https://doi.org/10.1016/j.habitatint.2021.102373



# Highlights

- This study focuses on predicting the quality of life (QoL) of the elderly based on dynamic neighborhood environment under diverse scenarios.
- An integrated prediction approach is proposed by taking advantage of artificial neural network (ANN) model, scenario analysis, and Monte Carol experiment.
- The change patterns of distribution curves of predictive QoL values under different scenarios are identified.
- The independent and compound effects of natural progressions and human interventions of neighborhood environment are forecasted to assist in developing neighborhood environment for supporting aging-in-place.

# Predicting the elderly's quality of life based on dynamic neighborhood environment under diverse scenarios: an integrated approach of ANN, scenario analysis and Monte Carlo method

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**Declaration of interests**

None.

**Acknowledgments**

This study was funded by the Department of Building and Real Estate at Hong Kong Polytechnic University and the Department of Construction and Real Estate at Southeast University. Thanks to all respondents and experts who have made great efforts in the study progress.

# Predicting the elderly's quality of life based on dynamic neighborhood environment under diverse scenarios: an integrated approach of ANN, scenario analysis and Monte Carlo method


## Abstract

There is an increasing global population of older adults in recent years, and the trend will be more acute in the following decades. Owing to low mobility and physical impairment, the elderly are sensitive to their nearby neighborhood environment. However, it is challenging to accurately judge changes of the elderly' quality of life (QoL) before conducting improvement strategies of neighborhood environment due to complicated environmental impacts. This study proposes a QoL prediction approach by integrating artificial neural network (ANN) model, scenario analysis and Monte Carlo experiment. The QoL of the elderly is measured from four domains, and the neighborhood environment is measured by 16 key indicators. Based on the measurement data collected from Nanjing, the ANN model is trained to fit the influence relationship between neighborhood environment and the elderly's QoL. Scenario analysis sets up potential scenarios for neighborhood environment under natural progressions and human interventions. Finally, Monte Carlo experiment is conducted to predict the probability distribution of the elderly's QoL values under potential scenarios by using the trained ANN model as functions. The predictive QoL values of the elderly show the change pattern of the elderly's QoL with dynamic neighborhood environment, reveal the independent and compound effects of natural progressions and human interventions, and confirm the mutual promotions between human interventions. Furthermore, the integrated prediction approach can be implemented in other cities and regions to forecast the local elderly's QoL under possible scenarios, and offer concise evidence for deciding improvement strategies of neighborhood environment to support aging-in-place.

**Keywords**: neighborhood environment, quality of life, elderly, ANN, scenario analysis, Monte Carlo.

## 1. Introduction

The aged population keeps increasing rapidly all over the world. The United Nations population report showed that the number of countries and regions with over 15% of population aged over 65 increased from 3 in 1990 to 51 in 2019, and is predicted to increase continuously (United Nations, 2019). The aging issue has become much severe than before. To tackle this issue, "age-friendly cities and communities" (AFCC) have been proposed and popularized worldwide (Evans, Oberlink, & Stafford, 2020; Kihl, Brennan, Gabhawala, List, & Mittal, 2005; World Health Organization, 2007, 2015). AFCC requires cities and communities to support people to age actively, respond to age-related demands and references, respect the elderly's decisions, and contribute to all areas of community life. These requirements are generally achieved through relevant policies, services, settings, and structures (World Health Organization, 2007; Torku, Chan, & Yung, 2020). Worldwide governments have formulated policies and initiatives towards promoting the life quality of the elderly (CUHK Jockey Club Institute of Ageing, 2018; Buffel & Phillipson, 2016).

As the AFCC develops, the elderly are encouraged to age in their own residences instead of professional care institutions, such as nursing homes (Iecovich, 2014). The benefits of aging-in-place include enabling the elderly to stay in their familiar living environment with a high-level of privacy and dignity (Wiles, Leibing, Guberman, Reeve, & Allen, 2011), saving cost on care institutions, and considerably relieving the stress of local governments on financial support. Owing to the declining mobility and competence of the elderly, the successful implementation of "aging-in-place" largely depends on the quality of living environment of the elderly (Ellis et al., 2018). The outdoor activity range of the elderly is mostly limited within the neighborhood environment, so neighborhood environment is considered as a determining factor of "aging-in-place".

The quality of life (QoL) is a worldwide accepted official index of individuals' life. The QoL of community-dwelling older adults can reflect the performance of "aging-in-place" quantitatively. World Health Organization (WHO) defined QoL as "*individuals' perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns*" (WHOQOL Group, 1995). WHO official assessment of the QoL, namely, WHOQOL-BREF (World Health Organization, 1996), measures QoL in domains of physical health, psychological health, social relationship, and the overall perception of life (Yu, Ma, & Jiang, 2017).

Neighborhood environment is an integral part of the elderly's living environment. The neighborhood environment is regarded to consist of many components: the physical environment, the social environment (Nicklett et al., 2017), neighborhood facilities, neighborhood safety, and so on (Zhang, Li, Ahrentzen, & Feng, 2020). Its impacts on the elderly's QoL have attracted significant attention from researchers and the public in recent years. Previous studies approved components of neighborhood environment indeed have significant influences on the elderly's psychological health (Wen, Hawkley, & Cacioppo, 2006), self-rated health (Putrik et al., 2015; Spring, 2018; Yu, Wong, & Woo, 2019), falls, injuries (Nicklett, Lohman, & Smith, 2017; Wong et al., 2017), and physical activities (Cerin et al., 2016; Chaudhury, Mahmood, Michael, Campo, & Hay, 2012; Nathan, Barnett, Barnett, Cerin, & Van Cauwenberg, 2017). Studies usually demonstrated impacts of particular components of neighborhood environment on specific domains of the elderly's life. For instance, several different studies analyzed the social neighborhood environment impacts the elderly's physical activities (Chaudhury et al., 2012; Ellis et al., 2018), mental health (Van Dyck, Teychenne, McNaughton, De Bourdeaudhuij, & Salmon, 2015), and capability wellbeing (Engel et al., 2016).

Findings of previous studies reveal which components of neighborhood environment affect the elderly deeply, and which should be given priority during the improvement of age-friendly neighborhoods. However, it is still not enough to assist in decision-making quickly. As time passes, urban neighborhood environment keeps changing due to environment's natural progressions or human interventions. In order to offer quantitative evidence for reference, it is essential to clarify how much the elderly's QoL will be affected by their changing neighborhood environment in the future. Current studies lack the way to forecast the variation of the elderly's QoL caused by potential dynamic neighborhood environment.

This study aims to propose an integrated approach to make predictions of the elderly's QoL based on neighborhood environment under most likely scenarios. Artificial neural network (ANN) model is used to fit the complicated relationship between neighborhood environment and the QoL of the elderly, scenario analysis helps to develop potential scenarios of neighborhood environment that may change the elderly's life quality, and Monte Carlo experiment is applied to simulate data distributions of dynamic neighborhood environment under scenarios and predict the distribution of the QoL values in scenarios. The change pattern of the elderly's life quality can be identified based on the prediction results. This study offers an effective tool to understand the effects of neighborhood environment's natural progressions and human interventions on the elderly's QoL, provides explicit evidence to assists in developing livable neighborhood environment for aged residents, and ultimately supports their aging-in-place.

The content is structured as follows. Section 2 reviews related studies, section 3 proposes an integrated prediction approach, section 4 shows the results and findings in each step of the integrated approach, section 5 discusses the change patterns of predictive QoL values and the effects of natural progressions and human interventions.

## 2. Related studies

Studies have been conducted to explore the neighborhood environmental impacts on the elderly. Previous studies were used to apply correlation analysis, linear regression (Chan & Liu, 2018; Huang et al., 2019; Yu et al., 2017) and qualitative analysis (Leung, Wang, & Chan, 2019) to detect relationships between neighborhood environment and the elderly. However, sometimes different studies drew inconsistent conclusions about the same relationship. For example, some studies showed the neighborhood greenspace affects the elderly's health by providing open spaces for walking or exercising (Chan & Liu, 2018), particularly benefits the elderly's mental health (Wu & Ren, 2020), while others found no significant relationship between greenspace and the elderly's health (Huang, Chu, Kung, & Hu, 2019; Vogt et al., 2015). It is may due to differences in study participants, study areas (Vogt et al., 2015), data analysis methods. Like correlations analysis and linear regression, general data analysis methods are quite effective in analyzing the impact on only one dependent variable once, without involving all variables at the same time. Thus, some researchers adopted other methods to further verify the influence relationship from the holistic perspective, like structural equation model (SEM) (Leung et a., 2020). Actual environmental impacts on individuals are more complicated than linear or direct relations. Previously used data methods are not effective enough to explore all significant environmental impacts (Kim, Kim, & Srebric, 2020), which leads to difficulties in simulating the actual relationships and predicting the QoL based on neighborhood environment.

