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Designing a Mixed Evaluating System for Green Manufacturing of Automotive Industry

Projektowanie mieszanego system oceny zielonej produkcji dla przemysłu samochodowego

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Abstract
The article proposed, from a sustainable development perspective, an index system based on Sustainability Balanced Scorecard (SBSC), including the main index of Financial, Internal process, Customer, Learning and growth, Social and the sub- index which comprised 28 indexes to evaluate the Green Manufacturing (GM) of automotive industry. Based on the index system, an evaluation model integrates by back-propagation artificial neural network (BPANN) and genetic algorithm (GA) was introduced. Using established model and indicators evaluated GM in four automotive companies; the key result of the evaluated show that: China's automotive manufacturing enterprises still have big room for improvement in respect of customer satisfaction, resource consumption, community service, low-carbon activities etc., so the strategy and management activities that put much pressure on these respect are necessary.

Key words: SBSC, GM, index system of automotive industry, GA, BPANN

Streszczenie
W artykule zaproponowano wykorzystanie systemu wskaźników opartych na Zrównoważonej Karcie Wyników (Sustainability Balanced Scorecard – SBSC). Zgodnie z koncepcją rozwoju zrównoważonego uwzględniono następujące główne wskaźniki: finansowy, procesów wewnętrznych, klienta, wzrostu i uczenia się, społeczny, a także 28 podwskaźników. Celem była ocena Zielonej Produkcji (Green Manufacturing – GM) w przemyśle motoryzacyjnym. Wprowadzono model oceny oparty na systemie wskaźników, łączący propagację wsteczną sztucznej sieci neuronowej (back-propagation artificial neural network – BPANN) oraz algorytm genetyczny (genetic algorithm – GA). Za pomocą wybranego modelu i wskaźników dokonano oceny Zielonej Produkcji w czterech firmach motoryzacyjnych. Wyniki wskazują, że chińskie przedsiębiorstwa motoryzacyjne mają jeszcze dużo do poprawy w kwestii satysfakcji klienta, zużycia zasobów, pracy społecznej, działań niskoemisyjnych, itp. Konieczne jest zatem obranie strategii oraz gospodarki, które kładą nacisk na wymienione kwestie.

Słowa kluczowe: SBSC, zielona produkcja, system wskaźników przemysłu motoryzacyjnego, GA, BPANN

Introduction

With the increasing awareness of sustainable development, organizations are obliged to take into account environmental practices and social responsibility to strengthen the green image of their own companies, alongside with the true intent of keeping the stable development (Yang et al., 2011; Tseng, 2011a; Tseng and Chiu, 2012; Lin, 2013). In this regard, companies, especially automotive companies, which is almost the biggest manufacturing industry in the world and now it can be considered to be unsustainable in many aspects, try to put more standards and obligations on activities, such as reducing carbon emission, implementing sustainability concepts to prevent environmental deterioration and pollution, undertake more social responsibility etc., as an increasingly important issue for a business (Sarkis et al., 2011; Vachon and Klassen, 2008). GM can be regarded as an approach to the philosophy of sustainable development of automotive industry. GM refers to a novel manufacturing method which can reduce consumption and pollution, conserve energy, and provide more community service, it is a continuous application of an integrated environmental strategy to processes and services to increase efficiency and reduce risks to humans and the environment, and it is also an efficient method to pursue ecological benefits and social harmony (Despeisse et al., 2012; Lee and Chen, 2012; Oliver and Abhishek, 2013; Constantin and Antony, 2014). GM in automotive industry involves two primary purposes: (a) Promotes environmental compatibility during manufacturing processes and reduces the harm that the manufacturing process causes to humans and the environment; (b) Encourage companies to take more social responsibility, expanding the social impact, improve social performance, thereby improving the welfare of the stakeholder and achieve a harmonious society (Xiao, 2010; Sameer and Tobias, 2012; Cheng et al., 2013; Tseng et al., 2013; Wu and Olson, 2013).

Achieving GM in automotive industry to sustainable development means less resource waste and more social responsibility, it is very important for the environmentally conscious consumers and the sustainable society. But due to the limited understanding of GM and lack of criteria to evaluate manufacturing processes, there has not been a general framework to represent an organization's practical roadmap to management activities. The main objective of this paper is to propose comprehensive criteria to evaluate the GM in automotive industry using SBSC-BPANN. Besides, as it will be explored, there is no investigation of GM indicator in automotive industry using SBSC-BPANN, therefore, this is the first work attempting to use this technique to evaluate GM practices, the contribution of this paper is threefold: first, the validity and reliability of developed criteria for GM can be comprehended; Second, it proposes an integration of various criteria based on literature review, which allows us to have a clear and deep perception about the critical success factors influencing GM practices in automotive industry; third, in practice, these criteria can be used as benchmarking and improvement tools to ameliorate sustainable development practices.

The rest of this paper is structured as follows. In Section 2, an overview of GM and a comprehensive GM criteria system in automotive industry is proposed; In Section 3, research framework is put forward, and a BPANN method alongside with GA is presented; In Section 4, a real case study is elaborately explained; In Section 5, the finally section, conclusions and some managerial implications are drawn from the study.

2. Theoretical background

2.1. GM practices

Green Manufacturing is also known as sustainable manufacturing, clean manufacturing, environmentally conscious manufacturing and so on (Guo, 2014; Soubihia, 2015). Internationally, research on green manufacturing related content can be traced back to the 1980s, but the concept of green manufacturing system and the main content of the American Society of Manufacturing Engineers (SME) was published in 1996 on Green Manufacturing Blue Book *Green Manufacturing*. In 1998, SME published an online theme of green manufacturing report (*Trends of Green Manufacturing*), the importance and research issues related to green manufacturing has made a further introduction. In recent years, research on GM and related issues are very active, especially about the standards for the protection of the environment or which requires manufacturers to conform to.

