1):151–163
53. Dağdeviren M, Yavuz S, Kılınç N (2009) Weapon selection using the AHP and TOPSIS methods under fuzzy environment *. Expert Syst Appl 36(4):8143–8151
54 Cevoli C, Cerretani L, Gori A, Caboni MF, Toschi TG, Fabbri A (2011) Classification of pecorino cheeses using electronic nose combined with artificial neural network and comparison with GC–MS analysis of volatile compounds. Food Chem 129(3):1315–1319
55 Dębska B, Guzowska-Świder B (2011) Application of artificial neural network in food classification. Anal Chim Acta 705(1–2):283–291
56 Sun W, Xu Y (2016) Financial security evaluation of the electric power industry in China based on a back propagation neural network optimized by genetic algorithm. Energy 101:366–379
57 Golmohammadi D (2011) Neural network application for fuzzy multi-criteria decision making problems. Int J Prod Econ 131(2): 490–504