As artificial intelligence develops rapidly, machine learning methods have been frequently applied in the field of the built environment, instead of traditional data analyses. For instance, in the area of thermal comfort, the algorithm of random forests is applied to predict the elderly's thermal sensation based on four environmental variables and two human-related variables (Wang et al., 2019), while other several algorithms of machine learning are tested to build the personal thermal model, for predicting individual's thermal responses by their living environment (Kim, Schiavon, & Brager, 2018). Among several kinds of machine learning methods, the ANN model is used widely to make predictions related to the built environment. Researchers built an ANN model of building floor, nighttime outdoor temperature, and indoor $CO_2$ concentration, to predict the nighttime natural ventilation effect (Dai, Liu, Zhang, & Chen, 2019); based on the data of air temperature, mean radiant temperature, wind speed, relative humidity, and clothing value, another ANN model was also trained to predict thermal comfort evaluation in urban parks (Chan & Chau, 2019); and the ANN model was trained to simulate the energy consumption based on the office building features (Ilbeigi, Ghomeishi, & Dehghanbanadaki, 2020).

Even though demonstrated to be suitable methods for built environment-related predictions, machine learning methods, especially ANN model, are seldom used to develop practical prediction approach for environmental impacts on individuals' life quality. Moreover, machine learning methods have rarely been integrated with other types of simulation methods as well. For filling the research gap, this study integrates ANN model with scenario analysis and Monte Carlo experiment as a new approach to adapt to requirements on the elderly's QoL prediction.

## 3. Research Methodology

An integrated research methodology is proposed to predict the elderly's QoL based on their neighborhood environment, combining ANN model, scenario analysis and Monte Carlo experiment. Fig. 1 presents the logic of the integrated prediction approach. According to measurement instruments, data of neighborhood environment and the QoL can be collected, ANN model is used to simulate the relationship between the elderly's QoL value and their neighborhood environment. Scenario analysis helps develop a series of single and multiple scenarios of neighborhood environment that are likely to happen in the future. Monte Carlo experiment predicts probability distributions of the elderly's QoL value under diverse scenarios by importing the trained ANN model as the functional relation.

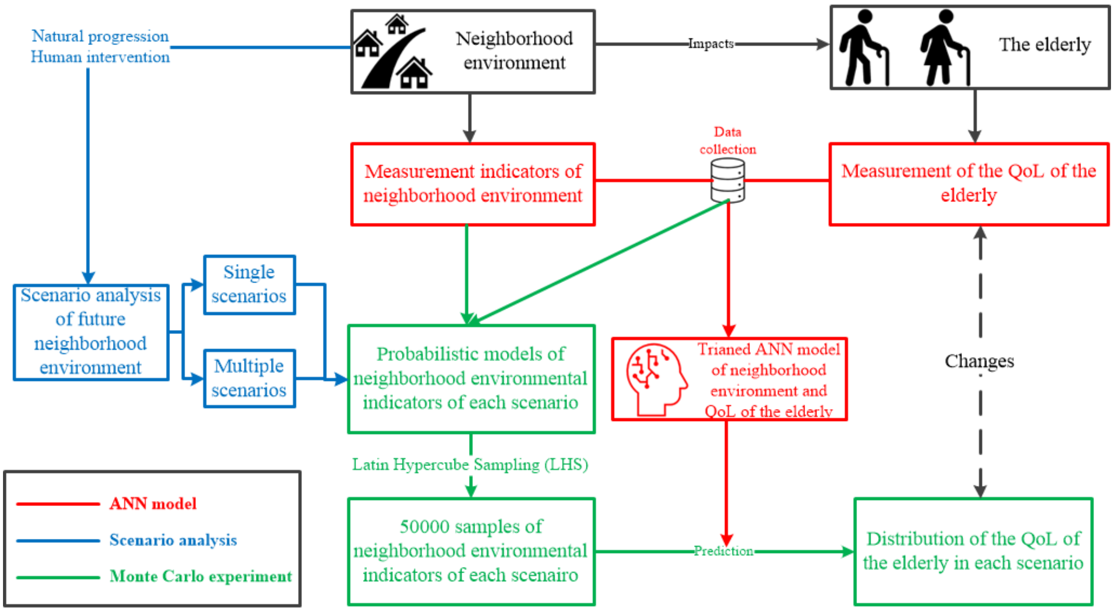



**Fig. 1.** The flow chart of research methodology

### *3.1 Measurement instruments*

To conduct the prediction approach, it is essential to determine the critical features of neighborhood environment that significantly influence the elderly's lives as inputs of prediction, and the main domains of the elderly's QoL as outputs of prediction. The detailed measurements of both neighborhood environment and the QoL should be determined at first.

This study measures the neighborhood environment by 16 indicators identified by prior research as critical indicators influencing the elderly heavily (Zhang, Li, Ahrentzen, et al., 2020). The detailed measurement items of each indicator are developed and proved valid and reliable, as shown in Fig. 2 (Zhang & Li, 2019a). Regarding the QoL, this study utilizes the official QoL measurement of WHOQOL-BREF. The measurement items qualify the QoL from four domains, containing overall QoL, physical health, psychological health, and social relationship (Yu, Ma, & Jiang, 2017), as shown in Fig. 3.