Sarkis (2001) use LCA to built the evaluates criteria system of GM, evaluates the types and quantities of product inputs such as energy, raw materials and water, and of product outputs, such as atmospheric emissions, solid and waterborne wastes, and end-product. Zhu et al. (2007a) also think that LCA methodology is an objective tool to identify and evaluate opportunities to reduce the environmental impacts associated with specific process or activity. They suggested that the four basic interrelated components of an LCA include: Inventory Analysis (INVAN), that is identification and quantification of energy and resource use and the environmental effects to natural resources throughout a product's life; Impact Analysis (IMPAN), that is assessment of the consequences and risks that wastes have on the environment; Life-Cycle Costing (LCC), that identifies all costs for a product throughout its lifetime; Improvement Analysis (IMPVAN), that is environmental auditing. LCA does provide a comprehensive framework that has not be delineated elsewhere. Yet, there still some limitations framework, for example, other decision factors need to be incorporated, strategic elements such as cost, flexibility, quality issues need to be integrated to help determine the full impact of the alternatives (Wang, 2008; Tuzkaya et al., 2009; Awasthi et al., 2010; Yin, 2013; Shen et al., 2013; Zhu, 2014)

D.A. Garvin (1987) is the first one who use KPI to built the criteria system of GM, and this approach been adopt by Li (2004) and Gao (2006). They suggested that every manufacturing sector has some resource limits and use of KPI to built the criteria system of GM could imply on the operational level that if a company has different resource limits, the key criteria should be scheduled first and the remaining

Table1. Summary of the previous researches

Authors	Green practice evaluating criteria
Leo A. (1986)	resources consumed, the operator of occupational health, other environmental impacts
D.A.Garvin (1987)	quality of key performance indicators, time key performance indicators, key performance indicators and flexible cost key performance indicators
G.K.Leong (1990)	quality, delivery speed, delivery reliability, costs, flexible terms
G.Azzone (1991)	internal indicators, external indicators
Munoz A. (1995)	material consumption, energy consumption, tool consumption, cutting fluid consumption, and toxicity of cutting fluid, etc.
Neely (1997)	divided indicators into the external validity of the evaluation system and the system of internal evaluation process efficiency, the quality indicators, including performance, features, reliability, consistency, persistence technology, usability, aesthetic level, quality awareness, value; Time indicators including manufacturing time, product introduction rate, delivery time, punctual delivery time, delivery frequency; Key performance indicators include the cost of manufacturing costs, added value, the sale price, operating costs, service costs; Flexible key performance indicators, including quality of raw materials flexibility, flexible output quality, new product flexibility, delivery of flexible, hybrid production flexibility, production flexibility
Katsundo (1997)	energy, equipment efficiency, resource utilization, loss and recovery rates
Wang (1999)	subsystems sustainability indicators, productive resources sustainability indicators subsystem, technical and economic performance metrics child business management and corporate indicators subsystem system
Xiang (1999)	technical attributes indicators, economic indicators and green indicators
Liu (1999)	T (time), Q (quality), C (cost), E (environmental impact) and R (resource consumption)
Jiao (2001)	green and sustainable economic growth and operational strength index system; green and sustainable technological progress indicator systems; enterprise and coordination of social indicators system; green and sustainable resource intensive development of integrated subsystems; green and sustainable green development subsystem
Sarkis (2001); Zhu et al. (2007a)	Eco design, environmental certification, development of clean technologies, the use of environmentally friendly materials, return and reuse of packaging, the use of life cycle assessment (LCA) or waste management, reduction in environmental emissions
Dong (2002)	Resources Carrying Capacity, Environmental carrying capacity, Economic development, Social Development
Handfield et al. (2002)	ISO 14000 certified, Ozone depleting substances, recyclable content, volatile organic compounds content, on Environmental Protection Agency 17 hazardous material list, remanufacturing/reuse activity, returnable or reduced packaging, take back or reverse logistics, participation in voluntary Environmental Protection Agency (EPA) programs, public disclosure of environmental record
Liu (2003)	noise, Wastewater discharge, Solid Waste, Dust, concentration of harmful gas emissions
Li (2004)	circular economy, green effect, resources and energy properties, production process attributes, sale and consumption of property, the potential environmental effects
Li (2004); Gao (2006)	Air Pollution, Water pollution, Noise Pollution, Solid Waste pollution, Soil pollution, Material Resources, Equipment resources, Human Resources, Energy Type, proportion of renewable energy use, Energy efficiency, Total energy consumption, Cost of production, Social costs, Productivity, Product development cycle, Storage time
Zhang (2004)	environmental indicators, resource property indicators, energy property indicators and social indicators
Hao (2004)	environmental, economics, society and resources
Rao and Holt (2005)	Green purchasing, green manufacturing, green packaging, and reverse logistics
Hervani et al. (2005)	Re-use, remanufacturing, and recycling which are embedded in green design, green procurement practices, environmental management, environmentally friendly packaging, transportation and product end-of-life.
Wang (2005)	the degree of attention of senior leadership, environmental protection facilities, the proportion of investment funds, whether take sustainable development as an important development strategy
Shen (2006)	Including manpower, resources, economy, technology, management, environmental
Liu (2006)	economic, benefits, operators, resource and energy use
Vachon (2006, 2008)	Environmental collaboration with suppliers and customers
Jiang (2006)	the value of the main natural resources, depletion of environmental resources, the cost of the loss of environmental resources, environmental restoration cost, replacement cost and the opportunity cost of environmental resources, improve the income of environmental resources, environmental and ecological potential, etc.
Chen (2006)	corporate environmental disclosure, environmental performance leadership degree of attention, the government and the public's perception of the four-level indicators and business
Srivastava (2007); Walker et al. (2008)	Product design, material purchasing, manufacturing processes, final product delivery, disposal, and the product end-of-life management

Authors	Green practice evaluating criteria
Jiang (2007)	Time, cost, quality, resource utilization, logistics, environment, flexible
Zhen (2007)	Green Energy, includes three aspects: energy efficiency, natural energy (Solar, wind, hydro, etc.) use, Waste energy (waste heat, waste steam, etc.) Use; green production process, includes four aspects: green design, green technology, green packaging, green management; green products, in this will be summarized in two aspects, Green product certification and product performance upgrades (overall recycling); Product Recycling, means the product parts and reuse parts, cannot re-use part of the treatment should be harmless
Li (2008); ang Liang (2010)	Atmosphere, Water, Solid Waste, Material Resources, Equipment resources, Human Resources, Comprehensive utilization of energy, Renewable energy usage, Energy input-output ratio, Clean energy usage, Business costs, User costs, Social costs
Wang (2008)	Openness, Green degree, Virtual degrees, Harmony
Guo (2009)	Resource consumption, Energy consumption, Recycling, Intangible pollution, Emissions of pollutants
Tuzkaya et al. (2009)	Green process management, green product, green image, environment and legislative management, pollution control, environmental costs
Hsu and Hu (2009)	Requirement of green purchasing, green materials coding and recording, capability of green design, inventory of hazardous substances, management of hazardous substances, legal-compliance competency, environmental management system (EMA), hazardous substance management system
Yu (2009)	Technological innovation capability, Resource utilization capability, Management capacity, Capacity for environmental protection
Xiao (2010); Li (2011)	Profitability, Development capacity, Operating capacity, Solvency, Resource consumption, Environmental Impact, Environmental Governance, Product Liability, Business ethics, Labor and Employment, Social Impact
Awasthi et al. (2010)	Use of environmentally friendly technology, use of environmental friendly materials, green market share, partnership with green organizations, management commitment, adherence to environmental policies, green R&D projects, staff Training, lean process planning, design for environment, environmental certification, pollution control initiatives
Ninlawan et al. (2010)	Green supply chain management practices; green supply chain management performance; green supply chain management pressure (market regulatory competition).
He (2010); Wang (2013)	Resource consumption rate index, Resources recycling targets, Waste emission targets, Disposal pollution index, Economic indicators
Tseng (2011a)	Reliability of delivery, profitability of the supplier, relationship to the supplier, green technology capabilities, conformance quality, flexibility of the supplier, service quality, green purchasing capabilities, life cycle assessment, green design, green certifications, internal green production plans, management support, green production, the reduction of hazardous materials in the production process, environmental management system
Azevedo et al. (2011)	Environmental collaboration with suppliers, environmentally friendly purchasing practices, working with designers and suppliers to reduce and eliminate product environmental impact, minimization of waste, Decreased consumption of hazardous and toxic materials, ISO 14001 certification, reverse logistics, environmental collaboration with customers, environmentally friendly packaging, working with customers to change product specifications
Yin (2013)	Economic performance, environmental quality, social development, Sustainable economic development, Environmental capacity for sustainable development, Capacity for sustainable development of society, Economic conditions and the extent of coordination, The degree of social and environmental coordination, Social and economic level, Policy and management level
Wang (2013)	Industrial scale, Industrial productivity, Market competitiveness, Innovation capacity, The level of carbon
Shen et al. (2013)	Pollution production, resource consumption, eco-design, green image, EMS, commitment of GM from managers, use of environmentally friendly technology, use of environmentally friendly materials, staff environmental training
Zhu (2014)	Production data, Personnel actual, Equipment actual, Material produced, Material consumed, Consumable actual

factors should be assigned to the later. Hence, energy efficiency indicators are transferred into measures and actions Handfield et al. (2002) thought, although *energy efficiency* represents an important success factor for the business model of a company and serve as competitive factor, but customers ask not only for efficient products but also for efficient production processes, so we should certified the ISO 14000 as evaluating criteria; Rao and Holt (2005), Tuzkaya et al. (2009), Hsu and Hu (2009) take the manufacturing process as evaluating criteria directly, they certified evaluating criteria into: green purchasing, green manufacturing, green packaging, and reverse logistics. But Leo (1986), Vachon (2006,2008), Xiao (2010) thought GM(or sustainable manufacturing) not only need to consider the ecological performance, but also need to consider about the social and economic performance, therefore, indicators connected with social and economic should be taken into account too. The summary of

previous researches is shown in Table 1.
From Table 1 we can know that, notwithstanding researchers use various methods to build the criteria system, but there are still some research limitations according to the practice, one is no links between strategic goals to operational measures, changes in the direction of energy efficiency and social responsibility reach out to all levels of the decision making process; the other is that the manufacturing sector includes many types, key indicators in each type are different, the existing research does not distinguish these different.

2.2. Some specific aspects of automotive industry's GM

Automotive industry is a high input, high output and industrial cluster development. In terms of promote the development of related industry, absorb new technologies and new materials, expand industry scale and market size, create value and taxes and jobs, stimulating effect on the national economy, all of these, other industries are difficult to compare. In general, automotive industry is a pillar industry of the national economy because it accounts for about 8% of national economic output and accounting for 30% of machinery industrial output in most of countries (Peng, 2006), sometimes it is even strong enough to control the movements of the entire national economy. However, automobile manufacturing is huge manufacturing system, the manufacturing process is always accompanied by a large number of resource consumption and significant environmental impact. According to statistics, except consume water, electricity and gas, the automotive industry also consume a large amount of limited resources, for example, it consumes 50% of rubber production, 25% glass products, 15% of steel production and 34% gasoline in the world every year (Liu and Yin, 2008). During the manufacturing and using process, automobile also produces prodigious amounts of emissions, such as VOC, paint waste, waste, etc. Harmful emissions exhaust by a car is three times larger than its own weight in one year, vehicle exhaust emissions account for about 85% of atmospheric pollution (Yin, 2008), all these indicate automobile industry have a tremendous negative impact on the sustainability.
It is urgent for automobile manufacturing enterprises to implement GM strategy; this is an important measure to response the global energy conservation strategy, and also the fundamental way to solve the problem of automobile industry innovation and development. However there are still some barriers that are faced by automotive industry, for instance, the limited level of technological access, the perception for a low level of innovation, the lack of environmental training in human resources and the shortage of financial resources. So introduce an advanced evaluating indicator system to solve these barriers and meet the optimization of enterprises' profit and sustainable development is the important subject of all auto manufacturing enterprises.

2.3. Proposed criteria for GM of Automotive Industry

In the following we would like to use SBSC – to propose an approach to evaluate performance of automotive industry's GM. SBSC was built by some scholars in order to define sustainability or environmental targets (Epstein and Wisner, 2001; Hockerts, 2001; Figge et al.,2002; Sidiropoulos et al., 2004). To facilitate company to implement their sustainability strategy successfully, these scholars often were adding an extra perspective for sustainability issues, or incorporating such issues into four standard BSC perspectives (Schaltegger, 2005; Yong-vanich and Guthrie, 2006; Hubbard, 2009; Panayiotou et al., 2009). For example, Figge (2002) added an extra nonmarket sustainability perspective into the four conventional perspectives and building a separate scorecard to address sustainability aspects; while Epstein (2001) proposed an environment perspective that can be used to address potential environmental and social goals.Considering the specific aspects of automotive industry's GM, we would add another variation, which is social perspective, into the four conventional perspectives of BSC. Referring to the already existing variation of the BSC, the SBSC have five perspectives: Financial; Internal process; Customer; Learning and growth; Social. There are three benefits to integrate social perspective into the traditional BSC: the first benefit is it will help everyone within the company to recognize the importance of social and environmental issues and how they could contribute to the company's financial success; the second benefit is assist managers in planning and decision-making of sustainability issues; the third benefit is it may strengthen company's accountability and legitimize their operation.

2.3.1. Financial perspective (C_1)

Financial indicator is the level of economic production and the basis of organization's survival and the development of sustainable economy (Leo, 1986; Tuzkaya et al., 2009; Hsu and Hu, 2009; He, 2010; Xiao , 2010; Yin,2013). Financial perspective aims at efficient utilization of resources as required in the sustainable development and introduce the restrictive conditions of resources and the environment to the industrial competitiveness evaluation, in order to distinction the key and difficult point during the period of GM, but also provide the basis for the management to develop appropriate industrial policies and environmental regulations (Wang, 2013). The following sub-criteria were used in this research:
C_{11}. ROE (Katharina, 2010; Wang, 2005; Awasthi et al., 2010).
C_{12}. Rate of EVA (Xiao, 2010; Awasthi et al., 2010).
C_{13}. Cost margins (Garvin, 1987; Li, 2004; Gao, 2006; Katharina, 2010; Tuzkaya et al., 2009).