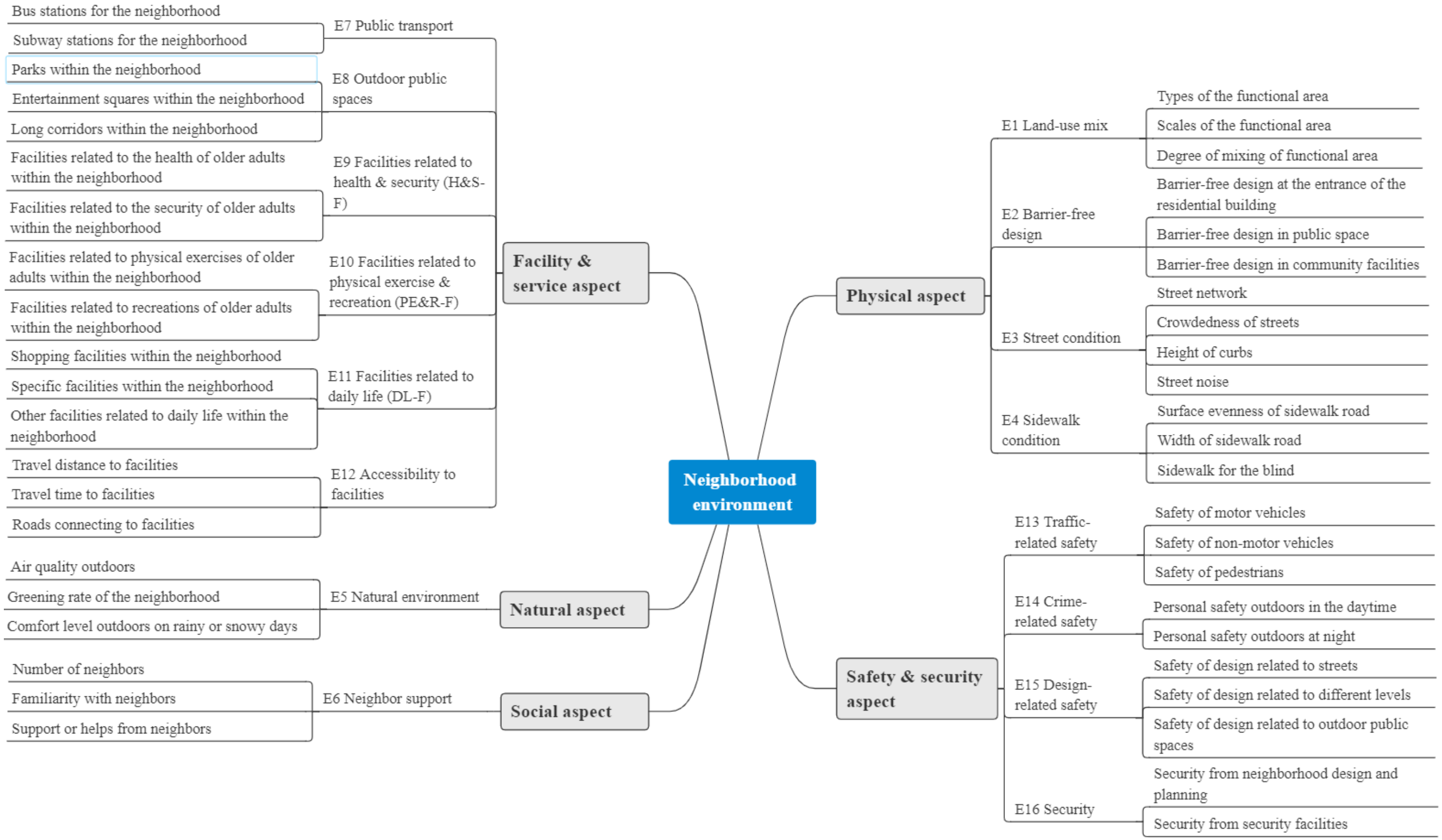



**Fig. 2.** Measurement items for critical indicators of neighborhood environment

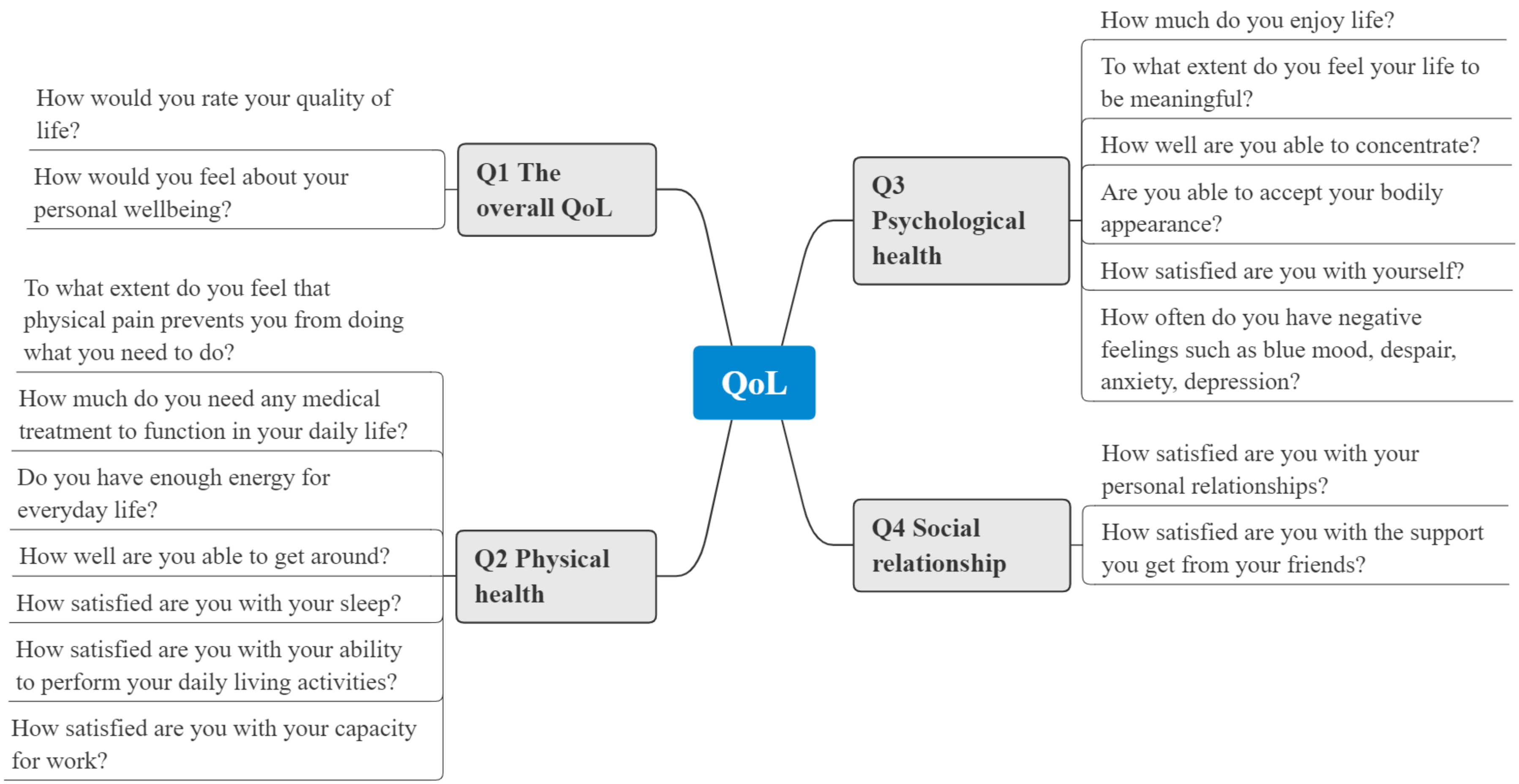



**Fig. 3.** Measurement items for the QoL of the elderly

### *3.2 ANN model of neighborhood environment and QoL of the elderly*

The complicated relationship between the neighborhood environment and the elderly's QoL has been proved to exist. Owing to the high capability to approximate the actual complex relations, BPNN (back propagation neural network), a widely-used ANN model, is used to establish the ANN model to simulate influence relations. The collected data are imported as the data set to train the ANN model. All procedures and settings are conducted in the Matrix Laboratory (MATLAB).

The general neural network contains input layer, hidden layer, and output layer (Zhang, Liu, Rao, Li, & Zhao, 2020). In the input layer, the 16 critical indicators of neighborhood environment are used as inputs of the model; while in the output layer, the four domains of QoL are regarded as outputs. However, the number of hidden layers and the number of variables in each hidden layer are not fixed. To prevent overfitting, one hidden layer is enough for the neural network. The hidden layer needs to be determined by the method of trial-by-error (Zhou, 2016). The initial number of hidden variables is set as 6 based on Equation 1 (Zhou, 2016). After determining the remaining parameters of the neural network, trials of ANN model training would be conducted by increasing the number of hidden variables from 6. After trials, the number of hidden variables would be finalized when the ANN model achieves the best performance.

$$l = \sqrt{n + m} + a \qquad (\textit{Equation 1})$$

Where, $l$ refers to the number of hidden variables, $n$ refers to the number of input variables, $m$ refers to the number of output variables, $a$ is a constant between [0,10].

Besides, the activation function of hidden layer is set as Sigmond function, the activation function of output layer is set as Pureline function, and the training algorithm is set as Levenberg-Marquardt (coded as "trainlm"). Moreover, "early stopping" is adopted to prevent further overfitting. The data set is divided into three sets: 70% data as training data set, 15% data as validation data set, and 15% data as test data set (Ilbeigi et al., 2020; Xu, Huang, Zhang, & Li, 2018). When errors of training data set decrease but errors of validation data increase, the process of training should be stopped and the trained network is returned. All settings for training the ANN model are summarized in Table 1.

**Table 1**

Structure of the ANN model (Chan & Chau, 2019)

| | | Setting |
|---|---|---|
| Structure | Input layer | 16 variables: indicators of neighborhood environment. |
| | Hidden layer | Number of hidden variables is determined by Equation 1 and trial-by-error. |
| | Output layer | 4 variables: the overall QoL, physical health, psychological health, social relationship. |
| Activation function | Hidden layer | *Sigmond* function |
| | Output layer | *Pureline* function |
| Training | | Levenberg-Marquardt |
| Data sets | Training | 70% |
| | Validation | 15% |
| | Test | 15% |

### *3.3 Scenario analysis*

Scenario analysis is a qualitative method to analyze future events by considering possible outcomes, usually used in geopolitics, finance, clinical medicine and education (Duinker & Greig, 2007). The usage of scenario analysis is not limited by hypotheses, so it is flexible enough to analyze and forecast uncertain development. Scenario analysis considers potential conditions and emergencies as many as possible, and provides evidence for decision-makers as much as possible. The steps of scenario analysis are described below.

*(1) Confirming the research topic.* Since this study aims to simulate the impacts of

neighborhood environment on the elderly's QoL, the topic of scenario analysis should focus on possible development related to the neighborhood environment and residents.

*(2) Ensuring analytical perspectives.* Many potential scenarios will occur within the neighborhood, and some of them can significantly affect the daily life of the elderly. The analytical perspectives related to the elderly should be decided to guide the scenario setting. Generally, the changes of neighborhood environment follow natural rules if there is no human intervention. Therefore, scenarios of neighborhood environment are analyzed from perspectives of natural progression and human intervention.

*(3) Setting potential single and multiple scenarios.* The single scenario of neighborhood environment considers only one possibility. From the perspective of natural progression, the neighborhood environment would deteriorate gradually (Zhu et al., 2020), and the population of the elderly would increase as the world trend (United Nations, 2019). From the perspective of human intervention, besides the well-known renewal projects of neighborhood environment (Zhu et al., 2020), governments would implement relevant rules or policies to facilitate aging-in-place, such as government funding for community care services (Zhang, Li, & Zhang, 2019), and social services and benefits for the elderly[1]. In practice, different single scenarios would not occur independently, but concurrently. The multiple scenarios are developed to mimic the actual situations by integrating several single scenarios. According to common sense, we suppose the aged population must retain increasing, the neighborhood environment may keep deteriorating, or get better by the urban renewal, and the supportive rules and policies may be launched or not.

### *3.4 Latin Hypercube Sampling (LHS)-based Monte-Carlo experiment*

Monte Carlo experiment is a numerical method to obtain certain statistical features by

[1] https://www.gov.hk/tc/residents/housing/socialservices/elderly/elderlyservices.htm

repeating random experiments (Zheng, Yu, Wang & Tao, 2019), according to *Law of Large Number* and *Central Limit Theorem*. This method is appropriate to solve issues of "expected value of random variables" and "probability distribution of events", which cannot be obtained easily (Robert & Casella, 2013). Monte Carlo experiment helps save time for decision-making by dealing with the randomness and uncertainty of studies and projects. Procedures of Monte Carlo experiment were modified to adapt the ANN model, and conducted in the software of the Crystal Ball and MATLAB.