C_{14}. Capital maintenance sustainable growth rate (Xiao, 2010; Awasthi, 2010).
C_{15}._Asset-liability ratio (Li, 2011; Wang, 2013; Xiao, 2010).
C_{16}. The proportion of investment in technology (Li, 2003; Li, 2011; Wang , 2013; Wang, 2013).

2.3.2. Internal process perspective (C_2)
It is necessary to optimize internal structures and processes at the policy as well as the administrative level that influence the overall goal of GM (Seyed, 2011). Internal process perspective is based on production planning and manufacturing in response to the request. If the process according to the actual needs of the manufacturing request is subdivided into a plurality of manufacturing elements, then for manufacturing a single request may be one or more manufacturing response (Zhen, 2007; Zhu, 2014). In the manufacturing process, the transfer of social risks and increase of waste may be prohibited (Li, 2003; Seyed, 2011). The following sub-criteria were used in this research:
C_{21}. Cannot be reused in the cycle component (Katsundo, 1997; Zhu et al., 2007a; Wang, 2008).
C_{22}. Manufacturing process noise emission (Liu, 2003).
C_{23}. Manufacturing process solid waste disposal recycling rate (Liu, 2003; Zhen, 2007).
C_{24}. Manufacturing process wastewater volume (Liu, 2003; Tuzkaya, 2009).
C_{25}. The amount of manufacturing process waste (COD, VOC, phosphorus, organic solvent) (Tuzkaya, 2009; Tseng, 2011a).
C_{26}. The comprehensive utilization of energy (Leo, 1986; Shen, 2013).
C_{27}. 100 km emissions, main including: HC, CO, NOX and PM (Tuzkaya et al., 2009; Hsu and Hu, 2009).

2.3.3. Customer perspective (C_3)
In this article, we define customers include not only as external customers, but also as internal customers (employees). And customer response is a comprehensive index of the target layer, used to measure the level of development of the manufacturing system, and the development of continuing development of the coordination degree (Vachon, 2006; Srivastava, 2007; Walker et al., 2008). Customer response is needed to select the descriptive indicators and assessment indicators to reflect the overall development in the term of service and related interest (Azevedo et al., 2011; Tseng, 2011a). The following sub-criteria were used in this research:
C_{31}. Customer satisfaction (Leong, 1990; Neely, 1997; Li, 2004; Srivastava, 2007; Azevedo et al., 2011).
C_{32}. Customer complaint rate (Neely, 1997; Li, 2004; Jiang , 2007; Azevedo et al., 2011).
C_{33}. Employee training (Gao, 2006; Awasthi, 2010; Yin, 2013).
C_{34}. Wages and benefits (Gao, 2006).

2.3.4. Learning and growth perspective (C_4)
Learning and growth perspective indicators are a measure of the level of industrial development potential of the industry. Quickly growth and sustainable development automotive industries are mainly marked by the level of technological innovation and product quality certification (Neely, 1997; Sarkis, 2001; Zhu et al., 2007a; Yu, 2009; Tuzkaya et al., 2009; Awasthi et al., 2010; Li, 2011; Tseng, 2011a; Wang, 2013; Shen et al., 2013). The following sub-criteria were used in this research:
C_{41}. New product development cycle (Neely, 1997; Tseng, 2011a; Wang, 2013; Shen et al., 2013).
C_{42}. Product quality certification (Handfield et al., 2002; Chen, 2006; Xiao, 2010; Azevedo et al., 2011; Wang , 2013).
C_{43}. Whether obtain the special subsidies for environmental protection (Chen, 2006).
C_{44}. The safety grade of automobile (Wang, 2008; Shen et al., 2013; You, 2014).

2.3.5. Social perspective (C_5)
The concepts of the BSC approach are widely applied to performance measurement, however, the traditional BSC technique ignores environmental and social aspects, so new social perspective was added for curing the problem. The SBSC combined with sustainable parameters helps to provide a meaningful instrument to the sustainability management (Chai, 2009). Therefore, the SBSC may not only help detect important strategic environmental and social objectives of the company but may also enhance the transparency of value-added potentials emerging from social and ecological aspects and prepare the implementation process of the strategy (Hsu, Hu, Chiou, Chen, 2011). The following sub-criteria were used in this research:
C_{51}. The proportion of investment in environmental protection (Munoz, 1995; Li, 2004; Hervani et al., 2005; Chen, 2006; Tuzkaya et al., 2009; Hsu and Hu, 2009; He, 2010; Li, 2011; Wang, 2013).
C_{52}. Tax returns (Xiao, 2010).
C_{53}. Employment contribution (Dong, 2002; Gao, 2006; Xiao, 2010; Yin, 2013).
C_{54}. Community donations (Xiao, 2010; Yin, 2013).
C_{55}. Fulfillment of environmental laws and regulations (Tuzkaya et al., 2009; Wang, 2013).
C_{56}. Low-carbon activities (Munoz, 1995 ;Li, 2004; Xiao, 2010; Yin, 2013).
C_{57}. Community Service (Hervani et al., 2005; Tuzkaya et al., 2009).

2.4. Review on methodology
The multi-criteria decision making (MCDM) as an important evaluation methodology in science assumes that the GM is complex and with the help of a more rational, explicit and efficient methods the evaluation can be improved (Zavadskas and Turskis,

2010; Liou, 2013; Rostamzadeh, 2015). Based on the extensive literature review there are a limited number of studies that used fuzzy MCDM methods for evaluation of GM criteria. For example, Liu (2003) applied Rough Set Theory to the green degree evaluation of military parts manufacturing, and evaluated the noise emission, waste water, solid waste, dust, harmful gases concentrations five indicators in the manufacturing process. Hao (2004) suggested it is efficient to use fuzzy mathematics and expert advice combination methods to evaluate. Xing (2007) believes that the assessment methodology of GM should be considered from the angle of time dimension of product system, and according to this, proposed three evaluation method: (1) One-way analysis of production systems consider only affect a single direction; (2) Entrance-exit analysis method of considered comprehensive performance of system entrance and exit; (3) Full life-cycle approach of considered production system from design to complete. Tseng and Chiu (2012) integrated gray theory, entropy weight and the analytic network process (ANP) together to evaluate the green practices under uncertainty, the study results indicated that the proposed approach is reliable and reasonable, but the limitation is the ability of experts which may influence the results of the study. Kannan et al. (2014a) used fuzzy TOPSIS to select green suppliers for a Brazilian electronics company based on the GM criteria. They compared the results obtained from the geometric mean and the graded mean methods with FTOPSIS.