*(1) Setting probabilistic models and functional relation*. At first, standard probabilistic models of neighborhood environmental indicators should be set by point estimation of collected data of neighborhood environment. Then concrete probabilistic models are determined for neighborhood environment under different scenarios according to scenario analysis results. In the Monte Carlo experiment, the functional relation between independent and dependent variables is also needed to make the prediction. The trained ANN model is imported as the functional relation between neighborhood environment and the QoL of the elderly.

*(2) Determining the sampling method*. Traditionally, Monte Carlo experiment uses simple random sampling, by which the results of sampling contain any values within the ranges of property models. When the sample size is large enough, many repeated values may appear in results of sampling. The aggregation results in a lack of samples with low probability. However, samples with low probability refer to the extreme conditions of neighborhood environment, which should not be omitted in this study. Thus, Latin Hypercube Sampling (LHS) is adopted in Monte Carlo experiment, instead of traditional simple random sampling. LHS generates near-random samples of parameter values from a multidimensional distribution (McKay, Beckman, & Conover, 1979), belonging to stratified sampling. LHS can ensure samples cover all probability intervals, reduce iterations, and improve sampling efficiency, ensuring the set of

random numbers is representative of the real variability[2].

*(3) Conducting experiments following statistical properties.* It is essential to specify how many simulations to run when the measurement of interest (median or mean) becomes stable (McMurray, Pearson, & Casarim, 2017). The more times Monte Carlo experiments, the results can represent more actual distributions. At least 10,000 times experiments are necessary for general studies. In this study, 16 indicators of neighborhood environment require more times experiments to reflect considerable possible conditions of 16 indicators. Thus, LHS-based Monte Carlo experiments are conducted 50,000 times to generate 50,000 samples of neighborhood environment. Then based on the functional relation of trained ANN model, 50,000 sets of predictions of the elderly's QoL values can be obtained for each scenario.

*(4) Fitting distribution of the predictive QoL values*. Distribution fitting is conducted to confirm the distribution curves of predictive QoL values of each scenario. Then, the change patterns of the QoL with scenarios can be identified by summarizing and comparing the distribution curves of the QoL values under different scenarios.

## 4. Results

### *4.1 Study area and data collection*

According to the measurements of both neighborhood environment and the QoL (Figs. 2 and 3), the questionnaire was designed to collect data about the QoL of community-dwelling older adults and their neighborhood environment. In the questionnaire, the first part investigates basic information about respondents; the second part inquires the perceived neighborhood environment of respondents, and questions are set according to measurement items in Fig. 2; the third part inquires the QoL of respondents, and

[2] https://en.wikipedia.org/wiki/Latin_hypercube_sampling

questions are developed based on measurement items in Fig. 3. Respondents are asked to score each question between 1 (very unsatisfied) and 5 (very satisfied) by five-point Likert scale. For instance, respondents answer two questions to present their social relationship, including "how satisfied are you with your personal relationship" and "how satisfied are you with the support you get from your friends". The values of 16 environment indicators and 4 domains of QoL are the average scores of their measurement items. Respondents of the questionnaire survey are required to be community-dwelling residents over 60 years old, also with good capability of thinking and communication to give their feedback.

This survey was conducted in 2019 at Nanjing, the capital city of Jiangsu Provence, the major cities located within the Yangtze River Delta, where older adults over 60 years old account for a proportion of 21.07% of the whole population. Nanjing is regarded as one of cities facing the most severe aging problem in China. In recent years, Nanjing government makes efforts to build a livable city for the elderly. Furthermore, the living environment of part of neighborhoods in Nanjing, a historical city, has worsened for a long time. Thus, the official interventions of old neighborhood renewal (ONR) have been implemented gradually in some areas of Nanjing (Zhu, Li, & Jiang, 2020).

204 respondents participated in the questionnaire survey in total, and finally, 192 eligible data were collected via the questionnaire survey. The basic information of respondents is listed in Fig. 4, which manifests that respondents were selected to cover different genders, age groups, types of residential building, households, and length of residence, for ensuring the reliability of data collection. The descriptive statistics of collected data are conducted to explore the data distribution, including mean value, standard deviation and variance, as shown in Table 2.

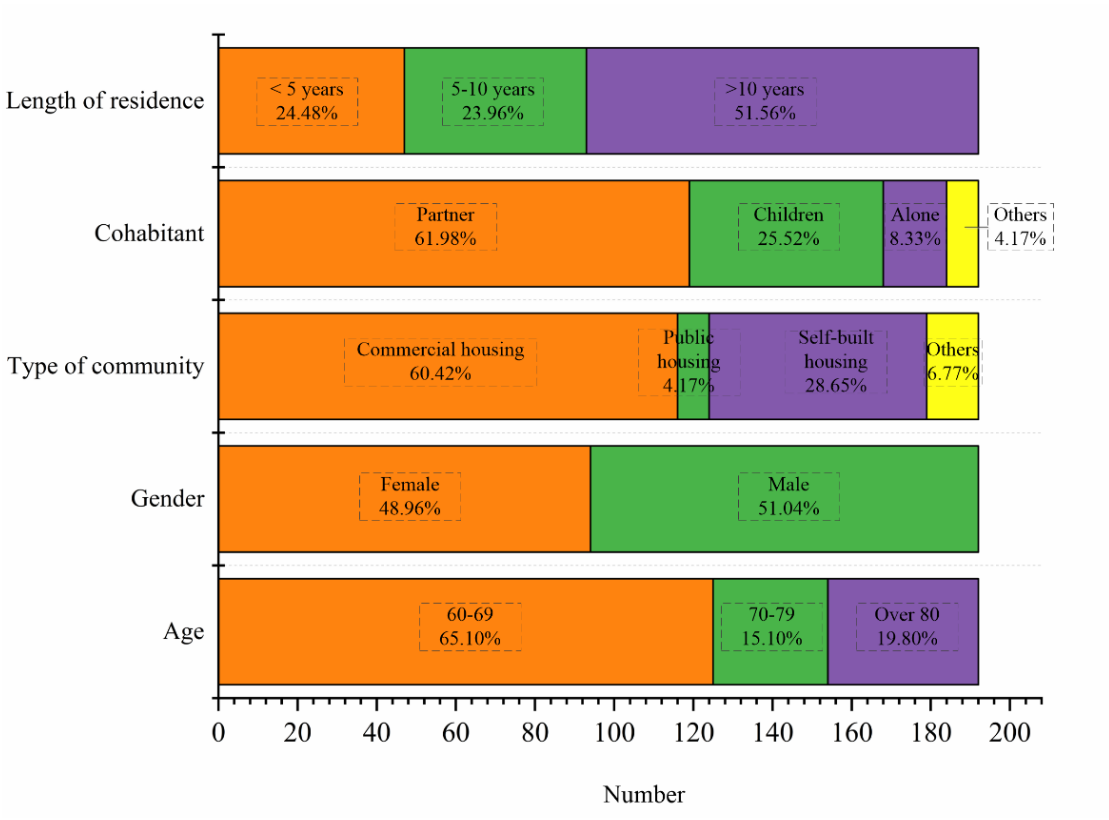



**Fig. 4.** The basic information of respondents

**Table 2**

The descriptive statistics of data collection

| Category | Code | Indicator/Domain | Mean | Standard deviation | Variance |
|---|---|---|---|---|---|
| Neighborhood environment | E1 | Land-use mix | 3.047 | 1.014 | 1.028 |
| | E2 | Barrier-free design | 2.873 | 0.981 | 0.962 |
| | E3 | Street condition | 3.352 | 0.872 | 0.760 |
| | E4 | Sidewalk condition | 2.913 | 0.851 | 0.724 |
| | E5 | Natural environment | 3.358 | 0.867 | 0.752 |
| | E6 | Neighbor support | 3.566 | 0.734 | 0.539 |
| | E7 | Public transport | 3.078 | 1.004 | 1.007 |
| | E8 | Outdoor public spaces | 3.200 | 0.882 | 0.778 |
| | E9 | Facilities related to health & security | 2.990 | 0.949 | 0.900 |
| | E10 | Facilities related to physical exercise & recreation | 2.917 | 0.985 | 0.969 |
| | E11 | Facilities related to daily life | 3.089 | 0.851 | 0.725 |
| | E12 | Accessibility to facilities | 3.250 | 0.893 | 0.797 |

| | | | | | |
|---|---|---|---|---|---|
| | E13 | Traffic-related safety | 3.191 | 0.925 | 0.856 |
| | E14 | Crime-related safety | 3.560 | 0.833 | 0.694 |
| | E15 | Design-related safety | 2.721 | 0.789 | 0.622 |
| | E16 | Security | 3.268 | 0.912 | 0.832 |
| QoL of the elderly | Q1 | Overall QoL | 3.497 | 0.773 | 0.598 |
| | Q2 | Physical health | 3.528 | 0.682 | 0.465 |
| | Q3 | Psychological health | 3.300 | 0.699 | 0.489 |
| | Q4 | Social relationship | 3.490 | 0.722 | 0.521 |

### *4.2 Results of the ANN model*

The influence relationship between neighborhood environment and the residents' life quality is regarded as a complicated many-to-many relationship, and it brings difficulties to accurately infer the QoL by the neighborhood environment in traditional ways. This problem can be solved effectively by training the ANN model to fit this complicated influence relationship.

The collected data are divided into three data sets: 70% for training, 15% for validation, and the remaining 15% for testing. Two performance indices of the model training manifest how the ANN model fits the relationship of the collected data, one is R value which measures the correlation between targets (collected data of the QoL) and outputs (predicted value of the QoL through the ANN model), the other one is mean squared error (MSE) which refers to the average difference between targets and outputs. The closer that R value is to 1 and MSE is to 0, the better fitting performance of the trained ANN model (Ilbeigi et al., 2020).

According to the description of the integrated approach, after well-setting of the model structure, the first thing is to determine the number of variables in the hidden layer by error-by-trail. The initial number is decided as 6, error-by-trail is conducted to test the ANN model performance with different numbers of variables in the hidden layer. After testing from 6 variables to 20 variables, we find that the model with 15 variables in the hidden layer has the best R value and MSE. Consequently, the number of hidden variables is determined as 15. By conducting the training, validation and test, the ANN model performs best after epoch 11. The results of R value and MSE are listed in Table 3, and the performance of the model training, validation and test are illustrated in Fig. 5. The MSEs of training, validation and test are between 0.097 and 0.287, and the average R value reaches 0.850, manifesting the ANN model can fit the collected data and reflect the actual relationship among critical indicators of neighborhood environment and domains of QoL quite well.

**Table 3**

Performance indices of the trained ANN model

| ANN model | R | MSE |
|---|---|---|
| Training | 0.930 | 0.097 |
| Validation | 0.769 | 0.287 |
| Test | 0.728 | 0.249 |

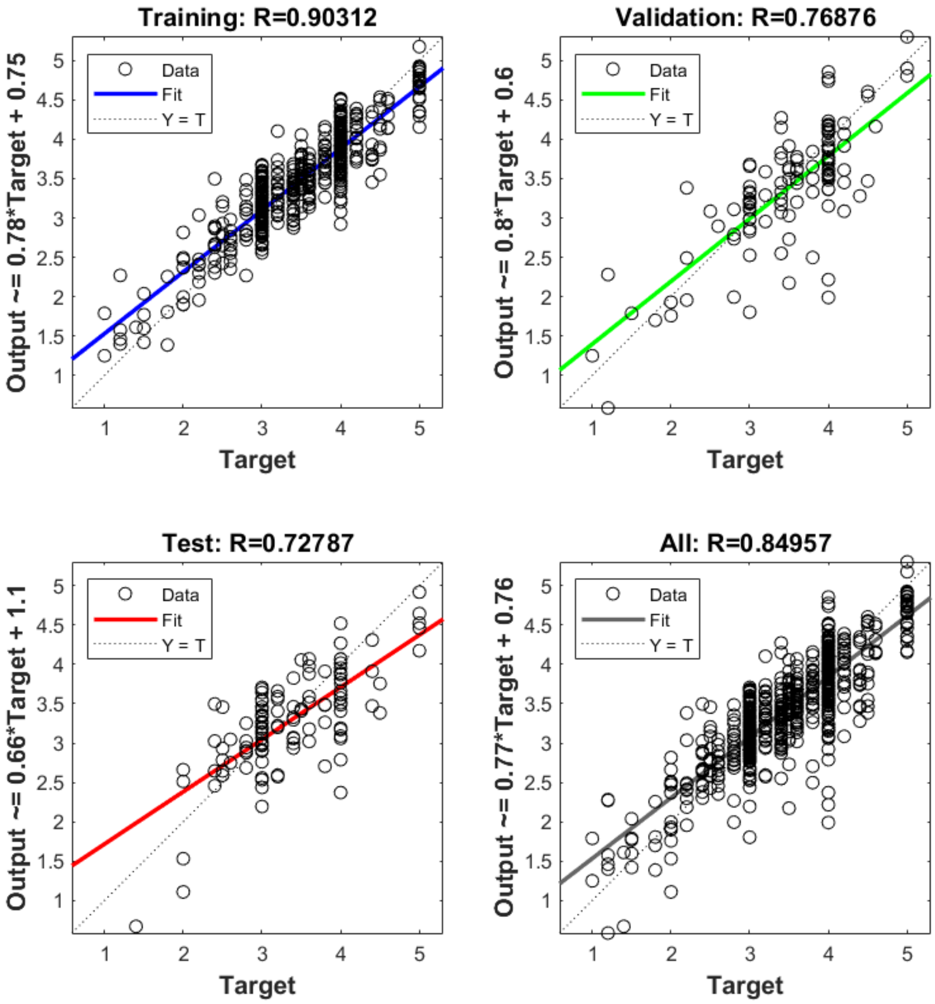



**Fig. 5.** The performance of the ANN model

### *4.3 Potential scenarios of neighborhood environment development*

According to scenario analysis procedures, four single scenarios and four multiple scenarios of neighborhood environment are developed from perspectives of natural progression and human intervention.

#### *4.3.1 Single scenarios of natural progressions*

***S1: Population aging.***

In terms of the official report *World Population Ageing 2019* (United Nations, 2019), population aging is a worldwide trend that most countries must face. Under natural progression, the demographic structure of neighborhood would keep aging continuously, also called "*population aging*". The increasing number of aged neighbors means that older adults would have more peers to get familiar, and support each other physically and psychologically. Meanwhile, a higher proportion of older adults implies growing demands and higher requirements on community care facilities, and the elderly's user experience and perception of original neighborhood facilities will decline therewith. Therefore, the neighborhood social environment would be better, while neighborhood facilities would be worse in this scenario.

***S2: Deterioration of neighborhood environment.***

Normally, except for the social environment, other components of neighborhood environment must deteriorate naturally. The old neighborhood, usually built in compliance with relatively low construction techniques and standards, would deteriorate quickly, and the new neighborhood with high construction standards would gradually deteriorate as time passes as well. Thus, the scenario of "*deterioration of neighborhood environment*" is foreseeable.

*4.3.2 Single scenarios of human interventions*

***S3: Renewal of neighborhood environment.***

One main human intervention is neighborhood renewal which can improve and rehabilitate the urban neighborhoods, often containing slum removal, building reconstruction, physical regeneration, and so on (Zhu et al., 2020). Since the importance of living environment has raised much attention, urban renewals have already conducted in many cities. For instance, Nanjing city has renewed 192 old neighborhoods involving areas of 6 square kilometers in 2018-2019 and plans to increase and expand the future renewal plans (Zhu et al., 2020). The scenario of "*renewal of neighborhood environment*" would bring significant improvements to physical environment, natural environment, facilities, and safety and security within the neighborhood.

***S4: Implementations of supportive rules and policies.***

Governments usually intervene in the neighborhood environment by implementing relevant rules or policies which are beneficial to aging-in-place, while facility operators and property management companies set rules to provide high-quality community services and activities. Unlike the neighborhood renewal plans, supportive rules and policies mainly concern community services and activities, such as launching official activities and services, setting standards on community services, funding and subsidizing organizations of community services (Chen & Han, 2016; Mahmood et al., 2012). So, the neighborhood facilities and social environment would be better in the scenario of "*implementations of supportive rules and policies*".

*4.3.3 Multiple scenarios*

According to the analysis of single scenarios, the renewal of neighborhood environment is a substitution of its natural deterioration, the aging trend of neighborhood population cannot be stopped, and the implementation of supportive rules and policies is uncertain in the future. Four multiple scenarios are set to represent the possible concurrences of single scenarios.

***S5 & S6: Concurrences of two single scenarios***

Given that population aging is inevitable, and supposing no supportive rule and policy release, there are only two possible scenarios. One multiple scenario S5 is no neighborhood environment renewal, a combination of S1 and S2 called "double aging", and the other multiple scenario S6 is conducting neighborhood environment renewal, a combination of S1 and S3.

***S7 & S8: Concurrences of three single scenarios***

Concurrences of three single scenarios can be developed by adding supportive rules and policies on S5 and S6. Multiple scenario S7 describes supportive policies are introduced in the context of "double aging"; and multiple scenario S8 means government implements both supportive policies and neighborhood renewals simultaneously, in the inevitable trend of population aging.

### *4.4 Monte Carlo experiment of the QoL of the elderly*

As shown in Fig. 1, the collected data and assumptions of scenarios assist in establishing probabilistic models of neighborhood environmental indicators, and the trained ANN model is used to the simulated relations. The next step is the conduction of Monte Carlo experiment to obtain the probability distribution of the elderly's QoL values.

#### *4.4.1 Probabilistic models of neighborhood environment*

In terms of the Central-limit theorem, as samples of independent random variable increase to infinite, its normalized sum tends toward a normal distribution even if the original variables themselves are not normally distributed (Rovai, Baker, & Ponton, 2013). In the social survey, the feedback is generally regarded to follow the normal distribution. Therefore, it is reasonable to infer the value of neighborhood environmental indicators is normally distributed with mean $\mu$ and standard deviation $\sigma$, referred to as $N(\mu, \sigma 2)$. Based on the collected data, point estimation method is applied to build the initial probabilistic models of neighborhood environmental indicators, as shown in Tables 2.