Recently, BPANN (back propagation artificial neural networks) method has been introduced as an applicable technique to be implemented within evaluation process. Feng (2015) structured BPANN method to optimize complex systems evaluating of tank bottom corrosion status based on online detection information are established to guide the assessment of tank bottom corrosion. Comparing with the result of acoustic emission online testing through the evaluation of test samples, BPANN model can evaluate tank bottom corrosion accurately and realize acoustic emission online testing intelligent evaluation of tank bottom. Zhen (2014) constructed a BPANN with a single hidden layer to evaluate the water quality in intensive shrimp tanks. Jia (2014) using BP neural network to construct an assessment model of drought at-risk populations under the circumstances of more parameters and unknown weights. BPANN has some advantages compared to other evaluation approaches: (1) powerful capability and functionality, BPANN have proven to provide an alternative approach for many complicated assessment problems that are difficult to solve by conventional approaches, such as function approximation and pattern recognition (Bishop, 1995; Luk et al., 2000; Jiang, 2001); (2) model both linear and nonlinear systems without the need to make any assumptions as are implicit in most traditional statistical approaches, so it can been widely used in various aspects of geographical and ecological sciences (Chang, 2007; Luk, 2000; Wang, 2011).

Because of its characteristics and capabilities, the application of BPANN method has been increased in recent years. This includes using BPANN in environmental quality evaluation (Zhu et al., 2009; Xie, 2013), assessment of drought at-risk populations (Kuo et al., 2007; Jia, 2014), evaluates competitive advantage (Luo, 2014), evaluates risk of logistics outsourcing (Liu, 2013) assessment of green technology innovation (Chen, 2013; Zhou, 2014), evaluates and predicts the water quality (Zhao et al., 2007; Yesilnacar et al., 2008; Dogan et al., 2009; Singh et al., 2009; Ranković et al., 2010; Jia, 2014; Zhen, 2014), Other applications can be considered in (Lopes, 2011; Irani, 2011; Liang, 2012; Ghasemi, 2012; Yang, 2012; Yang, 2012; Mo, 2013).

Literature review reveals that evaluation tools and criteria for GM are growing rapidly, but they still lack comprehensiveness and adequacy to assess fully the GM practices. These tools include methods such as rough set theory, fuzzy mathematics and expert advice combination methods, analytical hierarchy process (AHP), entrance-exit analysis method, fuzzy TOPSIS and life cycle analysis (Liu, 2003; Hao, 2004; Xing , 2007; Tseng and Chiu, 2012; Kannan et al., 2014a). Some of these tools have been or could be directly applied to various aspects of GM, but some does not have a massively parallel processing capabilities or non-objectivity with experience weight (Hao, 2004; Tseng and Chiu, 2012; Kannan et al., 2014a). This can be understood as a gap in the literature. In order to fill this gap and to support the theory and practice empirically and effectively, BPANN model is explored in this article. BPANN model has the ability of large scale parallel processing, good fault tolerance, self-organization and self-adaptive ability, and the association function, so it can avoid non objectivity of experience weight efficient. Calculation with the traditional BPANN model, fixed learning rate always leads to the slow convergence speed of network and long training time, and its convergence will been influenced by the choice of initial weights and need a lot of trial and error. In practical applications, several modified functions such as trainlm and genetic algorithms are used. Trainlm is a network training function that updates weight and bias values and fast computational speed, according to Levenberg Marquardt (Maier et al., 2010; Palani et al., 2008; Zhao et al., 2007); GA is a stochastic modeling procedure based on concepts from biological evolution; it is known to be (1) robust with respect to initial values, and (2) less likely to be *captured* by a local extremism. GA have been used in statistical modeling problems such as robust regression and experimental design (Burns et al., 1992; Neely et al., 1997; Routledge, 1999; Hamada et al., 2001; West and Linster, 2003; Meyer, 2003; Liu and Bozdogan, 2008; Howe and Bozdo-

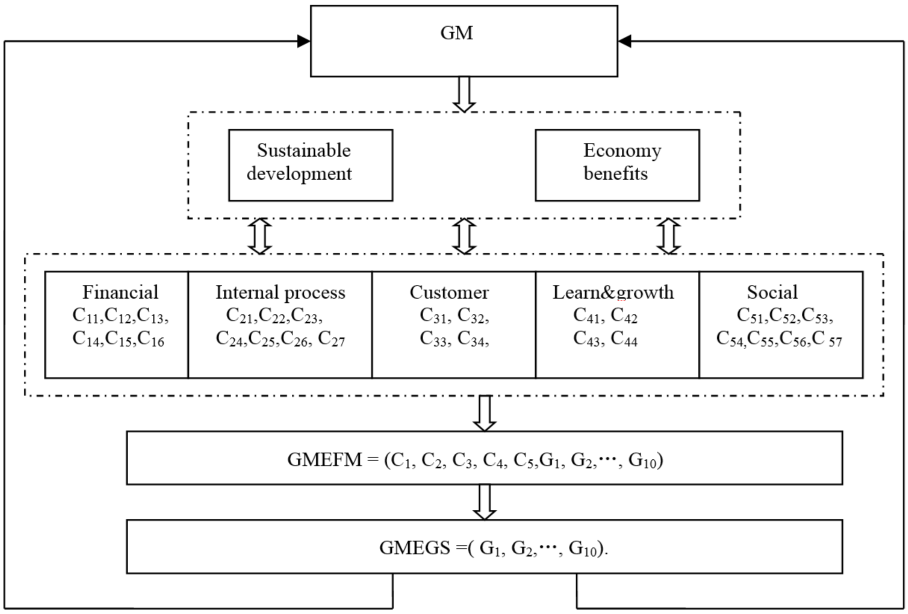

Figure 1. Evaluation Model of Green Manufacturing

gan, 2010). Because of network structure, learning efficiency coefficient and momentum factors of BPANN often require a lot of experience in setting or perform spreadsheet, so we will use GA to optimization the BPANN model in this study.

3. Research framework

3.1. Green Manufacturing Evaluation Model of Automotive Industry

Definition 1. Green Manufacturing evaluation factor set of automotive industry GMEFS= (Financial, Internal process, Customer, Learning and growth, Social) = (C_1, C_2, C_3, C_4, C_5)

In evaluation factors set, there are 5 factors and 28 sub-criteria, including: C_{11}; C_{12}; C_{13}; C_{14}; C_{15}; C_{16}; C_{21}; C_{22}; C_{23}; C_{24}; C_{25}; C_{26}; C_{27}; C_{31}; C_{32}; C_{33}; C_{34}; C_{41}; C_{42}; C_{43}; C_{44}; C_{51}; C_{52}; C_{53}; C_{54}; C_{55}; C_{56}; C_{57}.