The initial probability models of neighborhood environment vary with single and multiple scenarios, following the variation trend which is summarized from scenario analysis of neighborhood environment (as shown in Table 4). In this study, the neighborhood environmental renewal and supportive policies are regarded as human interventions, while the natural deterioration of neighborhood environment and the population aging are regarded as the natural progression. The natural progression is generally slow to take effect; conversely, the human intervention brings more instant and significant returns. According to the principle of entropy increase, the natural progression is always disordered, making the deviation value of each component increases. Otherwise, human intervention usually follows clear standards or requirements, shrinking the deviation value considerably. Consequently, for neighborhood environmental indicators, it can assume that natural progressions of neighborhood environment would cause 10% increase or decrease in their mean values and 10% increase in their deviation values, while human interventions in neighborhood environment will lead 20% rise in mean values and 20% decline in deviation values. Following the above rules, this study establishes the probabilistic models of neighborhood environmental indicators in single scenarios (Table A1) and multiple scenarios (Table A2).

**Table 4**

The changes of neighborhood environment in scenarios

| Scenarios / Neighborhood environment component | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 |
|---|---|---|---|---|---|---|---|---|
| Neighborhood physical environment | | - | + | | - | + | - | + |
| Neighborhood natural environment | | - | + | | - | + | - | + |
| Neighborhood social environment | + | | | + | + | + | ++* | ++* |
| Neighborhood facilities | - | - | + | + | --* | -+* | --+* | -++* |
| Neighborhood safety and security | | - | + | | - | + | - | + |

Notes: "+" refers to positive change; "-" refers to negative change; * refers to multiple changes.

*4.4.2 Probability distribution of QoL of older adults under diverse scenarios*

The LHS requires to set assumptions and run preferences before the conduction. 8 sets of assumptions are defined as 8 scenarios, and assumed distributions of neighborhood environmental indicators are defined as probabilistic models in Tables A1 and A2. In the run preferences, the number of trials to run is set as 50,000, the sampling method is set as LHS, and other setting keeps the default value. The results of LHS contain 50,000 times sampling of neighborhood environment for each scenario.

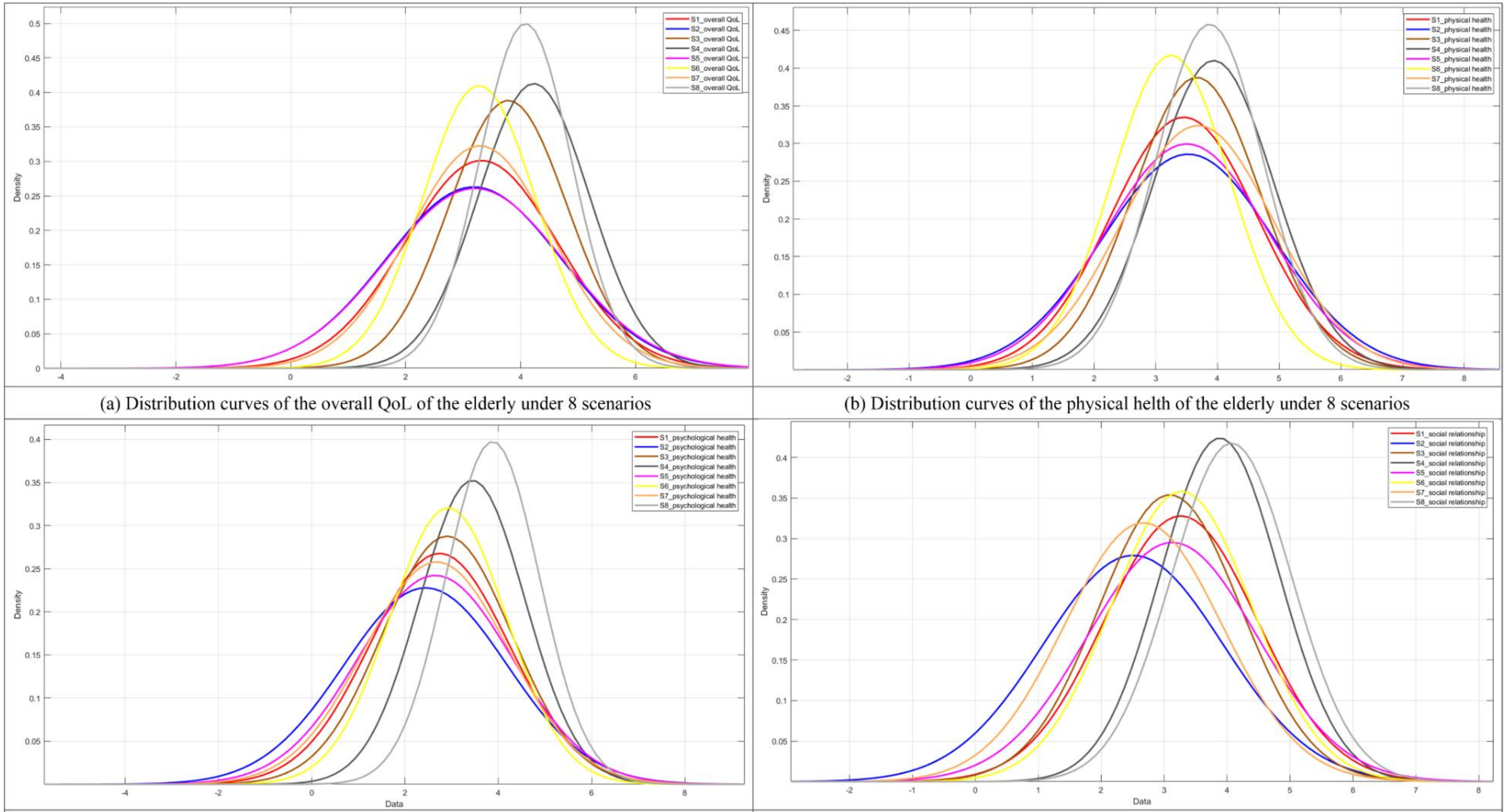
The results of LHS are imported into the input layer of the trained ANN model. Then we can obtain 50,000 outputs of the ANN model as predictive QoL values of each scenario. Results of distribution fitting prove the large-scale outputs are normally distributed at 95% confidence level. The distribution fittings of predictive QoL values are listed in Table 5. From Table 5, we can find the elderly's QoL values have some in common. No matter under whichever scenario, the elderly's psychological health always presents lower expected value and higher dispersion degree; on the contrary, the elderly's physical health usually has higher expected value and lower dispersion degree. That means most of the elderly's perception of psychological health is usually better than their perception of physical health. Even though four domains of the QoL perform quite dissimilarly under the same scenario, with positive enhancements of scenarios from S1 to S8, the differences of expected value and dispersion degree among four domains are reducing evidently.

Furthermore, Fig. 6 visualizes the distribution curves under eight scenarios as the overall QoL, physical health, psychological health and social relationship. Physical health of the elderly shows the fewest improvement of its expected value and dispersion degree. And their psychological health and social relationship show quite obvious perfection of expected value and dispersion degree. And their overall QoL presents much reduction of dispersion degree. The QoL values of all four domains achieve the best performance under the scenario of S8, demonstrating that human interventions in the neighborhood environment can bring actual positive effects to each domain of the elderly's lives.

**Table 5**

Distribution fitting of predictions of the elderly's QoL value

| Scenarios | QoL | Overall QoL | Physical health | Psychological health | Social relationship |
|---|---|---|---|---|---|
| Single scenario | S1 | $N(3.316, 1.753^2)$ | $N(3.454, 1.418^2)$ | $N(2.740, 2.219^2)$ | $N(3.266, 1.481^2)$ |
| | S2 | $N(3.183, 2.303^2)$ | $N(3.523, 1.947^2)$ | $N(2.440, 3.067^2)$ | $N(2.508, 2.042^2)$ |
| | S3 | $N(3.782, 1.055^2)$ | $N(3.664, 1.058^2)$ | $N(2.902, 1.923^2)$ | $N(3.091, 1.271^2)$ |
| | S4 | $N(4.229, 0.934^2)$ | $N(3.938, 0.946^2)$ | $N(3.443, 1.281^2)$ | $N(3.884, 0.885^2)$ |
| Multiple scenario | S5 | $N(3.202, 2.340^2)$ | $N(3.503, 1.775^2)$ | $N(2.647, 2.712^2)$ | $N(3.129, 1.827^2)$ |
| | S6 | $N(3.276, 0.947^2)$ | $N(3.248, 0.915^2)$ | $N(2.926, 1.548^2)$ | $N(3.276, 1.241^2)$ |
| | S7 | $N(3.291, 1.529^2)$ | $N(3.683, 1.516^2)$ | $N(2.676, 2.393^2)$ | $N(2.669, 1.561^2)$ |
| | S8 | $N(4.082, 0.637^2)$ | $N(3.870, 0.758^2)$ | $N(3.878, 1.007^2)$ | $N(4.070, 0.912^2)$ |




(a) Distribution curves of the overall QoL of the elderly under 8 scenarios

(b) Distribution curves of the physical helth of the elderly under 8 scenarios

(c) Distribution curves of the psychological health of the elderly under 8 scenarios

(d) Distribution curves of the social relationship of the elderly under 8 scenarios

**Fig. 6** Distribution curves of four domains of the elderly's QoL

## 5. Discussions

Predictions results of the QoL performance of the elderly under diverse scenarios help explore how natural progressions and human interventions of neighborhood environment change the elderly's life quality, and then provide targeted recommendations for future development of age-friendly neighborhood environment.

### *5.1 Natural progressions of the neighborhood environment*

"Population aging", "deterioration of neighborhood environment", and their combination called "double aging" are set as most likely scenarios of neighborhood environment under natural progressions. The distribution fittings of S1, S2 and S5 reveal the different performance of the elderly's QoL under three types of natural progressions, respectively.

In Fig. 6(a), the elderly perceive their overall QoL declining holistically with natural progressions of neighborhood environment. The expectation of overall QoL under neighborhood environmental deterioration is predicted to be lower than that under population aging, while the deviation is higher. It implies the natural deterioration will result in more significant decline in the elderly's overall perception of their life quality, and lead to larger individual differences. More specifically, there are few differences between distribution fittings of S2 and S5, indicating the reduction of the elderly's overall QoL during natural progressions is mainly caused by neighborhood environment deterioration. This is because the neighborhood environmental deterioration causes the overall deterioration of environmental components, which can be directly perceived by the elderly through their senses, and then lowers their experiences of comfort and control (Yu, Ma, & Jiang, 2017). Moreover, independent maintenance and operation of neighborhoods result in different levels of environmental deterioration among different neighborhoods, increasing the deviation of overall QoL.

Fig. 6(b) shows both population aging and deterioration of neighborhood environment would not lead to noticeable changes in the expected value of physical health, only enlarge the individual differences moderately. Physical health is primarily determined by the individual's physical condition, like diseases and injuries, so it is pretty hard for natural progressions of neighborhood environment to change the average level of physical health of the elderly remarkably (Zhang & Li, 2019b). The natural growth of aged population means more older adults with different physical conditions, increasing the deviation of physical health to a certain degree.

The psychological health and social relationship of the elderly perform similarly in natural progressions of neighborhood environment, showing the declining expectation and increasing individual differences. The negative effect of population aging seems slighter than environmental deterioration. Population aging also offers peers to build better social contact and obtain more peer support that benefits the elderly's social relationship (Luong, Charles, & Fingerman, 2011), and these formal and informal peer supports would improve their psychological health further (Chaudhury et al., 2012; Zhang & Li, 2019b). Furthermore, the change of distribution fitting from S1 to S5 is only the deviation increment. When population aging coincides with neighborhood environmental deterioration, the average level of the elderly's psychological health and social relationship is mainly determined by the aging degree of neighborhood population. And different degrees of environmental deterioration make the elderly's psychological health and social relationship diverse among different neighborhoods.

### *5.2 Human interventions in the neighborhood environment*

There are two typical human interventions in the neighborhood environment: environmental renewal and supportive rules and policies. The switch from S2 to S3 refers to neighborhood environment getting renewed artificially, and S4 means supportive rules and policies are implemented to facilitate neighborhood environment development.

The changes of distributions of predictive QoL values from S2 and S3 manifest the actual effects of neighborhood environmental renewal on the elderly's QoL. The neighborhood environmental renewal increases the elderly's expectation of the QoL, and the order of increment from high to low is overall QoL, social relationship, psychological health, physical health. Meanwhile, the renewal also reduces individual differences of the QoL, and the order of reduction from high to low is overall QoL, psychological health, physical health, social relationship. Similar to the environmental deterioration, the elderly's overall QoL is also sensitive to neighborhood environmental renewal, while the elderly's physical health is affected by the neighborhood environmental renewal very slightly. Also, neighborhood environmental renewal improves the elderly's social relationship and psychological health by offering better environment to enhance their social and emotional communications with the neighborhood, but its effects vary with individuals.

Furthermore, differences between predictive QoL values of S3 and S4 reveal supportive rules and policies are more efficient than neighborhood environment renewals in promoting life quality, especially psychological health and social relationship. Unlike the environmental renewal, supportive rules and policies released by local government or property management companies do not change the tangible neighborhood directly, but can enhance the social environment and community services through higher standards and financial support (Chen & Han, 2016). Supportive rules and policies are effective to address actual demands of the elderly on community services and formal support, due to prior investigations before the release (Gu et al., 2020). Besides, residents are generally encouraged to participate in prior investigations and the process of policy-making, enhancing public engagement of the elderly in the neighborhood. The elderly feel more familiar and controllable to their independent lives, and ensure their dignity of aging-in-place (Jayantha, Qian, & Yi, 2018; Yu, Ma, & Jiang, 2017).

### *5.3 Compound effects*

In reality, not all natural progressions can be prevented or replaced by human interventions. For instance, the trend of population aging is hard to be stopped immediately, while the trend of natural deterioration of neighborhood environment can be prevented by environmental renewal. Since concurrences of several scenarios must occur in the future, the compound effects of natural progressions and human interventions should be considered for conforming to reality as much as possible.

*(1) "Population aging" reduces positive effects of neighborhood environmental renewal.*

Since population aging is inevitable, the effects of neighborhood environmental renewal have to be considered under the impact of population. The difference between multiple scenarios S5 and S6 manifests these actual compound effects. Furthermore, by comparing the difference between multiple scenarios S5 and S6 with the difference between single scenarios S2 and S3, it can be found that population aging weakens the effects of neighborhood environment renewal on the elderly's QoL. Generally, the renewal of neighborhood environment optimizes the tangible components of neighborhood environment directly. The population aging brings more community-dwelling older adults to share the same neighborhood environment, offsetting the positive perception of daily life quality brought by environmental renewal. Similarly, the difference of predictive QoL values between S4 and S7 reveals the population aging only slightly reduces the effect of supportive rules and policies on the elderly's overall QoL. The implementation effect of many supportive rules and policies is not closely related to the population structure.

*(2) Human interventions can promote mutually.*

In view of the inevitable population aging, the interactions of human interventions are considered under the impacts of population aging. Through comparing the predictive QoL values of S6, S7 and S8, it can be found that implementing two types of human interventions in the meantime has greater compound effects than implementing one human intervention independently.

It is referred that “neighborhood environmental renewal” and “supportive rules and policies” can promote each other to achieve more significant compound effects on the elderly’s QoL. The usage guidelines and rules of neighborhood environment standardize the users’ behavior within the neighborhood. The policies can enrich the category of community services and enhance the service quality (Chen & Han, 2016). The rules launching formal neighbor support, like official activities, clubs, or unions, can facilitate the elderly to take advantage of renewed environment (Zhang & Li, 2019b). These rules and policies assist in promoting the elderly’s perception of QoL derived from neighborhood environment renewal.

In turn, the renewal of neighborhood environment promotes the performance of supportive rules and policies by providing tangible environment to carry out rules and policies smoothly. For instance, renewed facilities and physical environment are the basis to organize formal neighbor support required in supportive rules and policies, such as official activity teams and clubs for the elderly; enhanced street condition, sidewalk condition, barrier-free design, safety and security within the neighborhood also reassure the elderly to enjoy benefits and welfare brought by supportive rules and policies whenever and wherever.

### *5.4 Recommendations*

This study contributes to quantifying the predictions of the QoL of the elderly by dynamic neighborhood environment. Based on the predictions, convincing recommendations are proposed to guide the future development of neighborhood environment, for achieving significant advances in improving the elderly's QoL.

*(1) Formulating targeted supportive rules or policies.*

In the past, both the government and the public usually pay more attention to physical renewal than supportive rules and policies that are hard to bring some apparent changes immediately. Actually, the findings of prediction demonstrate the supportive rules and policies are more efficient than neighborhood environment renewals in promoting the elderly's QoL, especially promoting their psychological health and social relationship. Since supportive rules and policies are pretty flexible, decision makers should investigate the actual problems of current neighborhood services and facilities, then solve problems by releasing targeted rules and policies. For instance, if the operation of community facilities is quite difficult, policies would consider to increase the financial support for communities facility operators; otherwise, the form and rule about community services and activies can be optimized according to the elderly's preferences.

*(2) Enhancing mutual promotions of human interventions.*

Human interventions are proved to promote mutually. For maximizing mutual promotions between neighborhood environmental renewal and the proposal of policies and rules, systematic thinking is recommended to apply in deciding details of human interventions. Neighborhood environment and human interventions can be regarded as a system. Details of one human intervention should be decided with the consideration of the influences on the whole system.

As a result, the renewal scheme of neighborhood environment should consider meeting specific and potential requirements of rules and policies, convenient for further implementations of possible rules and policies. Meanwhile, relevant rules and policies need to assist the elderly in utilizing renewed neighborhood environment, such as organizing outdoor activities to enjoy the better natural environment, organizing night activities under better neighborhood safety and security. Furthermore, it would be beneficial to extend the scope of supportive rules and policies beyond the community services and activities. In practice, lacking effective policies has become the key barrier to carry out neighborhood renewal (Zhu et al., 2020). The supportive policies and standards should be developed to manage processes and operations of neighborhood environmental renewal projects, and evaluate the performance (Zhu et al., 2019).