Definition 2. Green Manufacturing rank set of automotive industry GMEGS = (G_1, G_2… G_{10}).

GMEGS green manufacturing rank set represents the state in which the car manufacturer's green manufacturing model belong to, such as: G_1 represents the international advanced level, G_4 represents the international advanced level, and G_6 represents the advanced level and so on.

Definition 3. Green Manufacturing evaluation fuzzy mappings of automotive industry GMEFM = (C_1, C_2, C_3, C_4, C_5, G_1, G_2… G_{10}).

GMEFM is a fuzzy mapping function of GMEFS and GMEGS, it establishes the nonlinear mapping relationship from GMEFS to GMEGS.GMEFM requires the mapping relations can overcome artificial weights, at the same time, have stronger robustness and adaptability.

Based on Definition1, Definition2 and Definition3, evaluation model of GM in automotive industry was built as Fig 1.

Figure 1 depicts the evaluation model of GM. The evaluation models of automobile manufacturers take GM and sustainable development as the ultimate goal, and divided this goal into social benefits and sustainable development two main evaluations. Primary evaluation factor set by the GM evaluation GMEFS = (Financial, Internal process, Customer, Learning and growth, Social) in the five factors reflect, and to decomposition of 28 sub-evaluation, then consisting of *2-5-2-8* evaluation index system. Through the evaluation index system and fuzzy mappings GMEFM, produce GM evaluation level: GMEGS=(G_1,G_2,…,G_{10}), the overall objective feedback as an important strategy to support the implementation of GM enterprises.

3.2. GA-BPANN model

Typically, the learning rate η and the momentum factor α of BPANN cannot be too large, otherwise they will affect the network strength and stability, but they cannot be too small either, too small they would affect the convergence speed of the network. Without the appropriate network, hidden layers and the number of nodes may lead to excessive training of BPANN. Optimization of network structure using genetic algorithms, can reduce the blindness of artificial selection of network structure, avoid network learning process *over training* phenomenon, enhance learning outcomes and predictive capability of the network. Thus, the GA-BPANN model can combine the ability of reflect complex nonlinear relationships and predict of BPANN with global optimiza-

tion features of genetic algorithms, and obtain a high value to deal with mathematical expressions without significant complications between variables and objective function value.
To facilitate the genetic operations, set up six DNAs, their relationship with the learning rate, momentum factor and the number of hidden layers shown in Figure 2.

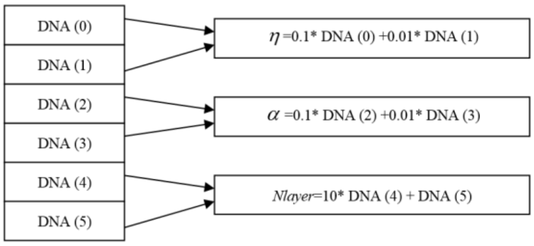

Figure 2.Genetic Algorithms DNA set

The following steps are the process of GA optimization BPANN:
Step 1. Generating a set of data randomly, using an encoding scheme to code each weight (or threshold) of the data, then construct a string (a string represents a kind of weight distribution of the network). In the premise of the network structure and learning rules have been given, the character string corresponds to neural networks which have a specific weight value or threshold value.
Step 2. Calculation of the error function of the neural network been generated in step1 in order to determine the fitness function value, the larger the error, the smaller the degree of adaptation.
Step 3. Select a number of fitness function value of the maximum of the individual, passed on to the next generation directly.
Step 4. Utilization of crossover and mutation genetic manipulation algorithms for processing the current generation groups, obtain the next population.
Step 5. Repeat Step 2, Step 3 and Step 4, so that a set of weights distribution which been determine at the initial phase could evolution constantly, until the training objectives are met.
By entering the characteristic number, evolution algebra, number of population, crossover and mutation probability, input learning sample statistically significant, we can get the final value of the improvement of the learning rate, momentum factor value and the number of hidden layers under constraints with the overall error, individual error and maximum number of iterations, then can determine the optimal network structure and parameter settings of BPANN; After this, input the training samples to BP artificial neural network, under set the maximum total error and individual errors, can determine the connection strength of the network and form a network weight matrix with constraints in a certain number of iterations; Thus completing the learning process of the network. Finally, substituted into the test sample and evaluate sample, detected and evaluated conclusions can be obtained. specific processes were shown in Figure 3.

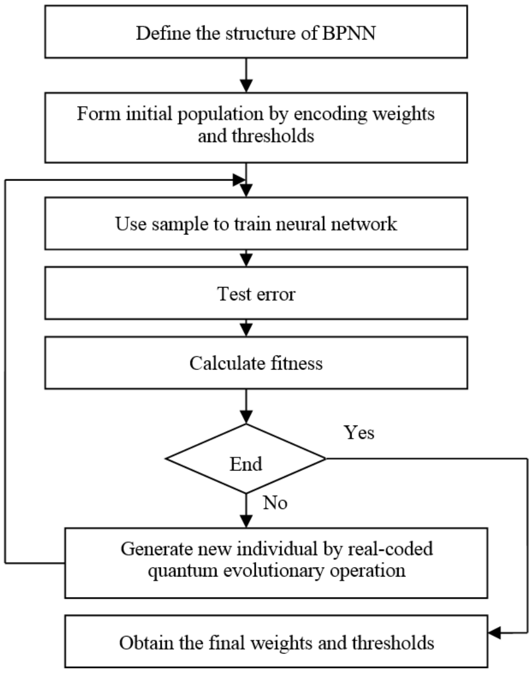

Figure 3. Flowchart of BPANN optimized by GA

3.3. Data acquisition, processing and evaluation

Financial (C_1) = (ROE, Rate of EVA, Cost margins, Capital maintenance sustainable growth rate, Asset-liability ratio, The proportion of investment in technology). ROE (C_{11}) = net profit /average shareholders' equity; Rate of EVA (C_{12}) = EVA/the total amount of capital, among them: EVA= NOPAT–TC*WACC (NOPAT represent net operating profit after tax; TC represent the total amount of capital; WACC represent the weighted average cost of capital); Cost margins, since the cost of automobile manufacturing enterprises difficult to measure, and even automobile manufacturing enterprise itself is difficult to provide accurate cost data, We use manufacturing cost efficiency coefficient (C_{13}) = (main business revenue–total profits) / total profit to reflect the cost of automobile manufacturers, this will not only ease to get the evaluate data, but also can reflects the company's manufacturing costs from the whole picture. Further, the reason for using the manufacturing cost efficiency factors, rather than simple cost, mainly taking into account the various car manufacturing companies may not be the same product mix; Capital maintenance sustainable growth rate (C_{14}) = the owner's equity at the end of the year/the owner's equity at the begin of the year, this is an important index to reflect the preservation and growth of investment, the higher the index, indicating the better state of the capital preservation, the faster growth of the owner's equity, the stronger their development potential; Asset-liability ratio (C_{15}) =total liabilities/total assets, this indicator reflects the degree of safety of the loans, low Asset-liability ratio indicate the enterprise has a good solvency and debt management capacity. The proportion of investment in technology (C_{16}) = investment in technology/the output value of enterprises, this is one of the important factors of innovation capability of enterprises.

Internal process (C_2) = (Cannot be reused in the cycle component, Manufacturing process noise emission, Manufacturing process solid waste disposal recycling rate, Manufacturing process wastewater volume, The amount of Manufacturing process waste, The comprehensive utilization of energy, 100 km emissions), Manufacturing process noise emission (C_{22}) use factory noise indicators to describe; Manufacturing process wastewater volume (C_{24}) use wastewater volume in the key painting and assembly processes to describe; The comprehensive utilization of energy (C_{26}) use energy use in effective output/total energy use to describe; 100 km emissions (C_{27}), mainly include: HC, CO, NOX and PM, use auto emissions standards to describe, weighted average of different emission standard car in the enterprises.

Customer (C_3) = (Customer satisfaction, Customer complaint rate, Employee training, Wages and benefits), Customer satisfaction (C_{31}) use customer satisfaction rate to measure, customer satisfaction rate = the number of satisfied customers/the total number of customers involved in the investigation; Similarly, Customer complaint rate (C_{32}) = the number of complaint customers/the total number of customers involved in the investigation; Employee training (C_{33}) use training expense ratio to describe, training expense ratio = training expenses/main business income; Wages and benefits (C_{34}) use the growth rate of wages and benefits to measure, the growth rate of wages and benefits = (wages and benefits of this year-wages and benefits of last year)/wages and benefits of last year.

Learning and growth (C_4) = (New product development cycle, Product quality certification, Whether the special subsidies for environmental protection were obtained, The safety grade of automobile), New product development cycle (C_{41}) use month to measure; Product quality certification (C_{42}), use 1 to describe *passing* and 0 to describe *not passing*; Whether obtain the special subsidies for environmental protection (C_{43}), use 1 to describe *obtain* and 0 to describe *not obtain*; The safety grade of automobile (C_{44}), use weighted average of automobile production and test data volume by C-NCAP to describe.

Social (C_5) = (The proportion of investment in environmental protection, Tax returns, Employment contribution, Community donations, Fulfillment of environmental laws and regulations, Low-carbon activities, Community service), The proportion of investment in environmental protection (C_{51}) = investment in environmental protection/the output value of enterprises, this is an important index to measure the international ecological protection problem; Tax returns (C_{52}) use the annual tax/enterprise sales revenue to measure; Employment contribution (C_{53}) use employment rate to describe, employment rate = (the number of employees at the end of the year-the number of employees at the beginning of the year)/the number of employees at the beginning of the year; Community donations (C_{54}) use charitable donations/enterprise sales revenue to measure; Fulfillment of environmental laws and regulations (C_{55}) use the number of be notified of environmental violations or accidents to measure; Low-carbon activities (C_{56}) represent enterprise spent how many human resources and how much time on the low-carbon charity, as well as enterprise's environmental awareness and participation of other public service activities, this index is a qualitative indicators, to be assessed by the respondents judgment. Community service (C_{57}) including provide training and practice base for community residents, encourage community-based enterprises open some public resources to community residents, resolve the issue seriously which connect with community residents interest, protect public resources and green landscaping, create a pleasant communities, this index was evaluated by the community residents.

In order to evaluated accurately, we use 10 grade range to evaluated according to the current automobile manufacturers in these indicators data, such as manufacturing cost efficiency coefficient (C_{13}), we set greater than or equal to 0.30 as grade1, specific of classification as shown in Table 2.

Get the learning samples from 5 groups data which generated randomly between 10 ranges, then we rank binary coding: 1 for 0001; 2 for 0010; 3 for 0011; 4 for 0100; 5 for 0101; 6 for 0110; 7 for 0111; 8 for 1000; 9 for 1001; 10 for 1010; Set maximum evolution algebra as 100, the number of the population as 10, crossover probability as 0.3, mutation probability as 0.1, the maximum individual error is 0.001, the maximum total error as 0.01, the maximum number of iterations as 20,000. Perform optimization through GA-BPANN model. After the operation, we get: best hidden layer unit is 32, the best learning rate η is 0.53, and the best momentum factor α is 0.75.The result been substituted into the network (determined network connection strength matrix by studying sample) thereby fixing the evaluation network structure. Finally by detecting samples tested, all samples were found to correspond to the original level of the interval, indicate the evaluation method is more reliable at this time.

4. Case Study

We selected a national automotive manufacturing company, a Sino-German joint venture automotive manufacturing company, a Sino-US joint venture automotive manufacturing company and a Sino-Japanese joint venture automotive manufacturing company as the samples of case study, all the relevant data of four companies as shown in Table 3. Through

Table 2. Evaluation System of GM for Automotives Industry

Criteria	Indicator	Grade									
		1	2	3	4	5	6	7	8	9	10
Financial	C_{11} (%)	10	9	8	7.5	7.0	6.5	6.0	5.5	5.0	4.5
	C_{12} (%)	10	9	8	7.5	7.0	6.5	6.0	5.5	5.0	4.5
	C_{13} (%)	.30	.25	.20	.15	.10	.05	.04	.03	.02	.01
	C_{14} (%)	1.40	1.30	1.20	1.10	1.00	.90	.70	.50	.30	.10
	C_{15} (%)	.00	.10	.20	.30	.40	.50	.60	.70	.80	.90
	C_{16} (%)	.70	.60	.50	.40	.30	.25	.20	.15	.10	.05
Internal process	C_{21} (kg)	1	5	10	15	20	30	40	50	80	100
	C_{22} (db)	40	45	50	55	60	70	80	90	100	120
	C_{23} (%)	100	90	80	70	60	50	40	30	20	10
	C_{24} (m^3/m^2)	.05	.10	.15	.20	.30	.40	.50	.60	.80	1.00
	C_{25} (g/m^2)	30	35	40	45	50	70	90	100	200	300
	C_{26} (%)	90	80	70	60	50	40	30	20	10	5
	C_{27}	5.00	4.50	4.00	3.50	3.00	2.50	2.00	1.60	1.30	1.00
Customer	C_{31} (%)	95	90	85	80	70	60	50	45	40	30
	C_{32} (%)	5	10	15	20	25	30	40	50	60	70
	C_{33} (%)	5	4.5	4	3.5	3	2.5	2	1.5	1	0.5
	C_{34} (%)	.070	.060	.055	.050	.045	.040	.035	.030	.025	.020
Learning &growth	C_{41} month	18	24	30	36	42	48	60	72	84	96
	C_{42}	1									0
	C_{43}	1									0
	C_{44}	10	9	8	7	6	5	4	3	2	1
Social	C_{51} (%)	.050	.045	.040	.035	.030	.025	.020	.015	.010	.005
	C_{52} (%)	.070	.060	.050	.040	.030	.025	.020	.015	.010	.005
	C_{53} (%)	.300	.200	.100	.090	.070	.050	.040	.030	.020	.010
	C_{54} (%)	.0050	.0040	.0035	.0030	.0025	.0020	.0015	.0010	.0005	.0001
	C_{55}times	0	1	2	3	4	5	6	7	8	9
	C_{56}	10	9	8	7	6	5	4	3	2	1
	C_{57}	10	9	8	7	6	5	4	3	2	1