*(3) Targeting the improvement of the elderly's physical health.*

Last but not least, current renewals, rules, and policies lack significant promotive effects on physical health. More creative human interventions in the neighborhood environment, especially which can promote physical health of the elderly, should be developed in the future. The rapid development of new technique and equipment offer good chance to solve this issue creatively. For instance, techniques of AI and digital information can be applied to optimize the neighborhood environment (Podgorniak-Krzykacz, Przywojska, & Wiktorowicz, 2020), such as automated alarm systems and smart community management platforms. And essential first-aid equipment, like the automated external defibrillator, should be placed in visible locations. These new interventions can assist in reducing the physical risks of injuries and sudden illnesses for the elderly, and ensure the elderly keep good physical health.

## 6. Conclusions

Under rapid development of cities, urban neighborhood environment keeps changing continuously. Affected by the neighborhood environment, the elderly's life quality varies as well. Previous studies focused on identifying the environmental factors that influence the elderly' life quality significantly, but seldom considered how the elderly's QoL varies with the dynamic neighborhood environment. Consequently, this study contributes to propose an integrated approach to predict the elderly's QoL based on the neighborhood environment under diverse scenarios, including simulating the actual relationship between neighborhood environment by training an ANN model, deciding the potential scenarios of neighborhood environment by scenario analysis, and making predictions of the elderly's QoL by Monte Carol experiment.

Based on the predictive QoL values, the change patterns of the elderly's QoL with diverse scenarios are identified and concluded by distribution fitting of predictions. The practical contribution of the integrated approach is to make certain the independent and compound effects of natural progressions and human interventions of neighborhood environment, and provide targeted recommendations to enhance neighborhood environment for better life quality of the elderly, as shown in section 5.4. In practice, this integrated approach can be applied in other countries and regions to forecast the future QoL of local elderly. Besides default scenarios in scenarios analysis, local users can set additional scenarios to adapt to regional development trends for obtaining the prediction under particular local scenarios, which can guide the improvement of neighborhood environment to support aging-in-place better.

Owing to the critical role of neighborhood environment in the elderly's daily life and its dynamic situations, this integrated approach is developed to predict based on natural progressions and human interventions in neighborhood environment. However, only eight scenarios are hard to cover all possible development of neighborhood environment. In the following research, more factors of living environment and more scenarios will be considered for optimization of the integrated approach and accurate prediction.

## Appendix

**Table A1**

Probability distributions of neighborhood environmental indicators in single scenarios

| Component | Indicator | Probabilistic models | | | |
|---|---|---|---|---|---|
| | | S1 | S2 | S3 | S4 |
| Neighborhood physical environment | E1 | $N(3.047, 1.014^2)$ | $N(2.742, 1.115^2)$ | $N(3.656, 0.811^2)$ | $N(3.047, 1.014^2)$ |
| | E2 | $N(2.873, 0.981^2)$ | $N(2.586, 1.079^2)$ | $N(3.448, 0.785^2)$ | $N(2.873, 0.981^2)$ |
| | E3 | $N(3.352, 0.872^2)$ | $N(3.017, 0.959^2)$ | $N(4.022, 0.698^2)$ | $N(3.352, 0.872^2)$ |
| | E4 | $N(2.913, 0.851^2)$ | $N(2.622, 0.936^2)$ | $N(3.496, 0.681^2)$ | $N(2.913, 0.851^2)$ |
| Neighborhood natural environment | E5 | $N(3.358, 0.867^2)$ | $N(3.022, 0.954^2)$ | $N(4.030, 0.694^2)$ | $N(3.358, 0.867^2)$ |
| Neighborhood social environment | E6 | $N(3.923, 0.807^2)$ | $N(3.566, 0.734^2)$ | $N(3.566, 0.734^2)$ | $N(4.279, 0.587^2)$ |
| Neighborhood facilities | E7 | $N(2.770, 1.104^2)$ | $N(2.770, 1.104^2)$ | $N(3.694, 0.803^2)$ | $N(3.694, 0.803^2)$ |
| | E8 | $N(2.880, 0.970^2)$ | $N(2.880, 0.970^2)$ | $N(3.840, 0.706^2)$ | $N(3.840, 0.706^2)$ |
| | E9 | $N(2.691, 1.044^2)$ | $N(2.691, 1.044^2)$ | $N(3.588\ 0.759^2)$ | $N(3.588\ 0.759^2)$ |
| | E10 | $N(2.625, 1.084^2)$ | $N(2.625, 1.084^2)$ | $N(3.500, 0.788^2)$ | $N(3.500, 0.788^2)$ |
| | E11 | $N(2.780, 0.936^2)$ | $N(2.780, 0.936^2)$ | $N(3.707, 0.681^2)$ | $N(3.707, 0.681^2)$ |
| | E12 | $N(2.925, 0.982^2)$ | $N(2.925, 0.982^2)$ | $N(3.900, 0.714^2)$ | $N(3.900, 0.714^2)$ |
| Neighborhood safety and security | E13 | $N(3.191, 0.925^2)$ | $N(2.872, 1.018^2)$ | $N(3.829, 0.740^2)$ | $N(3.191, 0.925^2)$ |
| | E14 | $N(3.560, 0.833^2)$ | $N(3.204, 0.916^2)$ | $N(4.272, 0.666^2)$ | $N(3.560, 0.833^2)$ |
| | E15 | $N(2.721, 0.789^2)$ | $N(2.449, 0.868^2)$ | $N(3.265, 0.631^2)$ | $N(2.721, 0.789^2)$ |
| | E16 | $N(3.268, 0.912^2)$ | $N(2.941, 1.003^2)$ | $N(3.922, 0.730^2)$ | $N(3.268, 0.912^2)$ |

**Table A2**

Probability distributions of neighborhood environmental indicators in multiple scenarios

| Component | Indicator | Probabilistic models | | | |
|---|---|---|---|---|---|
| | | S5 | S6 | S7 | S8 |
| Neighborhood physical environment | E1 | $N(2.742, 1.115^2)$ | $N(3.656, 0.811^2)$ | $N(2.742, 1.115^2)$ | $N(3.656, 0.811^2)$ |
| | E2 | $N(2.586, 1.079^2)$ | $N(3.448, 0.785^2)$ | $N(2.586, 1.079^2)$ | $N(3.448, 0.785^2)$ |
| | E3 | $N(3.017, 0.959^2)$ | $N(4.022, 0.698^2)$ | $N(3.017, 0.959^2)$ | $N(4.022, 0.698^2)$ |
| | E4 | $N(2.622, 0.936^2)$ | $N(3.496, 0.681^2)$ | $N(2.622, 0.936^2)$ | $N(3.496, 0.681^2)$ |
| Neighborhood natural environment | E5 | $N(3.022, 0.954^2)$ | $N(4.030, 0.694^2)$ | $N(3.022, 0.954^2)$ | $N(4.030, 0.694^2)$ |
| Neighborhood social environment | E6 | $N(3.923, 0.807^2)$ | $N(3.923, 0.807^2)$ | $N(4.707, 0.646^2)$ | $N(4.707, 0.646^2)$ |
| Neighborhood facilities | E7 | $N(2.493, 1.215^2)$ | $N(3.324, 0.884^2)$ | $N(2.992, 0.972^2)$ | $N(3.989, 0.707^2)$ |
| | E8 | $N(2.592, 1.067^2)$ | $N(3.456, 0.776^2)$ | $N(3.110, 0.854^2)$ | $N(4.147, 0.621^2)$ |
| | E9 | $N(2.422, 1.148^2)$ | $N(3.229, 0.835^2)$ | $N(2.906, 0.919^2)$ | $N(3.875, 0.668^2)$ |
| | E10 | $N(2.363, 1.192^2)$ | $N(3.150, 0.867^2)$ | $N(2.835, 0.953^2)$ | $N(3.780, 0.693^2)$ |
| | E11 | $N(2.502, 1.030^2)$ | $N(3.336, 0.749^2)$ | $N(3.003, 0.824^2)$ | $N(4.003, 0.599^2)$ |
| | E12 | $N(2.633, 1.081^2)$ | $N(3.510, 0.786^2)$ | $N(3.159, 0.864^2)$ | $N(4.212, 0.629^2)$ |
| Neighborhood safety and security | E13 | $N(2.872, 1.018^2)$ | $N(3.829, 0.740^2)$ | $N(2.872, 1.018^2)$ | $N(3.829, 0.740^2)$ |
| | E14 | $N(3.204, 0.916^2)$ | $N(4.272, 0.666^2)$ | $N(3.204, 0.916^2)$ | $N(4.272, 0.666^2)$ |
| | E15 | $N(2.449, 0.868^2)$ | $N(3.265, 0.631^2)$ | $N(2.449, 0.868^2)$ | $N(3.265, 0.631^2)$ |
| | E16 | $N(2.941, 1.003^2)$ | $N(3.922, 0.730^2)$ | $N(2.941, 1.003^2)$ | $N(3.922, 0.730^2)$ |

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