the optimized GA-BPANN model, that is, the number of hidden layer units is 32; learning rate is 0.53, the best momentum factor is 0.75, calculated with the data in Table 3, which were obtained from *China Automotive Industry Statistical Yearbook* and websites of various automobile manufacturers. The evaluation results was generate as show in the last row in Table 3. According to the previous level of encoding rules, we can determine the level of their GM which, namely: national automotive company to level 6, Sino-German joint venture automobile manufacturing enterprises to level 3, a Sino-US joint venture automobile manufacturing enterprises to level 4, Sino-Japanese joint venture automobile manufacturing enterprises to Level 5.

In respect of financial criteria, national automotive company lag lot was compared with the world famous automotive company in some indicators, such as ROE, rate of EVA and cost margins, but in indicators of Capital maintenance sustainable growth rate and Asset-liability ratio, national automotive company have a better performance, especially better than Sino-Japanese joint venture company. In respect of internal process criteria, national automotive company's performance is poor in almost every aspect except manufacturing process solid waste disposal recycling rate, this is probably because national automotive company manufacturing technology is still relatively backward, need to increase innovation investment. In respect of customer criteria, national automotive company have a better performance, especially in terms of employee training, this shows that national automotive company care about more employee development than other companies, and tries to make more contribution to improve employee's living standards. In respect of Learning & Growth criteria, although national automotive company obtains product quality certification, but still needs to be strengthened in terms of new product development and the safety grade of automobile, this indicate national automotive company need a strong scientific research strength to conduct development of innovative technology. In respect of social criteria, national automotive company has a good performance in employment contribution and community donations and low-carbon activities, all these also mean national automotive company pay more attention to the social impact and market reputation. From the perspective of the comprehensive performance, we can know if national automotive company want to catch up and achieve a good performance of green manufacturing, it is important to improve customer satisfaction and conduct more technology innovation, community service and low-carbon activities.

Table 3. The results of the GM evaluation for the four automotive manufacturers

Criteria	Indicator	national automotive company	Sino-German joint venture company	Sino- US joint venture company	Sino-Japanese joint venture company
Financial	C_{11} (%)	6.5	8	7	7.5
	C_{12} (%)	6.2	7.6	6.6	7.9
	C_{13} (%)	.169082	.298172	.201573	.258569
	C_{14} (%)	1.0348	1.0422	1.0203	0.9871
	C_{15} (%)	0.4596	0.6001	0.6269	0.6478
	C_{16} (%)	.4437	.6332	.4942	.3027
Internal process	C_{21} (kg)	38.25	2.23	2.47	4.75
	C_{22} (db)	57	50	55	52
	C_{23} (%)	100	100	100	100
	C_{24} (m^3/m^2)	.26	.18	.15	.22
	C_{25} (g/m^2)	47	39	38	45
	C_{26}(%)	73	87	80	77
	C_{27}	2.37	3.06	2.94	3.00
Customer	C_{31} (%)	69.5	90.3	89.2	79.4
	C_{32} (%)	20	15	30	35
	C_{33} (%)	2.56	1.82	1.11	1.60
	C_{34} (%)	.0415	.0635	.0453	.0386
Learning & growth	C_{41} (month)	33	14	24	18
	C_{42}	1	1	1	1
	C_{43}	1	1	1	1
	C_{44}	6.263	10.000	8.354	9.786
Social	C_{51} (%)	.0165	.0250	.0206	.0108
	C_{52} (%)	.0491	.0620	.0582	.0423
	C_{53} (%)	.1958	.0193	.0896	-0.0336
	C_{54} (%)	.0003	.0016	.0002	.0001
	C_{55}	3	1	1	2
	C_{56}	5	7	6	6
	C_{57}	2	3	3	4
Evaluation result		(0.00,0.99, 0.99,0.00)	(0.00, 0.00 0.99,0.99,)	(0.00, 0.99, 0.00,0.01)	(0.00,0.99, 0.01,0.99)

5. Conclusions and Implications for Automotive Industry

In the background of sustainable development, government and business promote GM vigorously, answering how to establish a reasonable evaluation index system of GM for the enterprise to carry out sustainable manufacturing, which has a positive meaning. This research using SBSC establishes a *2528* GM automobile manufacturing enterprise evaluation system, which includes: 2 main evaluation index (economy benefits and sustainable development); 5 criteria (Financial, Internal process, Customer, Learning and growth, Social), and 28 sub-criteria. By application of the SBSC, integrate energy efficiency to the strategic, the company's mission and vision can be developed out, moreover, it is feasible and simple for upper manager to control the whole process of GM.

Without the appropriate network hidden layers and the number of nodes it may lead to excessive training of BPANN. In order to reduce the blindness of artificial selection of network structure and avoid network learning process *over training* phenomenon, this research introduces genetic algorithms approach to optimization BPANN model, using genetic algorithms to determine the best hidden layer unit, the best learning rate η and the best momentum factor α, under the conditions of the identified parameter, realized automotive industry green manufacturing evaluation.

Through evaluate GM model of a national automotive manufacturing company, a Sino-German joint venture automotive manufacturing company, a Sino-US joint venture automotive manufacturing company and a Sino-Japanese joint venture automotive manufacturing company, the result shows that, compared with the world famous automotive company, China's automotive manufacturing enterprises have a good performance in the respect of employment contribution, employee training and wages and benefits, but there still have big room for improvement in community service, low-carbon activities, customer satisfaction, manufacturing cost efficiency and the proportion of investment in technology.

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